Scan of International Climate Information Portals

Clean Air Partnership

CONTENTS

EXECUTIVE SUMMARY

Climate information portals are a key climate service offering and can be broadly defined as web-based platforms for the dissemination of climate information and services. Climate information portals can provide value to a wide range of users from both the scientific and operational communities including climate scientists, impact researchers, consultants and all orders of government policy and decision makers. Of particular use to decision makers are those portals that display climate data, scenarios and projections, and allow users to select and visualize custom data selections for use in decision-making.

The CAP report characterised the landscape of climate information portals and their data offerings by examining similarities, differences and gaps in the provision of climate data offerings from quantitative interactive climate information portals. In doing so, the report employs three methods; 1) A literature review provides an up to date overview of existing evaluations of the current state of climate information provision and demand from portals and users respectively. 2) A jurisdictional scan identifies 62 climate information portals in existence and provides detailed cases studies on 15 of these portals. 3) An interview series with seven of the 15 portal operators provides greater qualitative insights into relevant portal development, operation and maintenance issues.

FINDINGS FROM JURISDICTIONAL SCAN

The 15 portals reviewed in Part 2 deliver climate information using 4 broadly different approaches. They are either a visualization platform, a map-based visualization platform, a decision-support tool or a climate data library / visualization platform. Most portals provided 2-4 different data tools to explore their climate information, visualising climate data in maps and time-series, with options for raw data download. There is variation in terms of geographic focus, most portals tend to provide climate information at global or national scales, with variation in the focus of national and sub-national scales. Most portals use data from newer CMIP5 outputs and use downscaling to present information at finer resolutions more suitable for the national and sub-national scales that they cover; similarly, most portals have transitioned to newer representative concentration pathways, typically providing at least 2 scenarios, a low and high emission scenario. The portals tend to provide observational data back until the 1950s or approximately the 1900s and generally select official reference periods recognized by the World Meteorological Organization or Intergovernmental Panel on Climate Change.

The 15 portals employ a diverse range of approaches to enable users to explore climate data over time, where most use either a 30-year or 20-year time interval to compute climate trends and tend to offer at least 3 future time periods. Nearly all portals provide a range of climate variables and derived indices to users to explore climatic change. Types of climate variable vary across the examined portals often relating to

the pertinence of certain aspects of locally relevant climate change impacts. Types of derived climate indices also vary across the examined portals, with most portals providing indices relating to temperature and precipitation, with fewer provide ocean- and wind-related indices.

FINDINGS FROM INTERVIEWS

Most of the climate portals selected for interview in Phase 3 were developed using government funding where development input was sought through stakeholder consultations and workshops. All portals interviewed had a means of collecting user feedback which has been integrated as part of the portal process. All interviewees identified the need for better communication with decision-makers and the need to help them interpret the technical data, and all interviewees identified the need to engage stakeholders from the beginning of the portal development process in order to ensure the portal is successful. Most interviewees suggested a need for training and outreach to help users understand how to use the portal and build a user base.

SUMMARY

While climate information portals use a range of approaches to provide climate data, with considerable variation in web design and user guidance materials, their underlying climate information, data tools and data visualizations remain broadly similar. Further interpretation, analysis and evaluation is largely left to the user to undertake. In terms of providing decision-relevant climate information, most portals can be said to be useful however not as many could be described as particularly user-friendly for decision makers.

RECOMMENDATIONS

Recommendations are grouped into two areas: user needs and communications, and data provision and management.

User needs and Communications

1. Explicitly identify and display the purpose, intended users and intended uses to avoid user confusion and avoid the misuse of climate information from a portal site.
2. Engage with real users to help ensure that the portal meets their needs, is accessible and includes the kinds of analytical capabilities that users are looking for (e.g. downloadable data and dashboards).
3. Use non-technical intuitive web design that is user- rather than data-driven. Many portals are structured around climate data itself and allow users to browse for datasets themselves (i.e. the climate dataset libraries), while the more intuitive user-friendly sites are designed from a user perspective and are structured around the insights that climate data is generating (i.e. the decision-support tool and visualization portals). Web design should minimize the number of clicks needed to access desired information and have a high level of intuitive interactivity e.g. sliders, drop-down menus and selection buttons. Ensure consistency across the portal in terms of: page design; units used for variables; colour-coding; etc.

4. Develop user guidance materials that employ user-appropriate language. This will allow users with varying degrees of expertise to understand portal content and operation. Also ensure user-appropriate labels on all products i.e. graph titles, axis labels, legends, etc.
5. Provide appropriate use guidance materials (e.g. site maps and decision trees to match user needs with suitable portal features, guiding principles on the appropriate use of climate data, use cases to suggest how to use data, FAQs and a glossary). These prevent the misuse of climate information in decision making and help users successfully navigate data options. Decision makers are not data experts and may not have the skill to identify data needs, navigate climate data and use it in appropriate ways unless guided. CCIA (Australia), Pacific Climate Futures and UKCP09 (United Kingdom) are examples of the provision of high quality appropriate use guidance materials. Cal-Adapt use cases are particularly well done and can be found in Appendix 2 of the report.
6. Provide explicit and transparent explanations of any downscaling methodologies that have been used. Downscaled data is still derived from GCM outputs and therefore still has inherent uncertainty associated with it. Rather, it better represents climate changes where local factors (e.g. topography, coastlines etc.) are also accounted for. Many portals do not explicitly highlight this fact. Providing such higher resolution data risks inferring reduced uncertainty and higher data quality to non-expert data users and, in turn, risks the misuse of climate data.
7. Ensure that a user feedback mechanism is supported and/or built into a climate data portal to have a clear pathway of communication with data users and portal developers.
8. Continual engagement and training is essential to continuously improve the portal by collecting user feedback and helping users understand how to use the portal, its tools and how to interpret the data. Where possible, ensure that there are dedicated staff working a Support Desk for the portal and helping end users.
9. Understand and develop a clear set of questions that the user might ask of the portal. Develop the portal layout and interface in response to these questions, and develop guidance for the user to answer the specific question. This can then be used in the creation of a FAQ page.

Data Provision and Management

10. Consider categorizing the data for different user groups (e.g. creating tiers of information for basic, intermediate and advanced users, specific sectors) to help tailor the information to their specific needs.
11. Consider integrating data that has been endorsed by government or other trusted data sources as the majority of other portals do so.
12. Climate information portals are most effective as decision-support tools, minimizing technical data choice through provision of decision maker-relevant information, presenting climate data aligned with decision maker needs.
13. Avoid an over-abundance of data options that are inappropriate for decision makers. For example, the ability to explore changes in advanced atmospheric, oceanic and biogeochemical quantities, advanced statistical analysis options, freedom to manually change projection reference periods, or freedom to select paleo-climate data may be beyond the technical skills of non-expert users and can lead to confusion.
14. Conversely, providing abundances of appropriate data choices can maximise a

portal's ability to meet a range of climate decision maker needs. This can mean provide, for example, numerous derived indices alongside climate variables, the ability to assess seasonality (e.g. monthly, 3-monthly, 6-monthly temporal averages) and the ability to explore projections across numerous 21st century time periods (e.g. 5- or 10-year time steps).

15. Uncertainty is often presented as singular averages and spreads from multi-model ensembles of direct climate model outputs which do not reveal clustering, spreads and likelihoods of ranges of climate projections. Data visualizations that reveal these aspects can be more useful to decision makers as a tool to inform higher quality climate decisions rather than discouraging action. CCIA, UKCP09 and Pacific Climate Futures provide good examples of how portals can handle uncertainty in sophisticated ways.
16. Portals which include multiple funding streams may be limited in what climate information is provided on the portal. Having a government-funded portal allows for sustained funding and improvement over time.
17. Use a 3, 4, or 5-year plan for future direction of the portal, and constantly update the portal based on the new models/science that emerge with time (e.g., IPCC reports).

ACKNOWLEDGEMENTS

Authors
Louis Coningsby, Clean Air Partnership
Kevin Behan, Clean Air Partnership

Interview series leads
Kristina Dokoska, Ontario Climate Consortium
Frances Delaney, Ontario Climate Consortium
Glenn Milner, Ontario Climate Consortium

Editorial and Project Oversight
Environment and Climate Change Canada

Interviewees
Laura Satkowski, U.S. Global Change Research Program, National Coordination Office
John Clarke, CSIRO Climate Science Centre
Susan Wilhelm, California Energy Commission
Geert Jan Van Oldenborgh, Royal Netherlands Meteorological Institute
Tobias Fuchs, Copernicus Climate Change Services
Ana Bucher, World Bank

The interpretation of the interviews reflect the interpretation of the authors and that they do not represent the views or are endorsed by the interviewed participants.

Designer
Leena Salem Design (leenasalem.com)

Recommended Citation
Clean Air Partnership (2018) Scan of International Climate Information Portals.
Produced for Environment and Climate Change Canada. 102pp.

Funded by:
Environment and Climate Change Canada
Environnement et Changement climatique Canada

Prepared by:
Clean Air Partnership

In collaboration with:
ONTARIO CLIMATE CONSORTIUM

LIST OF ABBREVIATIONS

CCAM: Conformal-Cubic Atmospheric Model

CCSM-4: Community Climate System Model 4.0

CESM-LENS: Community Earth System Model Large Ensemble Project

CLIPC: Climate Information Portal for Copernicus

CLM: Community Land Model

CMIP3: Coupled Model Intercomparison Project Phase 3

CMIP5: Coupled Model Intercomparison Project Phase 5

CMIP6: Coupled Model Intercomparison Project Phase 6

CORDEX: Coordinated Regional Climate Downscaling Experiments

CSIRO: Commonwealth Scientific and Industrial Research Organisation (Australia)

DWD: German Meteorological Office (Germany)

ENSEMBLES: ENSEMBLE-based Predictions of Climate Changes and their Impacts

ESRL: Earth System Research Laboratory (USA)

HadRM3: Hadley Centre Regional Climate Model version 3

HadSM3: Hadley Centre Simplified Model version 3

IPCC: Intergovernmental Panel on Climate Change

IRI: International Research Institute for Climate and Society (USA)

KLIWAS: Impact of Climate Change on Waterways and Navigation – Options to Adapt

KNMI: Royal Netherlands Meteorological Institute (The Netherlands)

LDEO: Lamont-Doherty Earth Observatory (USA)

LOCA: Localised Constructed Analogs

NASA: National Aeronautics and Space Administration (USA)

NCAR: National Center for Atmospheric Research (USA)

PIK: Potsdam Institute for Climate Impact Research (Germany)

PRISM: Parameter-elevation Relationships on Independent Slopes Model

REMO: Regional Climate Model (Max Planck Institute)

SPECS: Seasonal-to-decadal Climate Prediction for the improvement of European Climate Services

STARS: Statistical Analogue Resampling Scheme

SWICCA: Service for Water Indicators in Climate Change Adaptation

WCC: World Climate Conference

WCRP: World Climate Research Program

WETTREG: Weather-based regionalisation method

WMO: World Meteorological Organisation

1. INTRODUCTION

CONTEXT

It is widely acknowledged that "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia" (IPCC, 2013). Where at one time, international political leadership for climate action was lacking, the 2015 Paris Agreement requires countries to hold global average temperature increases at 2°C above preindustrial levels and pursue efforts to limit this increase to 1.5°C (UNFCCC, 2015). This legally binding agreement communicates with clarity the need for strong mitigation and adaptation decision making. In turn, this re-emphasises the need to operationalise climate change research and ensure that decisions are well-grounded in climate science. Climate services aim to do this.

Climate services involve "…the production, translation, transfer, and use of climate knowledge and information in climate-informed decision making and climate-smart policy and planning" (Climate Services Partnership, 2018). Climate services first emerged in the 1950s, typically in national governments' meteorological departments who collected and analysed climate data for use in sector-specific applications (e.g. agriculture and transportation) (Hansen et al., 2014). Climate services became officially recognised within the international climate change agenda in 1990 at the second World Climate Conference (WCC-2), with what could be considered a specific climate services agenda arising in the late 2000s at the WCC-3 (Hansen *et al*., 2014; Vaughan and Dessai, 2014). This conference created the Global Framework for Climate Services, a task force dedicated to "…coordinating actions to enhance the quality, quantity and application of climate services" (Hewitt *et al*., 2012). A number of other organisations have emerged in parallel; notably the Climate Services Partnership and the Climate Knowledge Brokerage that work to facilitate knowledge exchange and advancement in the climate services sector. This rise has mirrored advances in climate science. As the research community's ability to understand, model and predict climatic processes has improved over many decades, so too has there been a shift from the production of climate science to its application to inform decision making via climate services.

Today, climate services exist at local, national, regional and international scales, in a broad range of sectors (e.g. water, health, agriculture, disaster reduction management and so on) and are provided by both private and public sector actors (Vaughan and Dessai, 2014). Climate information portals constitute one such example. They can be broadly defined as web-based platforms for the dissemination of climate information that sit within the portfolio of emerging climate services.

WHAT ARE CLIMATE INFORMATION PORTALS?

There is no widely accepted definition of what constitutes a climate information portal (some papers and reports use the term platform), largely reflecting the current diversity of the different types in existence. There are climate information portals focusing on disseminating climatic data, scenarios and projections, and so take a quantitative focus. Meanwhile there are portals focusing on recent climate research and news, as well as information on mitigation and adaptation implementation, and so take a qualitative focus.

Quantitative climate information can be disseminated in different ways. A study by Hewitson *et al.* (2017), one of few studies that focused specifically on data-oriented climate information portals, created a typology of existing portals. They define 3 different types of quantitative portal: raw, static and interactive. Raw portals offer the user dataset downloads only. Static portals partly visualise data into pre-set maps, graphs and other graphics. Interactive portals enable the user to select and visualise data using their own selections (e.g. different models, emission scenarios, timeframes etc.).

HOW ARE CLIMATE INFORMATION PORTALS USED?

Climate information portals can provide value to users from both scientific and operational communities including climate scientists, impact researchers, consultants and government decision makers (Swart *et al.*, 2015; Groot *et al.*, 2015). Quantitative, interactive climate information portals employing data visualisation techniques can effectively present highly complex climate modelling outputs on climate variability and future projections in a manner useful for decision makers to incorporate into climate compatible development decisions. The marked increase in the number of climate information portals in existence in recent years speaks to this usefulness (Hammill *et al.*, 2013). Additionally, modern advances in information communication technology and data visualisation techniques has, and continues to, increase the extent to which non-experts can engage user-friendly platforms to find, interpret and analyse initially complex climate data to support climate change decision making (Houtkamp *et al.*, 2016). Further to this, increasing global internet penetration, notably in developing countries with limited current capacities to adapt to climate change, has the potential to add great value to adaptation efforts where it is needed most both now and into the future (Mason *et al.*, 2015). To summarise, quantitative interactive climate information portals have the potential to facilitate the delivery of decision-relevant climate information to a large number of users in different decision making contexts and add significant value relative to the resources used to service each user.
These advantages can position quantitative interactive climate information portals as essential climate services; involving the dissemination, transfer and use of climate data and projections by decision makers to support mitigation and adaptation decisions that are distributed across different geographic locations, in different sectors and at different decision making scales.

With a view to assess the current landscape of climate information portals as a climate service, this report focuses on those portals that display climatic data, scenarios and projections, and allow users to select and visualise custom data selections for use in decision making (i.e. quantitative, interactive climate information portals).

1.1 ABOUT THIS REPORT

1.2 OBJECTIVE

This report aims to characterise the landscape of climate information portals and their data offerings. Specifically, it aims to answer the following research question:

- What similarities, differences and gaps exist in the provision of climate data offerings from quantitative interactive climate information portals?

Research findings will form the evidence-base for implementable and operational recommendations for future portal development such that information provision and product offerings can be prioritised to fill gaps and better satisfy user demands. This report links to the body of existing literature aiming to improve the effectiveness of climate information portals, and climate services more broadly, as decision-support tools for climate compatible development.

1.3 METHODOLOGY

To answer this research question, this report employs three methods.

1. Literature review

Keyword searches on online bibliographic search engines (e.g. Web of Science, Scopus, Google Scholar and others), as well as targeted searches of the Climate Services Journal and existing climate information initiatives revealed a number of primary scientific resources as well as literature outside traditional commercial and academic channels (grey literature). Resources that sat within the scope of this project were selected for review. It is important to note that literature specifically examining the effectiveness of climate information portals for decision makers is sparse, something known both in advance of this report and confirmed by the literature review itself (see section 2). Reflecting this, the literature review forms a smaller line of enquiry, providing an up to date overview and evaluation of the current state of climate information provision and demand from portals and users respectively. The literature review gives way to the jurisdictional scan and interview series, gathering valuable primary data on the topic.

2. Jurisdictional scan

Keyword searches on relevant literature were used to conduct a preliminary scan of existing climate information portals and identified 62 distinct portals internationally (see Appendix 1). A number of selection criteria were devised in collaboration with the Project Team to allow for a focus on those portals which:

a. are non-Canadian and non-US national.
b. do not require payment for access.
c. state, or imply, that they are designed to be relevant for decision makers.
d. use secondary climate indices relevant for decision makers, and do not only provide raw data for download.
e. are interactive, enabling users to make selections to view tailored data (e.g. a user can select their desired timescale, emission scenario, model and so on).

All Canadian and certain US national portals were omitted due to existing familiarity with these portals from the Project Team. Applying these selection criteria to the preliminary 62 portals (see Appendix 1) revealed 15 portals that were within scope (see table 1).

TABLE 1 | THE 15 CLIMATE INFORMATION PORTALS

PORTAL NAME	ORGANISATION
Cal-Adapt	Geospatial Innovation Facility, University of California, Berkeley, USA
Climate Change In Australia	Commonwealth Scientific and Industrial Research Organisation, Australia
Climate Change Knowledge Portal	World Bank Group, USA
Climate Information Portal for Copernicus	Science and Technology Facilities Council, UK
Climate Wizard	The Nature Conservancy, USA
DWD German Climate Atlas	National Meteorological Service, Germany
The ESRL Climate Change Web Portal	Earth System Research Laboratory, USA
Climate Impacts Online	Potsdam Institute for Climate Impact Research, Germany
IRI/LDEO Climate Data Library	International Research Institute for Climate and Society, Columbia University, USA
NCAR GIS Program Climate Change Scenarios GIS Data Portal	National Center for Atmospheric Research, USA
Pacific Climate Futures	Commonwealth Scientific and Industrial Research Organisation, Australia
Partnership for Resilience and Preparedness	World Resources Institute, USA Future Earth, USA
South African Risk and Vulnerability Atlas	Science and Technology Department. South Africa
UK Climate Projections 2009	Environmental Agency, UK The Met Office, UK
KNMI Climate Explorer	The Royal Netherlands Meteorological Institute, The Netherlands

Table 1 shows the 15 case study portals, and their host organisations (with location), that are examined in this report.

3. Interview series

A series of structured interviews of approximately one hour in length were conducted with portal developers from a sub-selection of the 15 portals. The Project Team curated a series of questions (see Appendix 3) to provide insights on the:

a. development of the portal.
b. barriers to portal implementation.
c. evaluation and tracking of the portal.
d. future plans for the portal.

The climate portals selected for an interview were determined through a set of criteria. The portal should:

a. be live/still funded.
b. have gathered user experiences.
c. have a commitment to portal improvement.

A desktop review was conducted to identify contacts for the interviews. Once the key contacts were confirmed, individuals were contacted to schedule an interview. A formal interview guide, containing the interview questions, was distributed prior to the scheduled interview. The interview process was used to identify the lessons learned, the data they provide, the usefulness of that data, as well as the types of data they intend to provide in the future. A total of seven interviews were completed.

1.4 CONTENT

Section 2 presents findings from the literature review drawing on up to date literature on the provision climate information from online portals as well as assessments that have explored user needs. Section 3 presents findings from the jurisdictional scan of the 15 climate information portals. Section 3.1 presents a detailed documentation and analysis of each of these 15 portals. Section 3.2 synthesises findings from across all 15 portals and provides an overview of their currently provided climate data products. Section 4 presents findings from the interview series. Section 5 provides conclusions and recommendations for future portal development based on the findings of the literature review, jurisdictional scan and interview series.

2. LITERATURE REVIEW

The following is an extensive, yet non-exhaustive review of the small amount of current literature that has examined data offerings from climate information portals and user needs.

WEB DESIGN AND DATA PRESENTATION

There is a wide diversity of web design and data presentation approaches. Hewitson *et al.* (2017), in their typology of existing climate information portals, identify raw, static, and interactive portals. Raw portals provide climate datasets for download only. More elaborate portals convert raw data into climate variables and indicators, and employ data visualisation techniques to display data in a user-friendly manner. This is done statically, with pre-set maps, graphs and other graphics, or interactively, through the incorporation of a platform enabling users to make tailored data selections (e.g. climate variables, emission scenarios, timeframes etc.) and visualise them accordingly. Additionally, more advanced portals often allow users to compute new statistics, as opposed to providing only pre-computed content. In Hewitson *et al.*'s (2017) review of 42 existing portals, 19 facilitated interactive use.

Users highly value intuitive web design and data presentation however few portals currently serve this, demonstrating a gap in provision. Existing use cases on active climate portals showed users are discouraged by available climate information portals due to the high numbers of clicks and selection stages needed to arrive at data selections and visualisations that meet their needs (Hewitson *et al.*, 2017). Users have previously expressed desire for a greater harmonisation of tools, grids, colours, and formats across portal interfaces to better aid interpretation.

TARGET AUDIENCE

Existing studies conclude that many portals loosely define their target audience using unspecific terms such as "to advance climate science and research" and "to advance solutions to climate change" (Swart *et al.*, 2017). Specific identification of decision makers as a target audience is often absent though there are some exceptions (for example, the Service for Water Indicators in Climate Change Adaptation (SWICCA) portal specifically identifies consultant engineers and water sector adaptation policy makers as its users).

Surveys on user-needs in the Canadian context reveal public sector employees (specifically municipal decision makers) are a major group (Morand *et al.*, 2015). Common reasons for use are to develop climate adaptation plans (Morand *et al.*, 2015) as well as to provide advice on climate data and climate impacts to others (Bennett, 2015). There exists a gap where users have specific climate information needs, but portals rarely define their intended use or users. This results in users having uncertainty relating to the portal's ability to serve their needs.

PORTAL GEOGRAPHY

Figure 1 illustrates the distribution of the 42 climate information portals identified in Hewitson *et al.*'s (2017) study. The majority of portals are, as one might expect, headquartered in countries most engaged in international climate change decision making, with strong institutional capacities to research and manage climate/weather risks. Developed countries with well-established national meteorological offices and environment/climate change departments generally maintain a greater number of portals. Previous portal reviews have identified that national meteorological offices are a frequent location for climate information portals to be housed. Furthermore, portals are most often developed and coordinated though multi-national consortia, followed by national government departments and research institutes (Hewitson *et al.*, 2017).

FIGURE 1 | GEOGRAPHIC DISTRIBUTION OF EXISTING PORTALS

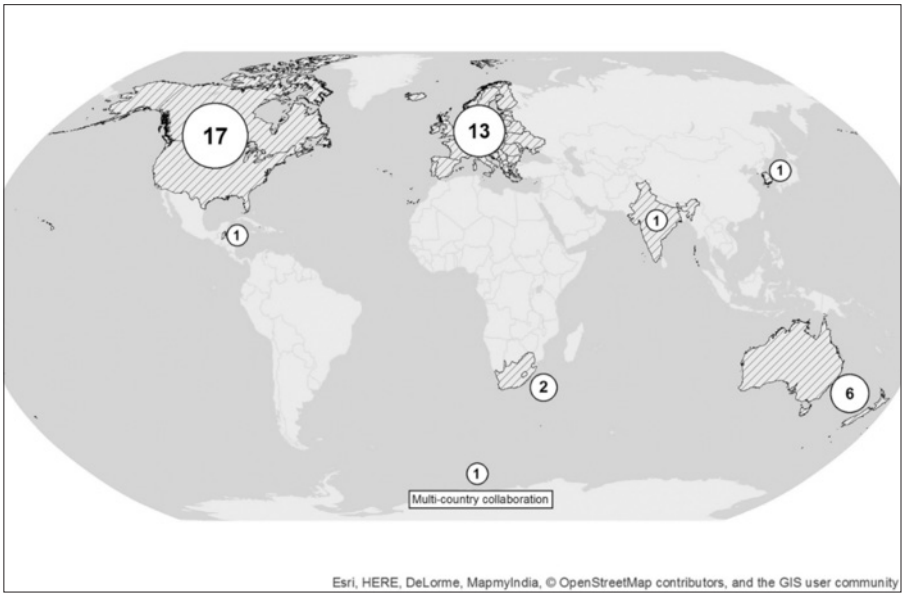


Figure 1 shows the location of 42 portals as examined in Hewitson et al. (2017)

Morand *et al.* (2015), in their survey-based overview of climate information needs in Ontario, Canada, highlight Environment Canada as the most frequently consulted source for climate data and projections. This is supported by other studies which illustrate a preference among users to contact national meteorological offices for such data (Bennett, 2015). International-scale studies on the geographic origins of portal users are lacking.

ACCESS REQUIREMENTS

Existing reviews note that nearly all climate information portals are free and open access; requiring a user to simply access the site or register for free to unlock full functionality (Hewitson *et al.*, 2017). Users have reiterated the importance of free and

open access climate information. Furthermore, this requirement is seemingly universal regardless of user type. Studies probing user needs from a diversity of decision makers found free open access to be a priority for all (Swart *et al.*, 2017). The need for free and open access appears to be well-met by current portals.

CLIMATE VARIABLES AND INDICES

The mix of climate data and projections provided by portals is diverse but there are a number of key trends. In terms of the climate variables, existing publications identify that nearly all portals provide mean temperature and precipitation variables. Further to this, a review of 17 portals found they commonly provide a number of additional sector-specific variables (e.g. ice days, frost days, cooling degree days and so on) (Sigel *et al.*, 2016). Other niche variables such as solar radiation change, cloud cover, soil temperature/moisture and others are rarely provided (Sigel *et al.*, 2016).

From a user perspective, climate variables relating to precipitation and air temperature are most commonly demanded. In Morand *et al.*'s (2015) survey, precipitation means and the frequency of precipitation events as well as temperature means, maxima and minima were all highly sought after. Other variables relating to air pressure, ocean surface temperature and sea level rise were less in demand. However, Morand *et al.* (2015) highlight this could well be influenced by the number of (adaptation) decision makers working in these areas and as well as the dominance of survey respondents from Ontario. Other international studies trying to identify user demands for climate information highlight the need, more generally, for climate variables that go beyond mean values and include maximums, minimums, 1 in 20 year events and more (Bennett, 2015). The lack of decision-relevant climate indicators (e.g. heating/cooling days) presents a significant gap between user need and service provision.

CLIMATE MODELS AND DOWNSCALING

Most portals display multiple global circulation model (GCM) outputs, known as multi-model ensembles. Existing studies also identify a switch occurring in the climate portals community. In terms of global data, this involves a switch from Coupled Model Intercomparison Project Phase 3 (CMIP3) GCM outputs to the newer CMIP5 data (used in IPCC Assessment Report 5). In terms of regional data, this involves a switch from using older ENSEMBLES[1] regional climate model (RCM) outputs to the newer CORDEX[2] outputs.

In terms of downscaled outputs, many portals employ downscaling techniques to increase the resolution of coarse GCM outputs which are typically 250-600km^2 (IPCC, 2013). There is considerable diversity in this area. In their review of 17 climate information portals, Sigel *et al.* (2017) identified that 12 of 17 portals displayed

[1] ENSEMBLES was a 2009 EU-funded Integrated Project, involving 70 partner institutions across Europe, to develop high resolution, global and regional earth system modelling outputs. It produced a probabilistic estimate of uncertainty in future climate at the seasonal to decadal and longer timescales.

[2] CORDEX is an ongoing project of the World Climate Research Programme developing higher resolution coordinated sets of regional downscaled modelling projections worldwide.

dynamically downscaled data (the rest statistically downscaled data). The methods used to downscale varied widely, and some climate portals do not specify which downscaling technique they have used (Hewitson *et al.*, 2017; Sigel *et al.*, 2016). Additionally, portals rarely provide visualisations for downscaled data outputs.

|Hewitson *et al.* (2017) links this to the reduced availability of downscaled outputs compared to GCM outputs. Downscaled data currently has no central archive, often remaining the property of the respective research centres in which they were developed and making it harder for portal developers to access multiple downscaled datasets as opposed to multiple GCM outputs which are readily available on the CMIP5 archive (Hewitson *et al.*, 2017).

Users have stated a preference for downscaled climate modelling outputs. Morand *et al.* (2015) identified spatial resolutions of 1km^2 to 4km^2 (municipal scale) and of 5km^2 to 100km^2 (regional scale) as important to users. This represents one of the largest gaps between user needs and service provision. Aside from resolution, user demand for statistically and/or dynamically downscaled data products is poorly understood making it hard to identify gaps in provision. Morand *et al.*'s (2015) survey showed that many users do not know what type of modelling outputs they currently use, and so could not state any preference for statistically or dynamically downscaled outputs.

EMISSION SCENARIOS

In their overview of 42 portals Hewitson *et al.* (2017) finds most portals provide the new representative concentration pathways (RCPs) only. Fewer portals use both RCP and Special Report on Emission Scenarios (SRES) or SRES scenarios only. As with the shift in climate model use described above, existing studies also highlight the trend towards the provision of newer RCP emission scenarios.

RCPs and SRES scenarios are currently equally preferred (Morand *et al.*, 2015). However, it is reasonable to assume that there will be an increasing user preference for RCP use over time as SRES-based modelling outputs become more redundant (and especially as newer CMIP6 outputs become available). With a trend towards RCPs use preferred by both providers and users, this is not a significant gap in provision.

HANDLING OF UNCERTAINTY AND METADATA

Many portals display the multi-model ensemble mean and range to convey uncertainty (Sigel *et al.*, 2016), while others provide probability of occurrence. Numerous portals also provide wider educational information on the concepts of uncertainty and confidence as well as typically giving text-based metadata (Hewitson *et al.*, 2017). Users value high quality metadata and information on uncertainty and confidence. More importantly, metadata outlining the uncertainty and confidence levels of specific modelling outputs and projections are needed. User consultations have stressed the need for providers to attribute specific uncertainty and confidence values to specific pieces of climate modelling data and projections, rather than generic conceptual overviews (Bennett, 2015). This highlights a considerable gap in provision with users' demands being poorly met by the provision of generic metadata and information around uncertainty and confidence.

USER GUIDANCE

The provision of user guidance varies significantly across different portals though in general materials such as user guides, FAQs and glossaries of technical terms are provided (Sigel *et al.*, 2017). Hewitson *et al.* (2017) highlights a general lack of high quality user guidance as well as abundances of technical language throughout portal websites. User guidance relating to the actual operation of portals is needed with many users suggesting the increased provision of tutorials, glossaries and FAQs to better explain portal content and operation as well as general information on climate change topics. Users also highlight the need for guidance materials to better guide users' selection, interpretation and use of climate data in decision making. In short, the provision of user guidance materials is key gap in provision.

2.1 THE CURRENT LANDSCAPE

This literature review highlights that there is a considerable gap between the supply of and demand for usable climate information for decision-makers despite the recent proliferation of climate information portals (Swart *et al.*, 2017; Barnard, 2014). Portal development is an emerging and fragmented area of practice (Hewitson *et al.*, 2017), which in its infancy has been marked by a duplication of efforts (Houtkamp *et al.*, 2016) and common gaps in existing provision (for users). This has emerged largely due to a lack of user requirements feeding into portal development (Swart *et al.*, 2017), although exceptions exist.

The current use of portals by decision makers can be time-consuming and frustrating, due to barriers that users must overcome such as an overabundance of possible data selections, inaccessible website design and data presentation methods, technical jargon, and a lack of high quality user guidance on both how to operate portals and appropriately use their information in decision making (Hewitson *et al.*, 2017). At best, this can reduce the effective uptake of portal information into climate compatible decision making, or at worst can lead to misinformed decisions.

In terms of climate data provision, an "IPCC-style business model" has dominated (Brasseur and Gallardo, 2016). This model, which long served the scientific community, has meant an abundance of coarse resolution global scale GCM data and projections on decadal to end-of-century timescales. This aligns well with scientific research needs of the IPCC, hoping to advance global scale mitigation efforts over long timeframes, but not for municipal decision-makers requiring data on shorter timeframes to support adaptation planning and strategies.

Portals usually display downscaled modelling outputs at resolutions more aligned with decision maker needs. However, the downscaling methods can be diverse, and methodologies can be laden with technical jargon. This could be due to a lack of user understanding between the type of modelling output they currently use and that which they would prefer (Morand *et al.*, 2015). There is a risk that climate portals are too complex in how they supply downscaled data (and metadata), and so infer a requirement for user skill and scientific authority. Existing use-case narratives have highlighted the risk where in time- and resource-limited decision making contexts, decision makers may select sub-optimal information in the face of such barriers (Hewitson *et al.*, 2017).

Furthermore, the development of portals has largely been supply-driven. This has constrained the effectiveness of climate information portals in a number of ways. Firstly, the proliferation of portals has centred on the premise that increasing the number and availability of climate modelling data and projections will successfully translate into its use in decision making and, in turn, successfully translate into effective climate-sensitive development (Houtkamp *et al.*, 2016; Swart *et al.*, 2017). This assumption has led to a duplication of similar efforts: a collection of portals which commonly over-supply data, under-guide the user and so are somewhat redundant to each other. There is a strong understanding that user requirements must guide portal development more explicitly if they wish to be effective for decision makers. Secondly, climate information portals work to provide and contextualise knowledge from the scientific community to decision makers (Vaughan and Dessai, 2014). The supply-oriented approach has successfully provided climate information almost to a point of overabundance. However, unintuitive web design and data presentation methods, and a lack of user guidance materials continue to limit the relevance and usability of climate information from portals. There is a sparsity of portals that effectively contextualise information, delivering decision-relevant climate information for decision makers (Lemos *et al.*, 2012).

Thirdly, many portals describe themselves as one-stop-shops for climate information. However, there is a diversity of decision makers (e.g. urban water planners, coastal managers, conservation officers etc.), and an equally diverse set of corresponding data needs (Groot *et al.*, 2015). Additionally, users express a desire to consult a variety of different sources to acquire decision-relevant climate information (e.g. national meteorological offices, academics, impact researchers and so on) (Morand *et al.*, 2015). There is criticism that some existing portals have inflated their utility to decision makers, and employed different web design and presentation methods while providing similar (if not the same) climate data (Hewitson *et al.*, 2017).

As stated above, climate information portals are an emerging and fragmented area of practice (Hewitson *et al.*, 2017). Subsequently, there have been large differences in resources (financial and otherwise) inputted into portal development. Portals have ranged from resource intensive multi-national collaborations to opportunistic research projects. This creates considerable uncertainty (within user and provider communities) around the continuity of many climate information portals and their subsequent ability to support decision making needs *into the future* (Swart *et al.*, 2017).

Nevertheless, primary data characterising the current and future provision of climate information from portals, to identify areas of commonality, difference and gaps in provision is scarce. As such, this report includes a jurisdictional scan and interview series on climate information portals and providers.

3. JURISDICTIONAL SCAN

This section presents the findings of the jurisdictional scan. Section 3.1 explores each climate information portal in detail. These sections describe what climate information they provide in terms of

- data tools
- climate models and downscaling
- emission scenarios and timeframes
- climate variables and indices
- handling of uncertainty
- metadata
- user guidance
- website design

Insights that inform this report's recommendations are identified at the end of each portal's section. More comprehensive strengths and weaknesses are outlined in annex 1. Section 3.2 synthesises findings from across all 15 portals and provides an overview of their currently provided climate data using various tables and figures. Areas of similarity, difference and gaps in the provision of climate data from the 15 portals are highlighted and inform this report's recommendations.

3.1.1 CLIMATE CHANGE IN AUSTRALIA

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Decision-support tool displaying plausible climate futures based on CMIP3 and CMIP5 outputs	○ University-based institute	○ Global	• Terrestrial	○ 1-3
	• Government department	○ Regional	• Oceanic	○ 4-6
	○ Multi-national collaboration	• National		• >6
	○ National meteorology office	• Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 2015
Headquarters: Canberra, Australia

Climate Change in Australia (CCIA) was developed and funded by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology. The Australian Government's Department of the Environment also contributed funding.

CCIA is a sophisticated decision-support tool for climate adaptation decision making and contains one of the largest amounts of content compared to the other portals. It presents information on observed and future climate change, general climate change topics, impacts and adaptation information and allows raw data downloads. In this way, CCIA is one of the most comprehensive of the 15 portals examined.

The "Climate Change In Australia Projections Technical Report" forms the comprehensive report on which all the information found in CCIA is based upon. In this manner, CCIA is similar to Pacific Climate Futures and UKCP09 (i.e. all based on comprehensive reports).

CCIA is characterised by the provision of sophisticated application-ready data for use in decision making processes and extensive user guidance materials on the appropriate use of such information.

Provision of climate information

Data tools

DATA TOOL	OVERVIEW	OUTPUT
Regional climate explorer	• Generates text-based projection summaries of future climate change for regions of interest.	Text-based key messages
Summary data & extremes explorer	• Generates bar plots of future climate change across four time periods and emission scenarios and for regions of interest.	Bar plots
Map & timeseries explorer	• Map-based visualisation interface. • Displays terrestrial climate projections based on user-defined parameters (e.g. emission scenario, model, variable and so on).	Maps and timeseries
Thresholds calculator	• Map-based visualisation interface. Generates maps of threshold-based climate indices under user-defined climate parameters.	Maps
Australian Climate Futures Tool	• Displays climate projections in terms of the degree of model agreement under selected parameters.	Multi-variate tabulated model output
Climate analogues explorer	• Visualises the projected future climate of a location of interest with the present climate of another.	Bar plots
Coastal and marine explorer	• Same as map explorer but covers oceanic climate variables.	Maps
Raw data download	-	NetCDF, .csv, JSON, ASCII formats

CCIA also features a useful data explorer which, in tabulated form, describes the differentiating characteristics of these data tools. This is advantageous in helping users to navigate the large quantity of climate information provided.

Climate models and downscaling

CCIA uses both CMIP3 and CMIP5 data. Forty CMIP5 GCMs that have undergone model evaluation for performance over Australia are presented in the projected changes sections. Meanwhile, the application-ready sections use a subset of 8 CMIP5 GCMs that represent the range of projections in the 40-member ensemble. The portal also uses 18 older CMIP3 models. The portal contains six dynamically downscaled data products from CSIRO's Conformal-Cubic Atmospheric Model (CCAM) and 22 statistically downscaled data products using the delta change technique (CCIA, 2015). Using these downscaling methods and scaling creates an output resolution of 5km^2 for most of the datasets presented (some climate variables are presented at 7.5km^2).

Emission scenarios and timeframes

The projected change data uses the IPCC-recognised reference period of 1986-2005 while the application-ready data uses the WMO-recognised 1981-2010 reference period. The portal provides all SRES scenarios and all RCPs. Both projected change and application-ready data allow for monthly, 3-monthly, 6-monthly and annual averages to be obtained.

Climate variables and indices

CCIA focuses on climatic change and provides no data on impacts, exposure or vulnerability. CCIA does feature an "Impacts and Adaptation" section although this gives summary information in text form.

The projected change section provides a total of 14 climate variables and 8 derived indices. Meanwhile, the application-ready data contains a smaller selection of 8 climate variables and 2 indices. Similar to other portals, the majority of variables and indices relate to temperature and precipitation.

Handling of uncertainty

CCIA handles uncertainty in one of the most sophisticated ways across the 15 portals. The form of uncertainty information differs depending on the data tool in use. CCIA uses the ensemble median and spread (10th and 90th percentiles) in its bar plots and timeseries outputs.

CCIA's multi-variate tabulated model outputs present uncertainty information in terms of the degree of model agreement and likelihood for ranges of climate change from across the multi-model ensemble; that is, the extent to which models project the same/differing ranges of change for a given variable/index, region, time period and so on. This is a more obscure way to convey the spread and clustering of climate projections when compared to other portals.

CCIA also provides additional background information on uncertainty concepts. The portal contains a "Climate Campus" section which acts as a centralised resource for background information on the concepts (as well as other topics).

As described above, the use of a model evaluation process removes unrepresentative and highly uncertain model outputs and, in turn, removes the less decision-relevant climate data. Eliminating data choice in this way helps create application-ready data and removes data management, selection and analysis demands on the user.

Metadata

CCIA provides high-level text-based metadata in its "Data explorer" section which, in tabulated non-technical form, outlines the portal's data tools and the underlying data they draw from. CCIA appears to provide metadata in an accessible form for non-technical users.

User guidance

CCIA contains a very large quantity of climate information and data tools and, correspondingly, provides an extensive portfolio of user guidance materials. CCIA does not feature a central user guide but takes a different approach. Instead the portal contains distributed guidance material and uses text-based descriptions and tutorials coupled to each data tool to guide the user on portal content and function. CCIA's "Climate Campus" section provides educational material and resources on general climate change topics in an accessible format. CCIA provides some of the most extensive educational information of any portal. Additionally, CCIA contains a "Publications Library" section to provide access to the more detailed technical reports that underlie the platform.

CCIA employs a decision-tree (in a similar way to UKCP09) and tool rating system to guide users to suitable climate information and tools. These very effectively dissect the large volumes of information on the portal and ensure that different user needs and skill levels are matched to appropriate data and tools. This promotes the appropriate use of CCIA's climate data for its intended purposes.

The appropriate use of climate information is a consistent theme throughout CCIA's guidance materials. Numerous general pieces such as "Important considerations when exploring climate data" and "Common mistakes when using climate data" work to educate users on the mindful use of climate information in line with its limitations. Furthermore, the use of pop-up data disclaimers and other cautionary-style messages, embedded for the user to see as they use various data tools, effectively indicate how (and how not) specific data from the portal should be used. Strong appropriate use guidance serves to advance this portal's effectiveness as a decision-support tool.

Website design

CCIA's design focuses, to a lesser extent than some other portals, on aesthetic qualities and does feature extensive text-based web pages. While this may be less appealing to the time-limited users, effective user guidance does work to maintain ease of use albeit meaning portal operation is more time consuming.

Main insights

Application-ready data

CCIA is a sophisticated decision–support tool that has tailored scientific climate projections data into application-ready data to increase usefulness for decision makers (similar to Pacific Climate Futures). Firstly, CCIA undertook model evaluations to curate a subset of representative climate projections data. This assists (especially non-technical) users by reducing data choice and management requirements. Secondly, displaying information as multi-variate tabulated model outputs highlights the degree of model agreement and likelihood of occurrence. This mode of delivery enables decision makers to assess the plausibility of different climate futures, and is clearer than traditional map- and timeseries-based outputs.

***INSIGHT:** Climate information portals can provide application-ready data by undertaking model evaluations and, in turn, present data in ways that highlight the range and plausibility of different climate futures. This better satisfies decision maker needs than the visualisation of scientific-format climate data.*

Appropriate use guidance

CCIA also focuses on the appropriate use of its information. CCIA clearly differentiates its tools for different skill levels and purposes (e.g. via the tool rating system and decision-tree). This effectively matches user-needs to suitable areas of the portal (in a similar manner to UKCP09 and Pacific Climate Futures). Furthermore, cautionary guiding principles on the use of climate information for decision making purposes are emphasised. These needs-based guidance materials help ensure CCIA's information is

appropriately used (and mitigates against its misuse). Other portals tend to provide data-driven user guidance which is less effective at ensuring decision maker needs are met.

***INSIGHT:** Climate Information portals can focus on the provision needs-based user guidance. This effectively matches informational needs to suitable portal content and promotes the appropriate use of climate information in decision making processes.*

3.1.2 UK CLIMATE PROJECTIONS 2009

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Decision-support tool for probabilistic climate projections based on CMIP3 and HadSM3 outputs	○ University-based institute	○ Global	• Terrestrial	• 1-3
	• Government department	○ Regional	• Oceanic	○ 4-6
	○ Multi-national collaboration	• National		○ >6
	○ National meteorology office	• Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 2009
Headquarters: Exeter, UK

The UK Climate Projections 2009 (the UKCP09) portal was developed by the UK's Environment Agency and the Met Office. Funding was received from the Department of Food, Agriculture and Rural Affairs, the Department for Business, Energy and Industrial Strategy, the Department of the Environment (Northern Ireland), the Scottish Government and the Welsh Assembly Government. Numerous data partners were used to curate climate data for the portal.

UKCP09 is an extensive and sophisticated decision-support tool presenting probabilistic climate change projections over the UK and surrounding marine regions. This means information is displayed in terms of the projected climatic changes associated with user-specified probability levels or in terms of the probability levels associated with user-specified thresholds of climatic change.

CCIA, Pacific Climate Futures and UKCP09 are similar portals in their overall approach. All three provide decision-supportive application-ready data. UKCP09 is also based on seven comprehensive scientific reports which detail the underpinning research and findings of the portal; again similar to CCIA and Pacific Climate Futures. At the time of writing, work on the updated UKCP18, reflecting more up to date climate information, is reaching its final stages and is due for release in November 2018 (UKCP09, 2018).

Provision of climate information

Data tools

DATA TOOL	OVERVIEW	OUTPUT
Maps and key findings	• Displays non-interactive probabilistic climate projections data for a desired emission scenario, location, climate variable.	Maps, timeseries and text-based key messages
User Interface	• Displays interactive probabilistic climate projections data after selecting various user-defined parameters in a step-by-step process (e.g. climate variable, location, time period, emission scenario and so on). • Outputs are viewable in terms of projected climatic changes at user-specified probability levels or in terms of probability levels at user-specified thresholds of climatic change. • Viewable as 25km^2 grid boxes, administrative basins or river basins.	Maps, joint probability plots, plume plots, return period plots, probability density functions (PDFs) and cumulative density functions (CDFs)[3]
Raw data download	-	.csv, netCDF and shapefile formats

Climate models and downscaling

UKCP09 uses 13 GCMs by combining projections from 12 CMIP3 GCMs with a perturbed physics ensemble of the Met Office's own HadSM3 model to produce the probabilistic climate projections. These outputs are dynamically downscaled to a resolution of 25km^2 using the HadRM3 model. A custom Weather Generator is also used to statistically downscale a selection of variables to daily timeseries at a 5km^2 resolution (provided as separate datasets).

Emission scenarios and timeframes

UKCP09 uses the WMO-recognised 1961-1990 reference period for its climate projections. Outputs can be explored under all SRES scenarios in 10-year time steps that use an overlapping 30-year time interval. To enable assessments of seasonality, monthly, 3-monthly and annual averages for user-defined climate parameter selections can be acquired. Projections can also be viewed as absolute and relative changes.

Climate Variables and indices

UKCP09 provides a wide selection of 38 climate variables and 9 derived indices with the majority relating to temperature, precipitation and marine changes (and a few relating to water vapour and radiation fluxes).

Handling of uncertainty

UKCP09 employs one of the most sophisticated handlings of uncertainty from all 15 portals examined here. The portal's attribution of probability to its climate projections is highly useful in helping users navigate uncertainty. In UKCP09, the probability

[3] Available outputs vary depending on the user-defined parameters selected.

measures the degree to which a particular climate projection is consistent with the information used in the analysis. Furthermore, users can explore climatic changes at given probability levels (e.g. 50% probability of occurrence) and/or the probability levels of given thresholds of climatic change (e.g. 2°C warming). Quantifying uncertainty in terms of probability (i.e. likelihood of occurrence) enables users to better identify (and plan for) ranges of climate outcomes in a way that is more obscure when presenting direct climate model outputs. This ability aligns more directly with decision maker problem framings and needs.

Interactive online user training and background information on uncertainty in climate change projections is provided as well as user guidance on how UKCP09's probabilistic climate projections present uncertainty.

Metadata

As discussed above, UKCP09 is grounded in seven comprehensive scientific reports with outline the detailed metadata for data presented in UKCP09. Additionally, a table of data products usefully outlines the broad data characteristics of each portal feature as does the user guide.

User guidance material

UKCP09 presents sophisticated probabilistic climate change projections that arguably require a higher level of skill from users to successfully understand and use compared to the visualisation of direct climate model outputs that other portals tend to provide. Correspondingly, UKCP09 provides extensive user guidance and includes a user guide, an extensive interactive glossary whereby key term definitions appear as the user hovers over them, an FAQ section and educational pieces on general climate change topics. Moreover, UKCP09 provides extensive appropriate use guidance. The use of a site map and decision tree works to match user needs with suitable portal features while guiding principles on the use of UKCP09's data recommends how it's information should (and should not) be used in climate decision making processes. Lastly, UKCP09 also provides 7 online training modules relating to climate change topics in general and the content and use of the portal itself. In a similar manner to CCIA, UKCP09 provides some of most comprehensive user guidance portfolios among the 15 portals.

Website design

In a similar manner to the Climate Futures tool of CCIA and Pacific Climate Futures, the portal's User Interface tool walks users through parameter selection screens to produce outputs. This approach is more text-heavy and less aesthetic than those portals that use large visualisation interfaces and can mean immediate clarity and ease of use is reduced. Nevertheless, the numerous user guidance materials of UKCP09 do work to ensure clarity is not lost for the user.

Main insights

Application-ready data

UKCP09 provides tailored application-ready data (similar to CCIA and Pacific Climate Futures). Probabilistic climate change projections convey climate futures in terms of the likelihood of occurrence as opposed to displaying direct climate model outputs. Likelihood of occurrence can more directly align with decision maker problem framings

and encourage a consideration of ranges of possible climate futures. Other portals tend to display direct climate model singular ensemble averages and spreads. Additionally, the various outputs of the User Interface are publication-ready and can be easily exported for use.

INSIGHT: With a view to meet decision maker needs, climate information portals can tailor scientific climate data into more usable forms for decision makers (e.g. probabilistic climate projections) and, in turn, serve more direct decision-support functions.

Appropriate use guidance

As outlined above, UKCP09 focuses on the appropriate use of its climate information (e.g. a site map, decision tree, 11 guiding principles on climate information use and online user training modules). These features help guide different users to suitable climate data held across the portal's features and explain the portal's intended users and uses much more explicitly than the majority of other portals. In doing so, the portal promotes the appropriate use of its information (and mitigates against its misuse) effectively.

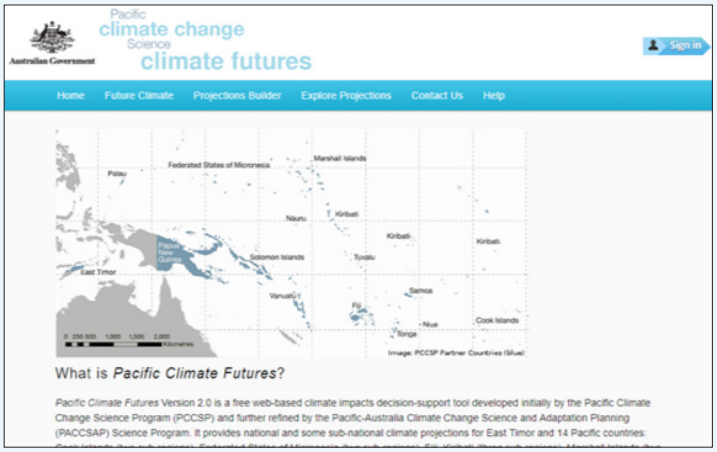
INSIGHT: When targeting decision makers, climate information portals can supplement climate data with appropriate use guidance materials. These can explicitly explain a portal's intended users, uses and how its information can be suitably used in decision making processes.

3.1.3 PACIFIC CLIMATE FUTURES

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Decision-support tool displaying plausible climate futures based on CMIP3 and CMIP5 outputs	○ University-based institute	○ Global	• Terrestrial	○ 1-3
	• Government department	• Regional	• Oceanic	• 4-6
	○ Multi-national collaboration	○ National		○ >6
	○ National meteorology office	○ Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 2011
Headquarters: Canberra, Australia



Work for Pacific Climate Futures, launched in 2011, was a joint undertaking by Australia's Bureau of Meteorology and CSIRO as a key initiative under the Pacific Climate Change Science Program (Pacific Climate Futures version 1) and the Pacific-Australia Climate Change Science and Adaptation Planning Program (version 2; released in 2014). Pacific Climate Futures was a precursor to the larger CCIA portal released in 2015 and as such bears numerous similarities.

Pacific Climate Futures is a sophisticated decision-support tool for the 14 Pacific Island States and East Timor providing national climate projections as well as representative CMIP3 and CMIP5 outputs that are ready to use in climate risk/impact assessments. In this manner, Pacific Climate Futures provides application-ready climate information similar to CCIA[4]. As a single decision-support tool, Pacific Climate Futures illustrates how portals can take a narrow but in depth approach to the provision of climate information; providing smaller amounts of data that is evaluated for representativeness and appropriateness for use in decision making as opposed to providing larger amounts of climate data.

[4] The Climate Futures tool found in CCIA is a refined version of the one used here by Pacific Climate Futures.

Provision of climate information

Data tools

DATA TOOL	OVERVIEW	OUTPUT
Future climate change	• Displays climate projections information for a user-defined region, time period and emission scenario. • Output is divided and displayed in terms of maximum consensus, least change and potential high impact climate futures.	Text-based key messages, tabulated model output, scatter diagrams and timeseries
Projections builder	• Sophisticated tool for use in climate risk/impact assessments. • Displays application-ready projections data under various user-defined parameters (e.g. regions, variables, emission scenarios). • Users employ their existing knowledge of the sensitivity of the system in question to describe best and worst case scenarios. • Tool then ranks models and displays outputs from representative models in terms of the best case, worst case and maximum consensus climate futures.	Tabulated model outputs
Explore projections	• Displays probabilistic climate projections under various user-defined parameters (e.g. region, time period, emission scenario and so on). • Multi-variate tabulated outputs illustrate the degree of model agreement, and so likelihood, across the multi-model ensemble. • Contains guidance notes advising the user on unsuitable models.	Multi-variate tabulated model outputs
Compare tool	• Same as above however from allows a comparison across two projections.	Multi-variate tabulated model outputs

Similar to CCIA, this portal differentiates its tools for different skill levels (basic, intermediate and advanced) requiring the user to undertake training and tests to access more complex tools. Employing this system effectively guides heterogeneous users to suitable portal content and mitigates against the misuse of climate information.

Climate models and downscaling

The portal utilises a large range of 18 CMIP3 and up to 43 CMIP5 GCMs. For each group, 6 dynamically downscaled data products are presented at a 14km^2 resolution using CSIRO's CCAM model.

Emission scenarios and timeframes

Pacific Climate Futures uses a 1980-1999 and the IPCC-recognised 1986-2005 reference periods for its CMIP3 and CMIP5 projections respectively. The portal is one of only 3 portals enabling users to explore projections across all SRES and RCP scenarios. Furthermore, this portal allows users to explore projections with much freedom of choice. For CMIP3 outputs, the user can explore changes at three 20-year 21st century time periods. Meanwhile for CMIP5 outputs, a 10-year overlapping time interval is used to allow the user to explore projections at 5-year time steps; the smallest time step

across all 15 portals examined here. Furthermore, projections can be explored in terms of monthly, 3-monthly, 6-monthly and annual averages enabling the user to assess seasonality.

Climate variables and indices

Pacific Climate Futures provides 11 climate variables and 4 derived-indices which cover a balanced range of areas (temperature, precipitation, oceans, wind and water vapour).

Handling of uncertainty

Pacific Climate Futures handles uncertainty in a more sophisticated way than most other portals. It uses multi-variate tabulated model outputs to visualise the degree of model agreement and projection likelihood across the multi-model ensemble for ranges of climate change (using both a colour scale and by identifying the number and percentage of models in agreement). The ensemble median and spread can still be identified. However, rather than reducing the multi-model ensemble to a singular average and spread (like many portals choose), the tabulated outputs enable the user to better assess the range of projections within the ensemble via the visualisation of model agreement and projection likelihoods. This, in turn, allows the user to identify climate futures that are assumed to be more plausible than others as a means to navigate uncertainty. Through helping users better navigate uncertainty, as opposed to simply presenting uncertainty information (i.e. ensemble averages and spreads), Pacific Climate Futures takes on a more sophisticated handling of uncertainty.

Furthermore, all the GCMs contained in the portal have undergone evaluation for performance over the Pacific region in general. The portal's representative model wizard also serves the same function and selects models (and their outputs) that are deemed robust with respect to user-selected parameters and omits the inclusion of unrepresentative outputs. Again, this represents a more sophisticated handling of uncertainty compared to most other portals.

Metadata

In a similar manner to CCIA and UKCP09, Pacific Climate Futures is grounded in extensive background government research; in this case by Clarke *et al.* (2011) to develop the Climate Futures Framework, which forms the basis of the Climate Futures tool, and by the Australian Bureau of Meteorology and CSIRO (2011; 2014) which evaluated GCM and downscaled climate projections data from representativeness over the Pacific region. These documents provide extensive metadata on the data contained in this portal. Additional metadata in summary form is made available in the portal's user guide and throughout the various portal pages as the user uses its tools and interacts with the underlying climate data.

User guidance materials

A notable feature of this portal is the tool rating system which is discussed above and very similar to that employed by CCIA. As well as ensuring the appropriate use of the portal's climate information, from a user guidance perspective this rating system helps to guide users to suitable portal features that are within their skill level and where appropriate ensures users have received training prior to use. Pacific Climate Futures also contains a user guide, glossary, FAQ section and educational information on background climate change topics. These serve similar goals as those provided on other portals.

Website design

Pacific Climate Futures does not feature a centrally located map-based interface like that of many other portals and instead walks the user through parameter selection screens to display climate information. This approach relies more heavily on explanatory text as opposed to aesthetic graphical displays of climate information and so perhaps provides less immediate website clarity.

Main insights

Application-ready data

Pacific Climate Futures provides application-ready climate data to increase the usefulness and usability of information to decision makers in a similar fashion to CCIA. Firstly, the portal is grounded in an extensive climate model evaluation that has identified the most suitable GCMs and downscaled projections for the Pacific region (Australian Bureau of Meteorology and CSIRO, 2011; 2014). Secondly, the Pacific Climate Futures tool employs a "representative model wizard". This feature selects appropriate climate projections in line with selected parameters. In short, only plausible climate projections are given. This reduces the user effort required for the data management and analysis of abundant choices of climate information.

INSIGHT: Climate information portals can provide smaller amounts of highly useful application-ready data as opposed to increased amounts of "as-is" climate information. This eliminates user effort and can better serve a decision-support function.

Appropriate use guidance

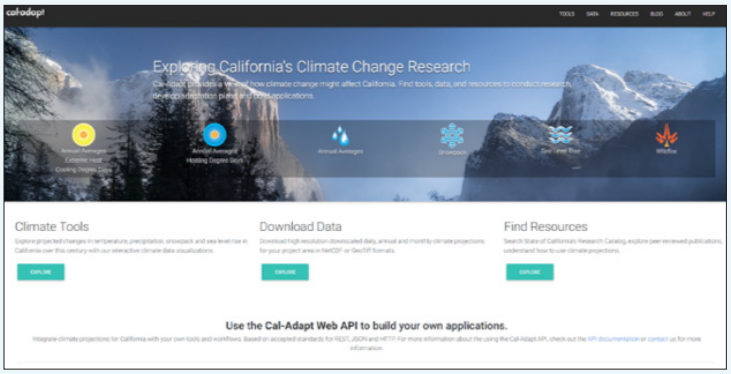
Pacific Climate Futures also provides user guidance to help ensure the appropriate use of its information. For example, the tool rating system ensures users with particular data needs are directed to appropriate tools. Additionally, guidance notes caution users against using single, possibly unrepresentative, model outputs. These measures guide users on how portal information should/should not be used in climate decision making.

INSIGHT: Appropriate use guidance can help ensure users with heterogeneous needs and skill levels are directed to suitable data products. Guidance also helps users understand how such products should/should not be used which can further ensure the appropriate use of climate information in decision making.

3.1.4 CAL-ADAPT

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Visualisation platform for downscaled CMIP5 outputs	• University-based institute	○ Global	• Terrestrial	• 1-3
	○ Government department	○ Regional	• Oceanic	○ 4-6
	○ Multi-national collaboration	○ National		○ >6
	○ National meteorology office	• Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW



Year created: 2011
Headquarters: Berkeley, California, USA

Cal-Adapt is a recently developed climate information portal created by the Geospatial Innovation Facility based at UC Berkeley with funding from the California Energy Commission's Public Interest and Energy Research Program. Data partnerships with the Scripps Institution of Oceanography, California Energy Commission, Geospatial Innovation Facility, University of California (Berkeley), California Natural Resources Agency, University of Washington, Santa Clara University, Google.org, US Geological Survey, Our Coast Our Future, Pacific Institute and University of California (Merced) were forged to identify and collate climate data for the portal. Google.org and the California Energy Commission also provided advisory oversight.

Cal-Adapt is a visualisation platform for downscaled CMIP5 outputs over the State of California. The portal is characterised by taking a subnational geographic focus only (the State of California) as well as employing intuitive and aesthetic web design.

Provision of climate information

Data tools

DATA TOOL	OVERVIEW	OUTPUT
Timeseries viewer	• Displays observed and future climate change under various user-defined parameters (e.g. emission scenario, location, time period). • Interactive sliders enable the user to quickly select a projection period. • Provided for 10 of 11 climate variables and indices.	Timeseries
Map viewer	• Same as above. • Provided for 5 of 11 climate variables and indices.	Maps
Raw data download	-	NetCDF and GeoTIFF files

Climate models and downscaling

Cal-Adapt uses 10 CMIP5 GCMs that have been selected by Californian state agencies for robust performance over California. Furthermore, four of these models are identified as representative models capturing the range in climate change projections over California. As such, they are presented by default when the user attempts to use the data tools. The 10 GCM outputs have been statistically downscaled using a Localised Constructed Analogs (LOCA) method (Pierce *et al.*, 2014). This provides outputs at a spatial resolution of 6km^2 across the State. Cal-Adapt presents no dynamically downscaled climate data products.

Emission scenarios and timeframes

Cal-Adapt uses the WMO-recognised 1961-1990 reference period and presents projections with respect to RCP4.5 and 8.5 (identified on the website as low and high emission scenarios). The portal uses no SRES scenarios. In terms of temporal averages, the user is able to select (from an interactive calendar) any annual date range to explore climate changes within the annual cycle. This offers the user considerable freedom of choice.

Climate variables and indices

The portal presents 6 climate variables and 3 derived indices covering temperature and precipitation, sea level rise, snow water equivalence and wildfires (area burned). Projection changes are viewable as absolute values although the use of an effective "quick stats" call-out box assists users in identifying relative climatic change by displaying the historical mean and modelled mean adjacent to each other (albeit without providing a specific value for relative change to the 1961-1990 baseline).

Handling of uncertainty

Cal-Adapt presents uncertainty by way of ensemble means and spreads (displayed in the portal's timeseries outputs). It also provides text-based information on the broad concepts of uncertainty and confidence and their relation to climate change decision making in general (see "Guidance on Using Climate Projections" section). Some brief text-based information is given on the appropriate use of Cal-Adapt's climate information specifically.

As outlined above, Cal-Adapt employs a model evaluation and selection process that identifies a sub-selection of 10 CMIP5 GCMs that are deemed to perform well over California. Further still, 4 priority GCMs of the 10-member ensemble are identified as representative of the range of future change which are displayed to the user by default. This helps the user explore more plausible climate projections. In this way, Cal-Adapt reduces the data choice it gives users and provides more decision-relevant climate data to users.

Metadata

Cal-Adapt contains a centrally located "Data" section through which all metadata is found. Metadata details data characteristics, such as spatial and temporal resolution, geographic extent and data provenance. Figure captions that accompany the portal's graphical displays also summarise the underlying climate data and link to the more detailed standalone metadata section.

User guidance

Cal-Adapt provides limited user guidance. A short text-based FAQ section is provided which, in the absence of other forms of user guidance, acts as the portal's guidance centre. The FAQ section gives additional information on general climate change topics and explains key terms. The piece also gives some general advice on the appropriate use of climate change projections through explaining what Cal-Adapt does, does not do and how it can be used (Cal-Adapt, 2018).

Cal-Adapt is one of the more public facing portals examined. It provides the basic features, such as email addresses to tackle user enquiries, and also contains the "Cal-Adapt Blog" to communicate relevant news and updates. The portal also has a social media presence. Through these public-facing elements, Cal-Adapt is similar to PREPdata.

Website design

While limited user guidance is provided, the portal uses a very intuitive and aesthetic design. It uses consistent page layouts, text formats, colours, legends and data display formats across the portal website which aids ease of use and aesthetics. The use of blank space between website components and the relatively stringent yet sufficient use of text (e.g. figure headings, labels, and captions) also adds clarity; succinctly explaining portal features and their operation.

Main insights

Intuitive website design

Cal-Adapt employs effective data tool design. The use of interactive sliders, large parameter selection buttons, high resolution outputs and highlighted call-out boxes effectively summarise its visualised data. More generally, the portal features the consistent and aesthetic positioning and formatting of portal elements. In turn, Cal-Adapt supports intuitive use and so assists users to find suitable climate information for their needs. This also decreases the need for overly extensive user guidance materials.

INSIGHT: Climate information portals can be developed with a focus on intuitive and aesthetic portal design. This can reduce user frustration and increase ease of use. This approach can be particularly effective if targeting first-time, inexperienced and/or non-technical users.

3.1.5 PARTNERSHIP FOR RESILIENCE AND PREPAREDNESS

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Climate data library and map-based visualisation platform primarily for downscaled CMIP5 outputs	○ University-based institute	• Global	• Terrestrial	• 1-3
	○ Government department	○ Regional	• Oceanic	○ 4-6
	• Multi-national collaboration	○ National		○ >6
	○ National meteorology office	○ Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 2018
Headquarters: Washington DC, USA

The PREPdata portal is an output from the PREPdata partnership which formed in 2016. The World Resources Institute and Future Earth are coordinators of the partnership while Resource Watch developed and maintain the portal. As a climate data library and map-based visualisation platform, PREPdata involves numerous global data partners. PREPdata was created in early 2018 making it the youngest portal of the 15 examined here.

PREPdata takes three central themes: improving access to timely, useful and credible climate data, the utilisation of high quality visualisation techniques and the use of user feedback mechanisms. The latter is PREPdata's unique characteristic (from the other 14 portals) and opens active and ongoing communication between providers and users to ensure that the provision of datasets is user-driven. The portal also features highly aesthetic website design to aid ease of use.

Provision of climate information

Data tools

PREPdata uses a central map-based visualisation platform (map viewer) through which users can view datasets covering the globe, the USA and India[5]. The map viewer offers a moderate degree of interactivity; enabling the user to further explore datasets under RCP4.5 and 8.5 and in 10- and 30-year time periods. Specific locations of interest can also be clicked on to acquire location-specific timeseries outputs.

PREPdata also provides a unique feature: a dashboard tool (see table below). This tool allows users to synthesise climate information (e.g. text, tables, charts, images and other elements) into personalised dashboards for a given geography or topic of interest. The dashboard resource bank serves to showcase climate preparedness activities in other communities as well as act as a collection use cases on how the tool might be used.

DATA TOOL	OVERVIEW	OUTPUT
Map viewer	• Main portal feature. • Large, high resolution display. • Interactive map-based visualisation platform. • Outputs can be explored in terms of emission scenario (RCP4.5 and 8.5) and across various time periods.	Maps and timeseries
Dashboard tool	• Users can create personalised dashboards for specific geographies or topics of interest. • Users can collate text, images, maps, timeseries and other information. • Information and data from both PREPdata and other sources can be used.	Personalised dashboards
Raw data download	• Download links direct users to data host sites.	Various file formats.

PREPdata displays information on a dataset-by-dataset basis within an interactive map-based visualisation interface. In turn, characteristics such as reference period, underlying GCMs, spatial resolution and so on vary depending on the dataset in question.

At present, PREPdata's datasets predominantly cover temperature and precipitation change, making it similar in this regard to many other portals. Across the provided datasets, 4 temperature and precipitation variables and 7 derived indices are available and are drawn from 32 CMIP5 GCMs. A range of other datasets displaying climate impact indicators (e.g. landslide potential, wildfire risk) are also available. Contrary to many other portals, PREPdata provides users with downscaled data from

[5] At the time of writing.

two different sources. Firstly, the LOCA statistically downscaled datasets (Pierce et al., 2014) are provided which cover the USA (and are also presented in Cal-Adapt). This data is downscaled from CMIP5 outputs to a resolution of 6km^2. Secondly, NASA's Earth Exchange Global Daily Downscaled Projections datasets are included which are global in coverage. These use a bias correction method to downscale CMIP5 GCM outputs to a 25km^2 resolution. At the time of writing, PREPdata is an active climate data library meaning content will continue to be updated.

In addition to climate datasets, PREPdata also links to a growing number of publications on climate impacts, online climate assessment and preparedness tools, data portals and multi-resource platforms.

Handling of uncertainty

PREPdata presents uncertainty in terms of the ensemble mean and spread (25th and 75th percentiles) in timeseries form. No additional educational materials on the concepts are provided. Accessing PREPdata's timeseries can be a challenge for the user as they are not displayed or accessible from the main map viewer and are instead displayed when the user selects to further explore an individual dataset meaning the portal's uncertainty information is considerably hidden in the overall portal architecture. This can be problematic for the users seeking such information and further problematic for inexperienced users who may be unware of the importance of uncertainty information.

Metadata

In a similar manner to the CCKP, CLIPC and the South African Risk and Vulnerability Atlas, PREPdata readily provides metadata on each dataset in its library. Metadata is also highly accessible from within the map viewer interface as the user selects datasets of interest. Metadata comprises a short yet information-rich text-based abstract as well as links to data provenance and external download locations.

User guidance materials

PREPdata's user guidance material is characterised by the unique use of a user feedback mechanism which, as discussed above, opens up provider-user dialogue to help ensure the curation of climate datasets and overall provision of climate information on the portal is based on user-needs. The user feedback feature is similar to a discussion forum in which users can submit requests for types of climate data, suggest datasets of their own for inclusion, highlight portal bugs and fixes and so on. PREPdata and other users can then interact with them to open further discussion and/or provide updates on progress. More generally, this characterises PREPdata (along with Cal-Adapt) as one of the more public facing portals examined here and encourages, for example, social media sharing and users to get in touch with the portal developers to a greater extent than the majority of other portals.

Outside the user feedback mechanism, PREPdata provides little user guidance material which largely reflects the aesthetic and easy to use portal design. A brief "How to" section forms the portal's main user guide (though at the time of writing it is awaiting completion) and an FAQ section provides further guidance.

Website design

PREPdata features highly aesthetic and easy to use website design reflecting its very recent launch. The use of a large high resolution map viewer provides clarity for users exploring datasets. Furthermore, the consistent and strategic use of an orange, blue

and white colour scheme, text sizes, fonts and formats and other features work to increase website clarity and ease of use.

Main insights

User feedback mechanisms

PREPdata uniquely employs, and makes easily accessible, a user feedback mechanism as a vehicle to open up provider and user dialogue on the site. This facilitates an effective communication of user-submitted data requests and updates on bugs and fixes. Where other portals simply provide basic contact information for enquiries, PREPdata actively seeks user input to understand information needs. In this manner, PREPdata supports the needs-based provision of climate information to a much greater extent.

INSIGHT: Employing user feedback mechanisms opens active provider-user dialogue as a way to ensure current and future data products meet user needs now and into the future (as well as support effective portal design). Employing this mode of needs-based climate data provision can allow portal developers to effectively identify and fill gaps in provision and maximise usefulness in decision making. This also mitigates against a climate information portal becoming redundant to other sources.

Multiple data sources

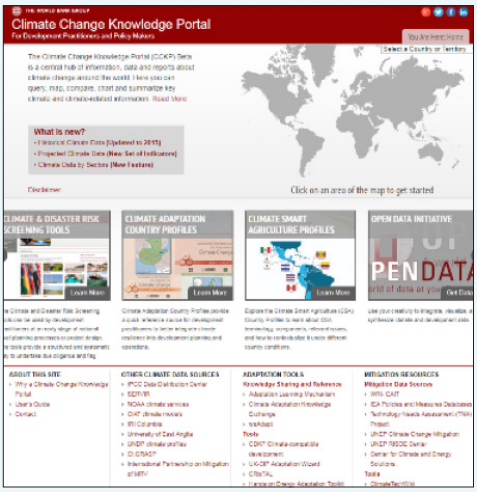
Many portals are data visualisation platforms for climate data from individual research programs (e.g. Climate Impacts Online, NCAR's Climate Change Portal, ESRL's Climate Change Web Portal). As such, they often contain data from only one source. PREPdata, as an institutional partnership and climate data library, is free to provide data from multiple sources. PREPdata also provides downscaled climate datasets from more than one source and which use more than one downscaling method.

INSIGHT: Climate information portals that are not tied to research organisations and programs have the ability to curate data from multiple sources into climate data libraries. In this way, climate information portals designed as data libraries can be more effective at providing data that covers a greater breadth of topic areas and from a balance of sources.

3.1.6 CLIMATE CHANGE KNOWLEDGE PORTAL

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Map-based visualisation platform for non-downscaled CMIP3 and CMIP5 outputs	○ University-based institute	• Global	• Terrestrial	○ 1-3
	○ Government department	• Regional	○ Oceanic	• 4-6
	• Multi-national collaboration	• National		○ >6
	○ National meteorology office	○ Subnational (Watershed Level)		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW



Year created: 2010
Headquarters: Washington DC, USA

The Climate Change Knowledge Portal (CCKP) was developed by the Climate Change Group at the World Bank with the technical support of numerous other institutions[6].

Similar to many other portals, the CCKP is a map-based visualisation platform for observed and projected climate changes. The CCKP is one of two portals examined here that provides climate data at global, regional, national and watershed levels.

Overall, the CCKP is characterised by high climate data coverage which is visualised effectively on a central, well-harmonised map-based visualisation interface. The CCKP also focuses on the visualisation climate data alone and undertakes little data manipulation with a view to create application-ready data. A new improved version of the CCKP that addresses many of the suggested improvements below is expected to be launched later in 2018.

[6] The Global Facility for Disaster Reduction and Recovery, the Green Growth Knowledge Platform, the Climate Systems Analysis Group, the International Research Institute for Climate and Society (IRI), the Nature Conservancy, and the National Center for Atmospheric Research (NCAR).

Provision of climate information

Data tools

The current CCKP directs users to a centrally located interactive map interface as its primary function. From here, the user can access the 5 different tools (see table above). The central map interface empowers the user to make their various parameter selections (e.g. emission scenario, climate variable/index and so on) to display relevant climate data.

DATA TOOL	OVERVIEW	OUTPUT
Historical data viewer	• Displays observed climate data for temperature and precipitation and location of interest. • Annual cycle graph presents monthly climatic averages.	Maps and timeseries
Projections data viewer (CMIP3 proection to be discontinued in 2018)	• Displays CMIP3 and CMIP5 climate projections data under various user-defined parameters (e.g. model, emission scenario, time period, variables, and so on). • Seasonal cycle graph presents monthly climatic averages. • Annual average for 4 different 20-year time periods.	Maps and timeseries
Compare & contrast tool	• Same as above but enables 2 sets of projections to be visually compared.	Maps
Downscaled projections viewer (to be discontinued in 2018)	• Displays downscaled CMIP3 climate projections data under user-defined parameters. • Annual cycle graph presents monthly climatic averages.	Maps and timeseries
Country-level data download	• Country-level aggregated climate data in monthly average	.csv files

The portal also features a Custom Historial Climate Analysis Tool, and Historical Variability and Global Drought Forecast Tools, which are hosted on the IRI/LDEO Climate and Society Map Room website. Accordingly, these have not been included in analysis here.

Climate models and downscaling

The CCKP uses CMIP5 and CMIP3 GCM outputs at an average resolution of ~100km^2 and is one of five portals to incorporate both generations of models.The CCKP-CMIP5 collection consists of 35 models that submitted daily data for all the RCPs. It is important to highlight that the CMIP5 modelling data has not been downscaled in this portal. The current CCKP contains 9 statistically downscaled CMIP3 GCM outputs using bias correction to a resolution of 50km^2. Unlike other portals, the CCKP contains statistically downscaled GCM outputs with global coverage. However, downscalled data is not available for download to avoid misguidance on decision making processes.

The revamped CCKP to be launched soon will not longer pursue the visualization of downscalled data.

Emission scenarios and timeframes

CMIP3 and CMIP5 GCM outputs are given relative to the IPCC-recognised 1986-2005 reference period, or can viewed as absolute values (Note: Absolute values are only availbe for basic climate variables such as temperature and precipitation), while the downscaled CMIP3 outputs are given in absolute form only.

In terms of emission scenarios, CMIP3 outputs are provided alongside A1, A1B, and A2 scenarios while CMIP5 outputs are provided with respect to all RCP scenarios. The CCKP provides a large range of emissions scenarios compared to other portals and is one of only four portals examined here that does so.

Outputs are viewable in end-of-century and annual cycle timeseries alongside the map viewer. This enables monthly averages to be derived.

Climate variables and indices

The CCKP provides 12 climate variables and 50 derived indices, as well as other impact and vulnerability indices, making it one of the most comprehensive portals in this area. Of the 62 variables and indices, all are related to temperature and precipitation.

Handling of uncertainty

The CCKP provides ensemble averages (mean and median) and spreads (10th and 90th percentiles) and visualises this in the timeseries' accompanying the main map viewer. However, ensemble averages and spreads are not available for downscaled GCM outputs. The current portal provides the user with a simple general information on the concepts of uncertainty in its Metadata documentation. However, it does not provide training on the handling of these concepts in relation to the CCKP's data. The revamp CCKP will bring some of these concepts to the portal.

Metadata

The CCKP provides effective and highly comprehensive metadata compared to most other examined portals. For example, in the map viewer there are clear "Show Metadata", "Show Source", and "Show Data Description" buttons which enable the efficient retrieval of auxiliary information. Furthermore, the same information is made available centrally in the user guide and in more depth in the "Metadata of the CCKP" guide.

User guidance

The CCKP portal provides effective user guidance on how to operate the website and its tools in the form of a central user guide as well as various assistance buttons attached to the portal's data tools. A site map also lays out the portal sections with clarity. However, beyond how to operate the portal, limited user guidance is given. For example, FAQ and glossary sections, use cases, and information on general climate change topics are absent. Contact details are provided as a means to resolve specific user enquiries and a news/updates exists in the form of a small call-out box on the homepage detailing the most recent portal developments.

Unlike CCIA, Pacific Climate Futures and UKCP09, the CCKP portal does not provide appropriate use guidance materials by, for example, employing a tool rating or decision tree system. This is due to the nature of the CCKP and its objectives at the time of

development. The CCKP is linked to the World Bank climate risk screening tools that provide appropriate guidance on risk ratings and decision support systems and is tailored to provide inputs within that process.

Website design

As an older generation of climate information portal, the current CCKP does not employ as many aesthetic features as some (e.g. Cal-Adapt or PREPdata) and relies on lower display resolutions intentionally, as it was meant to be used in low band with environments. Due to the intent of the CCKP to be cautious on using downscaled data, the global downscaled GCM outputs do not overlay onto the base map in the map viewer and no ensemble averages and spreads are displayed.

The map viewer is prominently featured on the portal's main landing page and takes justified prominence over auxiliary portal features. This intuitively guides users seeking to obtain climate data and projections to this tool. Additionally, the use of a selection cascade from global map, to region and then nation of interest can clearly guide the user to relevant climate information. The portal also features the intuitive and consistent design in the use of similar page layouts, fonts, sizes, and headings, among other features to enable clear use.

Main insights

High climate data coverage

The current CCKP successfully provides a high number of climate variables and derived indices. Furthermore, non-downscaled CMIP3 and CMIP5 data are available under all SRES and RCP scenarios while the portal's statistically downscaled CMIP3 data is global in coverage and also available under all SRES scenarios. The CCKP also provides data at global, regional, national, and watershed scales where the majority of other portals tend to take a more specific geographic focus. Providing such a high level of coverage in terms of variables and indices, emission scenarios, and geographic extent provides an effective range of climate data helping to increase portal usefulness for a higher number of users. Additionally, the portal does so using a single visualisation interface which aids ease of use and data comparisons.

Visualisation of "as-is" scientific climate data

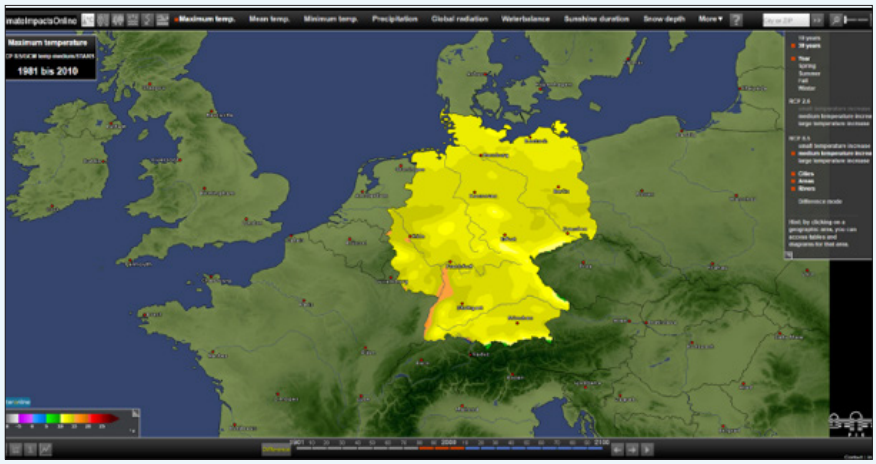
The CCKP visualises large quantities of climate data in traditional maps and timeseries outputs similar to IPCC-style scientific formats (as do many other portals examined here). Choosing these outputs means multi-model ensemble projections are either only viewable as single model projections or are reduced to central averages and model spreads.

INSIGHT: Climate information portals can employ sophisticated data visualisation techniques such as multi-variate tabulated model outputs or probabilistic climate projections. With a view to meet decision maker needs, these visualisation techniques can better convey degrees of model agreement and likelihood. This can be better at highlighting the range and plausibility of future changes in climate which can, in turn, feed into climate adaptation decision making.

3.1.7 CLIMATE IMPACTS ONLINE

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Map-based visualisation platform for downscaled CMIP5 outputs	○ University-based institute	○ Global	• Terrestrial	• 1-3
	○ Government department	○ Regional	○ Oceanic	○ 4-6
	○ Multi-national collaboration	• National		○ >6
	○ National meteorology office	• Subnational		
	• Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW



Year created: 2012
Headquarters: Potsdam, Germany

Climate Impacts Online is hosted and was developed by the Potsdam Institute for Climate Impact Research (PIK) in partnership with WetterOnline; a German meteorological service provider. Climate data from PIK's CLIMREG project is presented in the portal. WetterOnline provided portal development expertise. The portal was funded through the Climate-KIC (Knowledge and Innovation Community) at the European Institute of Innovation and Technology.

Climate Impacts Online presents downscaled climate projections (and climate impacts) over Germany. Climate Impacts Online is characterised by clearly described and explained downscaling methods and limited amounts of appropriate use guidance material.

Provision of climate information

Data tools

Climate Impacts Online features a centrally located map viewer as its single data tool (see table below and figure 2).

DATA TOOL	OVERVIEW	OUTPUT
Map-viewer	• Generates climate projections (and impacts) under user-defined parameter selections (e.g. emission scenario, climate variable, time period etc.). • Presents changes for agriculture, forestry, hydrology and energy sectors. • Tool interface also forms the portal's landing page.	Maps and timeseries

The map viewer features a high level of interactivity enabling the user to pan and zoom. Zooming reveals finer scale administrative regions and urban centres. Clicking on areas of interest generates timeseries and annual cycle graphs allowing the user to extract numerical values at point locations.

Climate models and downscaling

Climate Impacts Online uses 21 CMIP5 GCMs to force the STARS (Statistical Analogue Resampling Scheme)[7] RCM. STARS outputs are the only data product presented here. This model uses the highest, lowest, and average values for temperature development over Germany from 2011 to 2100 as projected by 21 GCMs as its input. STARS then generates the climatic change data (with climate impact data generated by subsequent impact models in the modelling chain). The downscaled data are interpolated to a 1km^2 resolution using the same method as the DWD German Climate Atlas (Shepard, 1988).

Emission scenarios and timeframes

Climate data is available for visualisation from 1901 to 2100. Data until 2010 is observational; 2011 and beyond is simulated. Climate Impacts Online uses a reference period of 1981-1990 for its simulated data. Climate variables can be explored under RCP 2.6 and 8.5. 3-monthly (seasonal) and annual temporal averages are available.

Climate variables and indices

Climate Impacts Online provides eight climate variables and 16 derived indices. 22 of the 24 presented variables and indices relate to temperature and precipitation changes (global radiation and daily number of sunshine hours are the exceptions). A range of additional climate impact variables, derived from the subsequent impact models in the modelling chain, are also presented and divided into agriculture, forestry, hydrology, and energy sectors.

[7] The STAR model is one of the 21 RCMs used in the DWD German Climate Atlas.

Handling of uncertainty

Climate Impacts Online presents the STARS ensemble median and spread (5th and 95th percentiles) to convey the uncertainty in projections. This is only available in the timeseries which are available by clicking on the administrative regions of Germany or urban centres. Only the median for a selected climate variable is presented in the map. No further user training or general information uncertainty in climate data is given.

Metadata

Climate Impacts Online provides extensive metadata in its user guide which is accessible through the help buttons on the portal interface. It is usefully divided into intuitive sections for the user to access (see figure 2). Many portals feature highly technical descriptions of datasets or only signpost the user on to (original) metadata resources, often via academic references, which can be more technical. Of specific advantage is this portal's clear and relatively non-technical explanations of the downscaling methods used to create its climate data (see model chain and realisations in figure 2). This is something commonly omitted by other portals examined here. Explaining these downscaling methods serves to help users better utilise presented climate information in defensible climate decision making processes.

User guidance materials

Climate Impacts Online provides relatively little user guidance materials. Given the site's ease of use (see Website design below) little guidance is seemingly required on how to operate the portal. The "Usage" section (see figure 2) trains users on how to operate the portal interface. This guide also contains a useful "Glossary" section which, in the face of the site's heavy use of text to describe metadata (e.g. downscaling methods), helps users to navigate through the inevitable use of technical terms. In this portal, hovering the cursor over terms in the map viewer produces a useful explanatory pop up window to explain terms on the fly. The "Scenarios" section provides some light background information on the emission scenarios used in portal however no other education pieces are given.

While easy use allows for relatively little user guidance on how to operate the portal, there is a lack of extended guidance on appropriate use. The portal identifies its usefulness at informing specific adaptation options in sectors however provides little explicit guidance as to how users should and should not use the portal's data (although downscaling methods are explained). Where non-technical users are using the portal, this can risk the misuse of its climate data. The transparency over the portal's downscaling methods does alleviate this to some extent however and represents a good practice.
Climate Impacts Online also positions its contact details prominently and, as figure 2 illustrates, make an appeal for comments and suggestions. Opening provider-user dialogue in this way can be a useful way to align provision with user needs (although PREPdata does this to the greatest extent of the 15 examined portals).

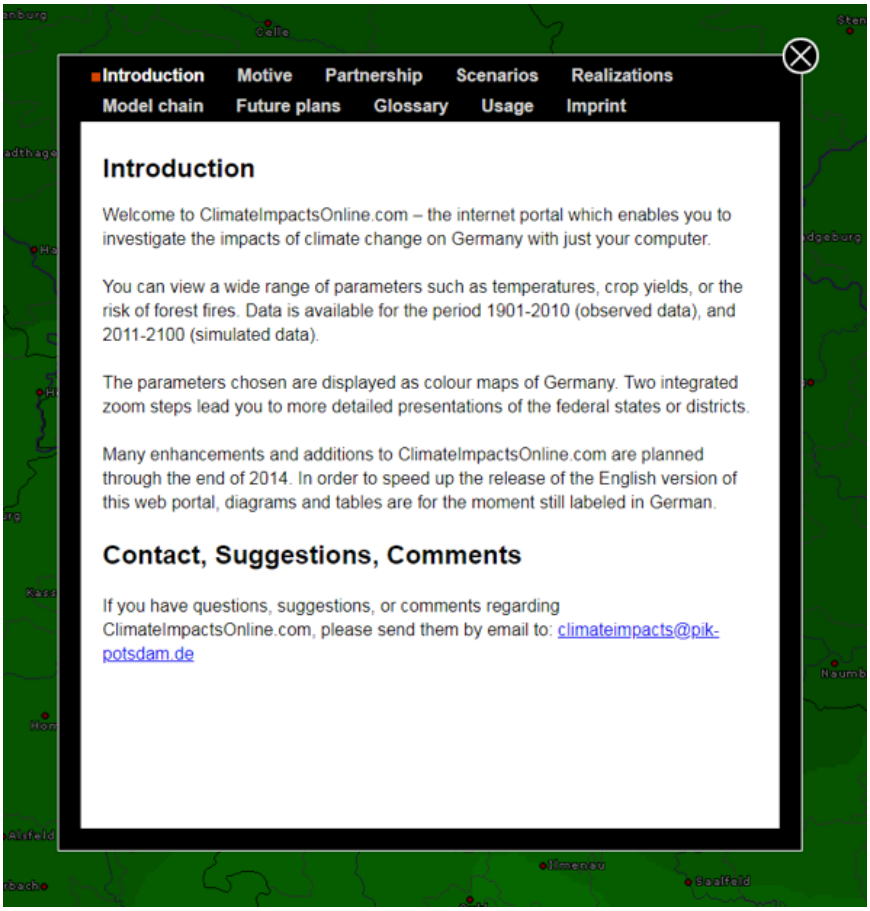
Website design

Climate Impacts Online is a clear and easy to use platform. Designing the map viewer as the main landing page makes all primary portal contents (e.g. climatic observations, projections, parameters selections and so on) accessible altogether in a central location. This produces low click counts and is intuitive for the user which reduces overall user effort. Correspondingly, this reduces the need for user guidance materials to train users

on how to operate portal features. Further to this, the map viewer is very large and uses relatively fine display resolutions, unlike other portals (e.g. Climate Wizard), which aids visual interpretation. A common red-black colour palette and text formats creates visual consistency for clarity and ease of use also.

FIGURE 2 | THE USER GUIDE POP-UP WINDOW

Figure 2 shows the user guide pop up window on the portal website giving users access to metadata and guidance on operating the portal.



Main insights

Explained downscaling methods

Owing to the portal's origins from an academic research program, Climate Impacts Online provides detailed explanations of the dynamical downscaling approach used by the STARS model to produce its climate projections over Germany. It also remains transparent about the use of interpolation to project data on to a 1km^2 grid and explicitly highlights that the underlying data is not produced with a 1km^2 spatial resolution. Many other portals fail to explain downscaling methods and/or simply hyperlink to original data sources which feature academic downscaling descriptions.

***INSIGHT:** Climate information portals can include clear non-technical explanations of any downscaled data products both in terms of the methodology used and the implications for the use of such data. Providing this information can better enable users to assess the quality of data for their purposes and, in turn, can foster appropriate data use.*

Lack of appropriate use guidance material

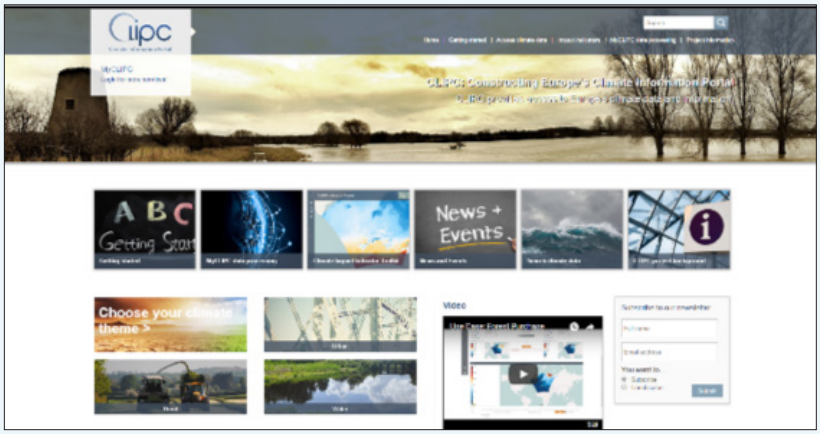
Climate Impacts Online provides numerous forms of user guidance on portal content and operation. However, the provision guidance material informing users about how to appropriately use the portal's information is lacking (e.g. use cases, guiding principles and so on). As with other portals, Climate Impacts Online largely assumes that users have the technical skill to use data in suitable ways to satisfy their data needs.

***INSIGHT:** Climate information portals can provide guidance material detailing suggested or intended uses of their climate data in decision making as a means to ensure information is used appropriately and is not misused.*

3.1.8 CLIMATE INFORMATION PORTAL FOR COPERNICUS

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Climate data library and visualisation platform for a wide range of datasets	○ University-based institute	○ Global	• Terrestrial	○ 1-3
	○ Government department	• Regional	• Oceanic	• 4-6
	• Multi-national collaboration	○ National		○ >6
	○ National meteorology office	○ Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW



Year created: 2016
Headquarters: Swindon, United Kingdom

The Climate Information Portal for Copernicus (CLIPC) was one of five parallel precursor projects to the Copernicus Climate Change Service. Funding came from the European Union's 7th Framework Programme for Research, Technological Development and Demonstration. CLIPC was developed as a multi-national collaboration between 21 key European institutions[8] with the Science and Technology Facilities Council (UK) as coordinator.

CLIPC is a climate dataset library and map-based visualisation platform for a total of 493 datasets over Europe. Data were contributed by the CLIPC consortium of European institutions. The portal also provides thorough metadata detailing data provenance and expert-based uncertainty and confidence assessments.

[8] The Royal Netherlands Meteorological Institute (KNMI Climate Explorer), the Potsdam Institute for Climate Impact Research (Climate Impacts Online) and the UK Met Office (UKCP09) were also members of this consortium.

DATA TOOL	OVERVIEW	OUTPUT
Dataset library	• Enables users to browse through 493 climate datasets. • Users search for data under various characteristics (e.g. climate variable/index, sources, keywords).	Various file formats
Map Viewer	• Enables users to select and visualise climate datasets from the library. • Datasets are divided into a variety of socio-economic and climatic areas. • Users visualise data on a dataset by dataset basis.	Maps and timeseries
Compare function	• Same as above but users can visualise and compare 2 different datasets alongside each other.	Maps
Combine function	• Sophisticated tool for combining 2 different climate variables/ indices from 2 different datasets. • Produces custom climate indicators for the user.	Maps
Heat stress scenario viewer	• Displays projections in the number of summer days under user-defined time periods and emission scenarios.	Maps

Provision of climate information

As a dataset library, CLIPC presents its climate information on a dataset by dataset basis rather than in a harmonised visualisation platform. Unlike other portals, CLIPC does not allow users as much freedom to select between climate parameters such as emission scenario, time periods and so on. Individual datasets must be selected.

Data tools

CLIPC places equal emphasis on its function as a dataset library and as a map-based visualisation platform meaning the latter is not as prominently located as in other map-based portals. CLIPC provides 5 data tools (see table below)[9].

Across all provided data, CLIPC gives access to a total of 6 climate variables and 26 derived indices with majority relating to temperature, precipitation or sea level rise. Other datasets focus on ecosystem impacts and human settlements.

Handling of uncertainty

Similar to many other portals, CLIPC provides timeseries' alongside its map-based data visualisations which contain GCM ensemble medians and spreads (20th and 80th percentiles) as a means to convey uncertainty.

CLIPC also provides the user with a "Confidence Summary" for each dataset which identifies the sources of nature of the data's uncertainty. Dataset confidence is rated

[9] CLIPC also contains a dataset processing wizard allowing the user to select raw climate datasets and calculate custom climate indices for customized uses. This tool is aimed at climate scientists and as such has not examined further.

and usefully visualised using a colour scale. Furthermore, the "Compare" tool inside the data visualisation platform enables the user to create climate signal maps as a means to visualise the robustness of projections. This is however only available for a small selection of climate variables (wet days, heavy precipitation days, tropical nights, ice days, frost days, heating days, summer days) and further highlights CLIPC's lack of consistency across data products which possibly inhibits its usefulness for decision makers. Nevertheless, these two features are unique to CLIPC and arguably represent more effective ways of presenting uncertainty and the limitations of climate data to the user beyond ensemble averages and spreads.

Metadata

CLIPC provides broad metadata descriptions on the portal's main landing pages and specific metadata descriptions are available by way of "info" buttons that accompany each selectable dataset. This is an intuitive method of provision. However, the metadata is laden with technical jargon, scientific abbreviations and symbols and generally appears to appeal to researchers as opposed to non-technical (decision maker) users.

User guidance

CLIPC provides numerous forms of user guidance. CLIPC does not provide a central user guide like many other portals and instead provides user guidance on how to operate the portal as distributed text across its webpages in addition to video tutorials. CLIPC is one of only two portals to use videos as a method of user guidance. CLIPC also uses videos to provide use cases and showcase how CLIPC data was used in five different climate change decision making processes.

CLIPC contains a very extensive glossary section which provides definitions to scientific terms both in a central section on the website and distributed across the portal's webpages by using hover boxes and in this manner is similar to UKCP09's glossary. The portal also contains a "Behind the data" section which, similarly to CCIA's "Climate Campus", serves as a central location for portal users to educate themselves on general climate change topics (although it is not as extensive). The portal uses an FAQ section, site map, and decision tree.

Website design

CLIPC, in general, appears to have a sufficiently aesthetic design assisting with ease of use through using a balance of blank space, text, pictures and so on. The consistent use of text formatting throughout the portal's webpages and the strategic placing of guidance buttons and hyperlinks further aids clarity.

This said, CLIPC's map viewer contains a number of suboptimal design elements. First and foremost, CLIPC presents dataset names that are arguably very inaccessible to a non-technical user. Datasets feature names such as "TXx MON EURO4M MESANv1 EUR-11 1989-2010" and use extensive scientific abbreviation and numbering that relate closely to underlying model simulations but arguably poorly guide lay users. Given that users are required to navigate these dataset names to select appropriate data this reduces CLIPC's ease of use. Similarly, the map viewer's timeseries outputs also feature scientific modelling abbreviations and unit symbols that could be hard to understand for non-technical users.

In addition to inaccessible technical display, a number of functional issues seem to exist such as colour legends not appearing automatically when data is visualised and units appearing absent from some map legends. In some cases, datasets displaying the same climate variable use different units (e.g. ˚C and K for temperature datasets). These work to inhibit ease of use for the user. Nevertheless, the Map Viewer is large and does use fine display resolutions contrary to some older portals (e.g. CCKP).

Main insights

Presentation of uncertainty and confidence information

CLIPC provides a more sophisticated presentation of uncertainty and confidence information than most other portals. CLIPC has, using expert-based judgement, assessed and visualised the sources and nature of uncertainty (e.g. incomplete knowledge of the climate modelling processes) in its datasets and, in turn, estimated the degree of confidence that users can have in each dataset. This arguably conveys more detailed information on uncertainty and confidence than graphical representations of multi-model ensemble averages and spreads.

INSIGHT: Climate information portals can provide high quality metadata to visually depict the sources and nature of uncertainty and confidence levels associated with provided data. This can aid decision makers by helping them identify high confidence, low uncertainty datasets that can be defensibly used in climate decision making processes.

High level of technical skill

CLIPC provides numerous forms of user guidance relating to portal content and operation (e.g. glossaries, video tutorials for data tools). However, overall CLIPC's data tools feature high levels of scientific jargon, unit symbols, abbreviations and so on that may be beyond the skill of inexperienced or non-technical data users to understand. Additionally, while high quality uncertainty and confidence information is provided, little user guidance is provided as to its meaning and implications for data use. Further still, the function of the combine function – to process 2 datasets in combination to produce customised climate indices – is a very advanced. In the absence of guidance as to how CLIPC's data and tools can be appropriately used, the portal relies the user's ability to know their data requirements, identify suitable data and use it appropriately.

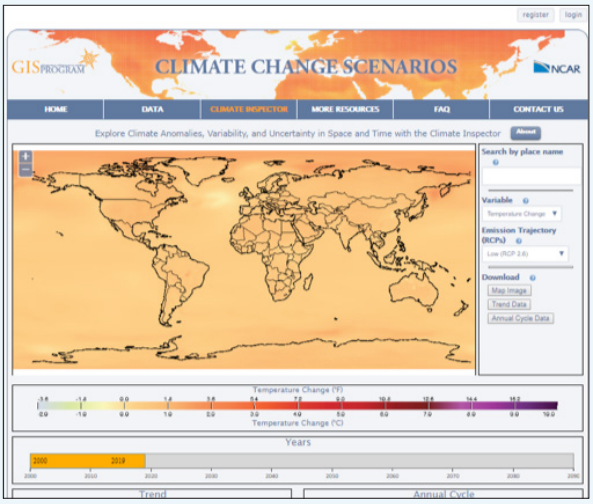
INSIGHT: Climate information portals can provide appropriate use guidance materials as a means to ensure that a fuller range of users (non-technical to technical; novice to experienced) can successfully satisfy their informational needs.

3.1.9 NCAR GIS PROGRAM CLIMATE CHANGE SCENARIOS GIS DATA PORTAL

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Map-based visualisation platform for CCSM-4 (CMIP5) outputs	○ University-based institute	• Global	• Terrestrial	• 1-3
	○ Government department	○ Regional	• Oceanic	○ 4-6
	○ Multi-national collaboration	○ National		○ >6
	○ National meteorology office	○ Subnational		
	• Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 2004
Headquarters: Boulder, USA



The National Center for Atmospheric Research's (NCAR's) GIS Program Climate Change Scenarios GIS Data Portal (the NCAR Climate Change Portal) was developed as part of NCAR's GIS Program; "…an interdisciplinary effort to foster collaborative science, spatial data interoperability, and knowledge sharing with GIS" (NCAR, 2018). This portal is designed to serve the GIS user community interested in climate change issues. The project received funding from the National Science Foundation. NCAR partnered with ESRI and the Open Geospatial Consortium for portal development expertise.

The NCAR Climate Change Portal is a map-based visualisation platform displaying outputs from NCAR's own Community Climate System Model 4.0 (CCSM-4) that fed into the IPCC AR5. With a focus on a single GCM, this portal provides a very small amount of climate information relative to other portals that feature multi-model ensembles and/or data from a range of sources.

Provision of climate information

Data tools

The portal features a simple, intuitively designed and easy to use map viewer and raw data download possibilities (see table below).

DATA TOOL	OVERVIEW	OUTPUT
Map viewer	• Visualises end-of-century climate projections under various user-defined parameters (e.g. emission scenario and climate variable). Global coverage. • End-of-century and annual cycle timeseries available.Users can search for specific locations of interest. • Users can select any 20-year time period of interest (2000-2100).	Maps and timeseries
Raw data download	-	netCDF formats, .csv

Climate models and downscaling

The portal is based on a single GCM: NCAR's own CCSM-4 which is part of the CMIP5 archive and outputs have been statistically downscaled for the contiguous USA only at a resolution of 4.5km^2. This has used a customised methodology by Hoar and Nychka (2008) (see White Paper).

Emission scenarios and timeframes

The portal uses the IPCC-recognised 1986-2005 reference period with climate projections available with respect to all RCPs. While other portals tend to allow the user to explore projections under pre-defined time periods, a freer approach is used here whereby users can select any 20-year 21st century time period of choice.

Climate variables and indices

In a similar manner to Climate Wizard, the NCAR Climate Change Portal presents future climate change in terms of average annual temperature and precipitation changes only with no derived indices. This represents a highly limited choice compared to other portals.

Handling of uncertainty

This portal presents the ensemble mean and full modelling spread of the CCSM-4 ensemble of simulations for user-selected locations of interest to convey uncertainty information. Because this portal uses only a single GCM, it is not a multi-model ensemble average like the kind provided by most other portals. Beyond this, limited user guidance is given on the concept of uncertainty in climate data.

Metadata

Metadata is provided via the portal's FAQ section where further details on the characteristics of the CCSM-4 model and its projections data is given as well as how to cite information and links to data provenance.

User guidance materials

The NCAR Climate Change Portal presents a small amount of user guidance materials which largely reflects the small amount of climate information presented by the portal.

A broad ranging FAQ section serves as the portal's only form of user guidance and as such covers numerous bases such as explanations of portal content and operation, metadata and key climate science terms and concepts. Guidance buttons coupled to the various parameter dropdown menus on the map viewer provide additional guidance as to its operation.

Website design

The NCAR Climate Change Portal contains a small amount of climate data and tools meaning clarity is easily achieved. In a similar fashion to the DWD German Climate Atlas, the portal's main landing page is its map viewer. The map viewer presents an interactive map, timeseries and annual cycle graphs of climate projections data in a single centrally located interface. Due to its comprehensiveness, it successful conveys large quantities of climate information in an intuitive and ease of use to manner.

Main insights

Visually comprehensive data visualisation tools

The NCAR Climate Change Portal features a comprehensive main landing page. In a similar fashion to the DWD German Climate Atlas, it is here that the majority of portal content is viewable via the interactive map viewer (and its timeseries and annual cycle graphs). Furthermore, parameter dropdown menus (e.g. emission scenario, climate variable) are clearly located around the map viewer. These design characteristics considerably aid ease of use.

***INSIGHT:** Climate information portals can feature visually comprehensive data visualisation tools as a means to display large quantities of climate data (e.g. recent observations and future projections) in a consistent format in a single location on the portal website. This can assist users with visual data interpretation to greater extent than separate data tools distributed across portal websites.*

Limited extent of climate information

Ease of use is further achieved because of the very small amount of underlying data and data tools the NCAR Climate Change Portal contains. In line with the portal's data distribution agreement, it contains only a single GCM (the least of any of the 15 portals examined here) and covers only two variables (temperature and precipitation). Additionally, downscaled data coverage is limited to the contiguous USA. Thus, insights into ranges of climate projections and uncertainties derived from multi-model ensembles are beyond the scope of this portal. Therefore, the portal serves a constrained range of informational needs and risks being redundant to other more data-rich climate information portals.

***INSIGHT:** Leveraging multiple data distribution agreements serves to permit a more extensive provision of climate data products (i.e. from multiple sources, using more GCM models, variables and so on) such that an expanded range of informational needs can be met. This also mitigates against redundancy to other portals.*

3.1.10 DWD GERMAN CLIMATE ATLAS

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Visualisation platform for downscaled CMIP3 outputs	○ University-based institute	○ Global	• Terrestrial	• 1-3
	○ Government department	○ Regional	○ Oceanic	○ 4-6
	○ Multi-national collaboration	• National		○ >6
	• National meteorology office	• Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 2010
Headquarters: Offenbach, Germany

The DWD German Climate Atlas is hosted by the German National vMeteorological service: the Deutscher Wetterdienst (DWD). This portal utilised expertise under the KLIWAS project, a research program of the German Federal Ministry of Transport and Digital Infrastructure, to collate and evaluate climate datasets for use in the portal.

The DWD German Climate Atlas is a visualisation platform for downscaled CMIP3 outputs over Germany and its regions. The portal is characterised by comprehensive data visualisation using a single tool, small quantities of user guidance materials and a lack of problem identification.

Provision of climate information

Data tools

The DWD German Climate Atlas is a relatively small climate data platform providing just one data tool, the Atlas (see table below and Figure 3).

DATA TOOL	OVERVIEW	OUTPUT
The Atlas	• Displays comparative maps and timeseries of climate observations and projections over Germany and its regions under various user-defined parameter selections (e.g. emission scenario, climate variable, time frame). • Limited interactivity.	Maps and timeseries

The Atlas tool is a one of the most visually comprehensive data tools across the 15 portals examined here. Firstly, it enables users to view both maps and timeseries of climate data on a single interface and, secondly, enables users to easily compare recent climate observations and future projections to a reference period. This said, its maps and timeseries are static and feature limited user interactivity. For example, basic pan and zoom abilities are not available and exact numerical values must be inferred from legends. This can reduce data tool usefulness.

FIGURE 3 | THE ATLAS TOOL

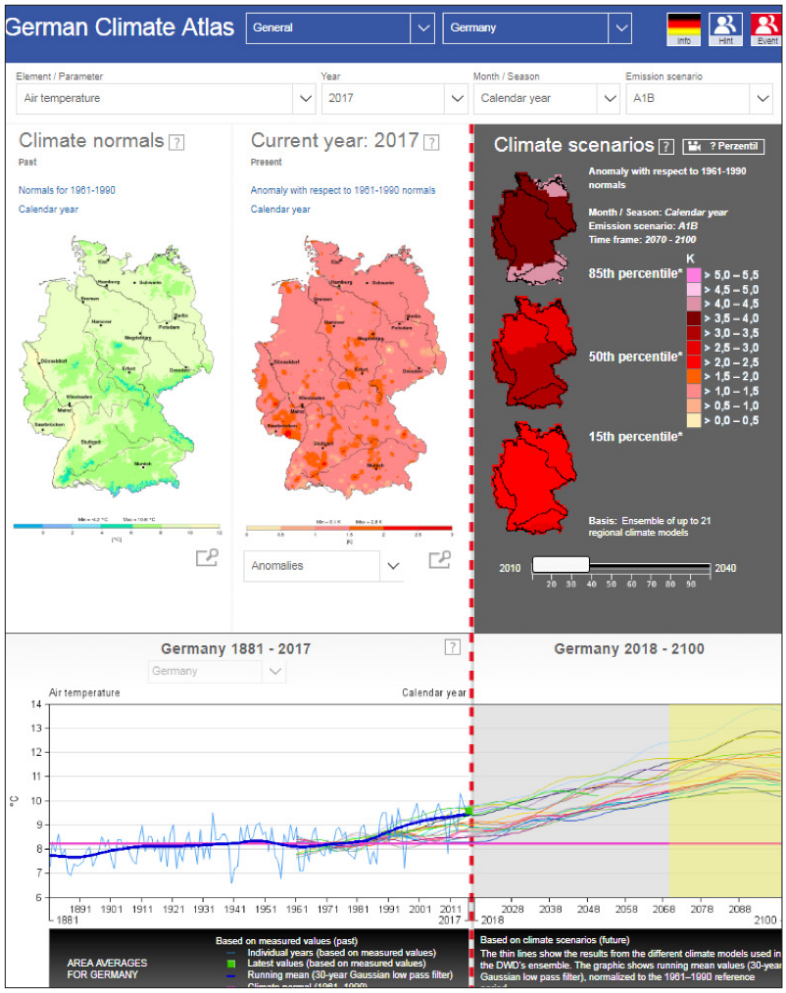


Figure 3 shows the main landing page for The Atlas tool; the single data tool of the DWD German Climate Atlas.

Climate models and downscaling

The DWD German Climate Atlas uses projections from 8 GCMs from CMIP3 archives. These GCM outputs are dynamically downscaled using 21 different RCMs including the EU ENSEMBLES project models and REMO, CLM, WETTREG, and STARS[10] models. Future downscaled projections are provided at a 25km^2 resolution. Observational data are interpolated on to a 1km^2 grid.

Emission scenarios and timeframes

The Atlas tool uses the WMO-recognised 1961-1990 reference period for its A1B. Work to include RCP 4.5, 6.0 and 8.5 is ongoing at the time of writing. The user can view projections in 30-year time intervals at 10-year increments from 2010 to 2100 and can select to view changes as monthly, 3-monthly and annual temporal averages.

Climate variables and indices

The Atlas tool divides its data into five societal sectors: general, agricultural, forestry, soil conservation, energy industry, and transport. It enables the user to explore changes in 4 climate variables and 7 derived indices. The Atlas tool also enables the user to explore a range of other impact indicators from across these five societal sectors. All variables and indices are viewable as absolute values or relative changes (to the 1961-1990 reference period).

Handling of uncertainty

The DWD German Climate Atlas readily visualises the ensemble median (50th percentile) and spread (15th and 85th percentiles) in its Atlas tool (again reflecting its comprehensiveness). Unlike other portals, no background information on the concepts of uncertainty and confidence in climate data is given.

Metadata

The DWD German Climate Atlas' metadata is centrally located in the portal's "Explanations" section which also serves as its user guide. Metadata is given in extensive text-based format describing various characteristics of the portal's underlying data such as its resolution and downscaling methods used. The metadata outlines the range of modelling simulations used on the portal and effectively gives data provenance (as academic references and hyperlinks to corresponding modelling projects) however the use of technical jargon and scientific modelling abbreviations is very high. This can reduce the metadata's accessibility for non-specialist users.

User guidance materials

This portal provides very limited user guidance materials. The "Explanations" section serves the portal's user guidance function however it is highly specific. Laid out more like a glossary, it gives specific text-heavy guidance on what the portal contains, the data it provides and how to operate it. Guidance buttons distributed across the atlas tool interface do usefully link to the user guide area. However, beyond this the portal offers no other forms of user guidance such as use cases, FAQs, a glossary for technical terms or the like. This leaves the user with comparatively little guidance concerning the portal's purpose, intended use or intended users.

---

[10] The STAR modelling simulations are also the basis for the climate data presented in Climate Impacts Online.

Website design

The DWD German Climate Atlas employs a number of features for ease of use (with obviously the portal's relatively small size (in terms of content) working to this effect also). For example, the Atlas tool usefully presents its maps and timeseries outputs adjacent to each other and divides observations and projections with a red hashed line, aiding the visual comparison of future projections against climate normals (see figure 1). Furthermore, intuitively positioned parameter dropdown menus, guidance buttons, legends and keys promote ease of use along with a general scarcity of text in the Atlas tool.

However, a number of functional issues constrain ease of use. As stated above, the lack of maps and timeseries for RCP projections is a significant gap in the portal's content. Additionally, K is the unit for the maps of climate normals and future projections while ˚C is the unit for the timeseries. Inconsistencies such as these can cause user frustration and reduce the efficiency with which users can acquire meaningful insights.

Main insights

INSIGHT: Climate information portals can feature visually comprehensive data visualisation tools as a means to display large quantities of climate data (e.g. recent observations and future projections) in a consistent format in a single location on the portal website. This can assist users with visual data interpretation to greater extent than separate data tools distributed across portal websites.

Visually comprehensive data tool

The Atlas tool is an information-rich data visualisation tool. Maps and timeseries of both historical observations, climate normals (reference periods) and future projections are all visualised at once. Further still, projections are broken down into percentiles (15^{th}, 50^{th} and 85^{th}) and are viewable as absolute values or relative changes and under a variety of annual averages. This effectively presents large quantities of climate information using a consistent visualisation platform and, in turn, assists users with comparisons across different climate projections.

Lack of problem identification

The DWD German Climate Atlas does not explicitly identify its purpose, intended users and potential uses. Many other portals do this, for example, through the use of prominently located text on their main landing pages. In the absence of this guidance, it is left to users to identify if the portal is appropriate for use which can create user frustration and confusion. This can disincentivise portal use in favour of those that clearly identify purpose, intended users and uses as this provides more clarity for the user.

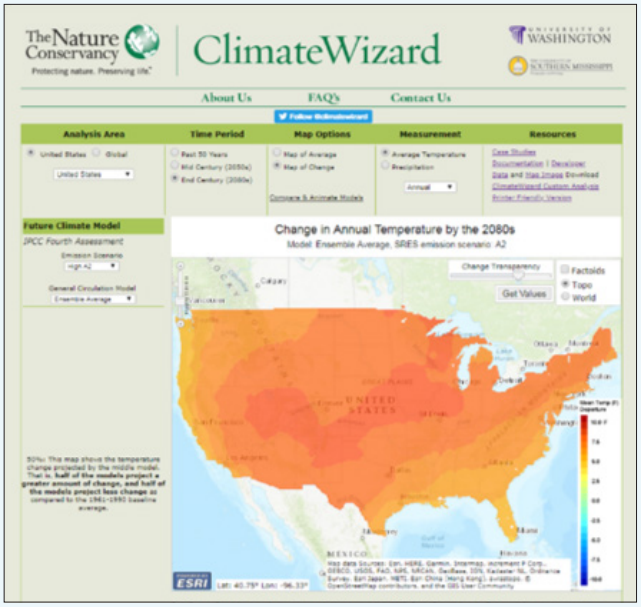
INSIGHT: Climate information portals can provide explicit and prominently located definitions as to their purpose, intended users and uses as a means to provide clarity as to how they can meet a user's climate data needs. This clarity can incentivise portal use through reducing confusion as to the value a portal can add.

3.1.11 CLIMATE WIZARD

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Visualisation platform for downscaled CMIP3 outputs	○ University-based institute	• Global	• Terrestrial	○ 1-3
	○ Government department	○ Regional	○ Oceanic	○ 4-6
	○ Multi-national collaboration	• National[11]		○ >6
	○ National meteorology office	○ Subnational		
	○ Research institute			
	○ National agency			
	• Not-for-profit initiative			

OVERVIEW

Year created: 2009
Headquarters: Arlington, VA, USA



Climate Wizard was developed by the Nature Conservancy (project development), the University of Washington (scientific analysis), and the University of Southern Mississippi (web development). Funding was committed by the Nature Conservancy, the Claneil foundation, and others. Data partnerships were formed with the Program for Climate Model Diagnosis and Intercomparison, the WCRP's Working Group on Coupled Modeling Office of Science and the US Department of Energy (WCRP CMIP3 datasets), the PRISM Group at the Oregon State University (observational dataset), the Climatic Research Unit at the University of East Anglia (observational dataset) and the American Geophysical Union (downscaled contiguous US dataset).

Climate Wizard was the one of the first online interactive map-based visualisation platforms for climate data and as such is characterised by a small amount of content and functionality compared to most of the other portals examined here.

[11] Displays national climate data for the contiguous USA only.

University of East Anglia (observational dataset) and the American Geophysical Union (downscaled contiguous US dataset).

Climate Wizard was the one of the first online interactive map-based visualisation platforms for climate data and as such is characterised by a small amount of content and functionality compared to most of the other portals examined here.

Provision of climate information

Data tools

Climate Wizard contains 3 data tools (see table below).

DATA TOOL	OVERVIEW	OUTPUT
Map Viewer	• Displays climate projections under various user-defined parameter selections (e.g. emission scenario, climate variable, time period). • Monthly, 3-monthly and annual averages available. • Default data tool.	Maps and timeseries
Compare and Animate Models tool	• Same as above but enables the user to visually compare 2 different projections.	Maps
Custom Analysis tool	• Allows users to select custom geographic areas to visualise historical and future climate change.	Maps
Raw data download	-	.asc files

Climate models and downscaling

Climate Wizard provides a 16 GCM ensemble from the CMIP3 archive across all 3 tools. The portal provides no dynamically downscaled data products and only provides one statistically downscaled product. This data product uses a quantile mapping bias correction method as per Maurer *et al.* (2007) and has been generated for the contiguous USA. Thus, it is only available when the user selects "United States" to view climate changes over the contiguous USA (as opposed to "global" which switches to non-downscaled GCM output) in the map viewer tool.

Climate Wizard provides its non-downscaled GCM outputs at 50km^2 resolution (or 0.5˚ grid cells) and its downscaled data at approximately 12km^2 (or 1/8th˚ grid cells) (Maurer *et al.*, 2007).

Emission scenarios and timeframes

Available across all its tools, Climate Wizard enables the user to explore changes with respect to B1, A1B, and A2 SRES scenarios and as absolute or relative changes. It uses the WMO-recognised 1961-1990 reference period for relative changes. Outputs are given as end-of-century projections, however the portal only allows the use to select between two time periods: 2040-2069 ("mid-century") and 2070-2099 ("end-of-

century"). This is one of the most restricted projection timeframe selections among the 15 portals. Owing to its age, the portal does not present newer CMIP5 GCM outputs. The user can further explore outputs by selecting different annual cycle time slices: annual, seasonal (3-monthly), and/or monthly changes.

Climate variables and indices

Climate Wizard presents changes in mean temperature and precipitation only in its map viewer and compare and animate models tool and as such gives access to the fewest number of climate variables of all the examined portals. This portal does not present any derived climate indices.

Handling of uncertainty

Climate Wizard provides a range of statistics to the user to explore the uncertainty in its underlying data. In the map viewer and compare and animate model tool the ensemble median, 20th, 40th, 60th, and 80th percentiles, full ensemble spread, and individual model outputs can be selected and visually compared using maps and timeseries. Climate Wizard is also transparent about the inherent uncertainty in climate data and provides some guidance as to how users could/should use its data because of this. No general information aimed at improving a user's baseline knowledge on the concepts of uncertainty and confidence in using climate projections is provided. However, the portal contains a text-based "Use and misuse of Climate Wizard" section which provides a series of recommendations as to the appropriate use of the data; for example, highlighting how "…areas with severe disagreement in models NOT be used for climate-related decisions – only areas with high model agreement should be used". This section is also transparent about the downscaling methods used and explains that, while the portal's statistically downscaled data better identifies actual climatic changes for smaller geographic areas, it is still based on coarse-scale GCM processes. Thus, the portal contains useful appropriate use guidance information helping the user to recognise the usability and limitations of the portal's data. Unfortunately, these guiding principles are not a prominent feature in the overall portal structure compared to its data tools and user guidance on how to operate the portal.

Metadata

Climate Wizard provides metadata in a central location and, unlike some other portals, it is not given in the map viewer as the user selects datasets. As such, it is left to the user to interpret what data selections in the map viewer correspond to the various metadata descriptions given in the "About Us" section which can constrain ease of use. The portal mostly links to each dataset's original source (via academic reference and hyperlink) and does not provide detailed descriptions on the site.

User guidance materials

Rather than providing a central user guide resource, Climate Wizard uses its FAQ section, which is structured similarly to a user guide document, as its main form of user guidance; describing the portal's data content, website structure and operation to the user. Use cases are also given which provide examples for how the portal's data has been used in climate change impact assessment, strategy development, and management and restoration. Aside from these features, Climate Wizard gives no further user guidance.

Website design

Climate Wizard is the oldest of all the 15 examined portals and such features dated web design (e.g. text fonts and colours) which reduces its aesthetic appeal compared to newer sites (that can utilise increased interaction and animation to improve clarity and ease of use). Nevertheless, the portal's (albeit dated) presentation is relatively intuitive for the user and through positioning its map viewer, as its main tool, prominently on the homepage and by positioning relevant interactive user menus around it guides the user around data with clarity (see figure 1). Some minor design choices constrain ease of use, such as the positioning of its "Case Studies" section (use cases) on the home page as opposed to with other user guidance in the FAQ section and the small size of the map viewer in general (see figure 1; red box).

Main insights

Lack of content and functionality

Owing to its age, Climate Wizard provides a limited breadth and depth of climate information. Projections can be explored with respect to only two climate variables (and no derived indices) and at only 2 21st century time periods. Additionally, downscaled data is provided over the contiguous USA only. This is a considerably reduced selection of data compared to newer portals which provide greater freedom of choice in terms of variables and indices, time periods, downscaled data and so on. In a similar manner to the South African Risk and Vulnerability Atlas, this makes Climate Wizard largely redundant compared to other portals.

INSIGHT: Climate information portals that provide significantly reduced quantities of older climate data and information relative to other sources can only serve a reduced set of user needs and are at high risk of being redundant to other sources. With a view to meet decision maker needs, it is strongly recommended that climate information portals look to provide up to date climate data and enable the user to explore information with respect to numerous variables, indices, emission scenarios, future time periods. Providing elevated freedom of data choice, which does not reach a point of over-abundance and confusion for the user, can successfully increase portal usefulness and mitigate against redundancy.

3.1.12 IRI/LDEO CLIMATE DATA LIBRARY

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Climate data library and visualisation platform for a wide variety of datasets	● University-based institute	● Global	● Terrestrial	○ 1-3
	○ Government department	○ Regional	● Oceanic	● 4-6
	○ Multi-national collaboration	○ National		○ >6
	○ National meteorology office	○ Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 1999
Headquarters: New York, USA

The IRI/LDEO Climate Data Library (IRI Data Library) is based at the International Research Institute (IRI) for Climate and Society at the University of Columbia, New York. It is the oldest of the 15 portals examined here. Created in 1999, it emerged as an evolution of the seasonal climate outlooks and observational and historical climate information that the IRI was already providing. As such, this portal focuses more strongly on the monitoring of current and near-future climate conditions as opposed to end-of-century global scale climate projections.

The IRI Data Library is characterised by its seasonal climate forecast tool which meets short-term climate data needs as well as the high technical skill needed to operate the portal.

Provision of climate information

Data tools

The IRI Data Library is an extensive climate data library and visualisation platform that provides access to the largest amount of climate data of any of the 15 portals examined here. A wealth of climate data from paleo-climatic, in-situ and satellite observations, reanalysed datasets and climate model outputs are provided. This portal is broadly divided into three main sections: a dataset library, where users can browse for climate

(and society) datasets, a map room, where users can browse maps and other figures that monitor climate conditions, and a functions tool where users can select and apply a wide range of statistical functions to the datasets contained in the library. The seasonal climate forecast tool[12] (within the map room) is one of the IRI Data Library's most unique and powerful features (see Main insights). It has been drawn out for closer analysis here.

DATA TOOL	OVERVIEW	OUTPUT
Dataset library	• Browser enables users to search for climate datasets under distinguishing features (e.g. climate model, time span, climate system component, author, institution).	Maps, timeseries, raw data displays
Map room	• Contains a range of maps and other figures that monitor climate conditions of the recent past and present. • Various topics (e.g. climate analysis, monitoring and forecasts, El Nino Southern Oscillation and others).	Maps
Seasonal climate forecast tool	• Provides probabilistic seasonal climate forecasts for temperature, precipitation, El Nino Southern Oscillation and other topics. Produces 3-month and 6-month forecasts. • Based on historical climatology for given locations.	Maps
Functions tool	• Users can search for and apply statistical functions to datasets held on the portal. • Coupled with a statistics tutorial section which provides user guidance on how to carry out analysis.	Various statistics.
Raw data download	-	Various file formats (including GeoTIFF and netCDF).

Climate data

The IRI Data Library takes a different approach to the provision of climate data than most other portals examined here. As a data library, the user selects individual datasets to view and manipulate rather than using a visualisation interface with freedom to chop-and-change between various user-defined parameters as in other portals. The variety of data provided by the IRI Data Library is such that a single interface would be inappropriate. Where many other portals draw all of their data from single sources (e.g. the WCRP's archives for CMIP3 or CMIP5 outputs), the IRI Data Library draws from a large range of verified international sources.

Data characteristics are correspondingly very diverse making it hard to summarise. Nevertheless, it contains the most extensive collection of climate data of all the 15 portals examined here. End-of-century multi-model ensemble climate projections of the kind provided by many other portals are just one type of climate data that the IRI Data Library draws from the scientific community. For example, a range of different data

[12] The CCKP links to this tool.

types such as paleo-climate proxies (e.g. tree rings), satellite and in-situ observations, re-analysed data and GCM outputs are provided. Additionally, data relates to more technically advanced physical atmospheric, oceanic and biogeochemical processes as well as common climate variables and indices. Observational data goes as far back as 1500. Data characteristics such as underlying GCMs, spatial resolution and time span, among others, vary on a dataset by dataset basis as the user selects them.

Metadata

The IRI Data Library provides extensive dataset-specific metadata which is displayed as the user selects to query particular datasets. Metadata identifies data provenance as well as typical characteristics such as temporal and spatial resolution, dataset type (e.g. observational, GCM output etc.). The IRI Data Library does not however provide any metadata that summarises the data content of the library as a whole. This makes can it difficult for the first-time users to assess if the portal's data content is fit for their purposes.

User guidance materials

The IRI Data Library provides a series of tutorial sections (and accompanying videos), a glossary and FAQ section as its user guidance materials. The tutorial series (three – part) provides guidance on data library structure, and how to identify, manipulate and statistically analyse datasets of interest while the glossary and FAQ section identify and explain key terms and previous user enquiries. These guidance pieces appear to target users with very high technical skill as they overlook many climate science concepts and terms that other portals choose to explain. They themselves also feature extensive scientific terminology, abbreviations and so on. In short, a limited amount of very technically advanced user guidance materials are provided relative to other portals.

Website design

The IRI Data Library's website design assumes high technical skill from its users. The portal has a lack of summary information about the overall composition of the portal and instead presents its climate information in terms of its detailed (and technical) distinguishing characteristics of its data (e.g. data source, type, institution etc.) rather than employing a needs-based presentation of data. This can reduce website clarity for non-technical and/or inexperienced data users.

Main insights

Seasonal climate forecast tool

The seasonal climate forecast tool provides climate forecasts over 3-month and 6-month periods into the future based on a probabilistic assessment of historical climatology for given locations. Across all 15 portals, only the IRI Data Library and the KNMI Climate Explorer feature such a tool and are therefore the only portals to provide short-term climate information to meet short-term climate decision making needs.
Insight: The provision of climate data and tools that are useful for short-term climate decision making needs (e.g. climate preparedness planning) represents a very large gap in provision of decision-relevant climate information. This tool serves as an example of how a data tailoring processes, in this case the use of statistical techniques on observational data to create probabilistic forecasts, can be employed to provide useful decision-relevant climate information that satisfies the needs of decision makers grappling with shorter time horizons.

High level of technical skill

The IRI Data Library targets users that have higher technical skill than the majority of other portals. The ability to statistically analyse data and browse for original datasets are given considerably more primacy than the interactive visualisation capabilities that often form the primary (or only) function of other portals. Furthermore, this portal provides an abundance of scientific climate data with less of an appeal towards application-ready data. This gives users an abundance of choice which can be highly useful for technically advanced users. Whereas, in the absence of user guidance materials and a data-centric website design, the portal relies on the user's ability to identify data needs, navigate appropriate data choices and select and use appropriate data in suitable ways.

INSIGHT: Providing advanced data manipulation abilities and extensive and diverse climate data can serve multiple and disparate informational needs. However, this also introduces an abundance of choice that may be beyond the skill of non-technical users. This can risk user confusion and the misuse of climate data. If providing high data choice and advanced analysis capabilities, detailed user guidance at a level that can guide non-technical users can be advantageous in ensuring a fuller range of users can benefit from a climate information portal.

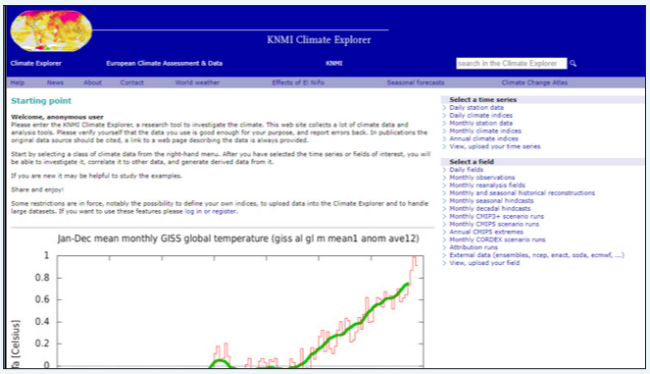
3.1.13 KNMI CLIMATE EXPLORER

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Visualisation and analysis platform for CMIP3, CMIP5 and CORDEX outputs as well as observational datasets	○ University-based institute	• Global	• Terrestrial	○ 1-3
	○ Government department	• Regional	• Oceanic	○ 4-6
	○ Multi-national collaboration	• National		• >6
	• National meteorology office	○ Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 1999
Headquarters: De Bilt, The Netherlands

Originally an informal side project of one reseracher at the Royal Netherlands Meteorological Institute. Some parts have been supported by the EU-based ENSEMBLES and SPECS projects, the Red Cross/Crescent Climate Centre and the Dutch Ministry of Infrastructure and Environment. It is now recorgnised as a KNMI product and KNMI are working towards producing a new operational version.



The KNMI Climate Explorer is primarily a visualisation and statistical analysis platform for hundreds of different climate datasets. It has four specialised interfaces: a climate change atlas, global scale seasonal forecasts, recent world weather and non-interactive information on the climatic effects of the El Nino Southern Oscillation (ENSO). The portal provides an abundance of climate data, facilitates a high degree of interactivity and requires high technical skill.

Provision of climate information

Data tools

The KNMI Climate Explorer provides four data tools (see table below) which are marked by high degrees of data choice and interactivity.

DATA TOOL	OVERVIEW	OUTPUT
Climate Explorer	• Gives access to hundreds of climate datasets: station data, climate indices, analyses, reanalysis and model output on seasonal and climate time scales (CMIP3, CMIP5, high-resolution runs). • Enables transformations of these data, eg averaging over regions, computing extreme indices. • Provide a statistical toolset: correlations, spectra, trends, extreme value statistics (with trends), etc.	Maps and timeseries
Seasonal forecast tool	• Enables users to explore short-term climate forecasts using 15 different forecasting systems. • Users have numerous technical data options (e.g. choice of underlying observational dataset used, method of bias correction, forecast statistic to be displayed and so on).	Maps
Effects of El Nino	• Presents non-interactive maps of the climatic effects of El Nino/La Nina throughout 4 seasons. • Covers global changes in precipitation, temperature and tropical cyclone patterns.	Maps
World weather	• Displays overviews of recent global scale weather. • Covers various annual timescales and climate variables.	Maps and timeseries

Climate models and downscaling

The KNMI Climate Explorer provides data from the full CMIP5 ensemble of 61 GCMs and the IPCC AR4 CMIP3 subset ensemble of 17 GCMs (though the number of CMIP5 GCMs used varies depending on the dataset in question (between CMIP5: full ensemble, CMIP5: IPCC AR5 subset and CMIP5: Expert Team On Climate Change Detection and Indices (ETCCDI) extreme indices ensemble). The CMIP5 and CMIP3 outputs are available at original and at 250km resolutions. Dynamically downscaled European CORDEX data is provided at a spatial resolution of 50km. This is the only downscaled data product provided, some recent high-resolution global models are also available.

The KNMI Climate Explorer also provides many observational (station data and analyses) and reanalysis datasets based on satellite observations and in-situ observational datasets from different climate data centres. Users can also upload their own data to analyse in the context of the data store. Observational data goes back as early as 1850. The "Atlas" interface makes a subset of these available in an easier-to-use way than the main system. This interface is the one that is discussed in the following paragraphs.

Emission scenarios and timeframes

The KNMI Climate Explorer provides the A1B scenario for CMIP3 projections and all RCPs for CMIP5 projections. Downscaled CORDEX projections can be explored under RCP 2.6, 4.5 and 8.5.

In terms of timeframes, this portal provides the highest freedom of choice. Firstly, the portal uses the IPCC-recognised 1986-2005 reference period as default however allows the user to define any range of years and is the only portal to allow a free selection of reference period. Secondly, any length user-defined time period can be selected to view climate projections. Thirdly, averages across any user-selected number of months can be selected to explore annual seasonality.

Climate variables and indices

The KNMI Climate Explorer Atlas interface provides access to up to 11 climate variables and 28 derived indices across its underlying data (a high number compared to other portals examined here) with the majority relating to temperature and precipitation changes.

Handling of uncertainty

The KNMI Climate Explorer presents uncertainty information in the usual way by displaying ensemble median and spread (2.5th and 97.5th percentiles) as well as the 5th, 10th, 17th, 25th, 75th, 85th, 90th, 95th percentiles from across the ensemble spread. These can be viewed in map and timeseries form. No educational information on the concept of uncertainty in climate data is provided.

Metadata

The KNMI Climate Explorer provides brief metadata on each of the 10 datasets held on the portal. Metadata explains overall data characteristics and provenance though does so using abundant technical terminology which in the absence of user guidance material affects its usefulness for non-specialist audiences.

User guidance materials

The KNMI Climate Explorer provides some data-oriented user guidance materials. However, this portal emphasises its intended use as a scientific tool for climate analysis whereby users should verify themselves that selected data is suitable for their purposes (KNMI Climate Explorer, 2018). The portal provides a "Help" section (though this section is under construction) which acts as triples as a user guide for portal content and operation, a glossary for some technical terms and an area for use cases; hypothetical examples on how to select, visualise and analyse the portal's climate information. Guidance buttons are also distributed across the portal interface which gives further assistance as the user makes climate data parameter selections. In short, the KNMI Climate Explorer is characterised by a small amount of highly technical data-oriented user guidance (similar to the IRI Data Library) as opposed to the provision of needs-based user guidance such as decision-trees or appropriate use guidance for example. In turn, this portal relies on the technical skill of the user know their data needs and successfully select and appropriately use its climate data.

Website design

Similar to many other portals, the KNMI Climate Explorer utilises a website header to clearly identify and direct users to main portal features. Generally, this portal focuses on the technical exploration of climate data and less on aesthetic design features.
The KNMI Climate Explorer features scientific-format maps and timeseries that use many conventions of the climate science research community in their figure titles,

captions, labels and so on. These are characterised by technical labels and so on. These are characterised by technical jargon, scientific abbreviations and symbols. These characteristics, with are not accompanied by user guidance material, can be unclear to non-technical or inexperienced users.

Main insights

Data variety

While most portals strongly tend towards the provision of long term future climate projections data, the KNMI Climate Explorer contains a more expansive set of data (and from more diverse sources) than many other portals examined here. The portal provides non-downscaled and downscaled GCM outputs, reanalysed satellite observation data and in-situ observation data as well as a seasonal forecast tool to meet short-term climate decision making needs (in a similar manner to the IRI Data Library).

INSIGHT: Climate information portals can consider providing other types of climate data besides long term climate projections and provide data products (e.g. short-term forecasting tools) to meet additional climate decision making needs besides already well-served long term climate strategizing.

High freedom of data choice (and technical skill)

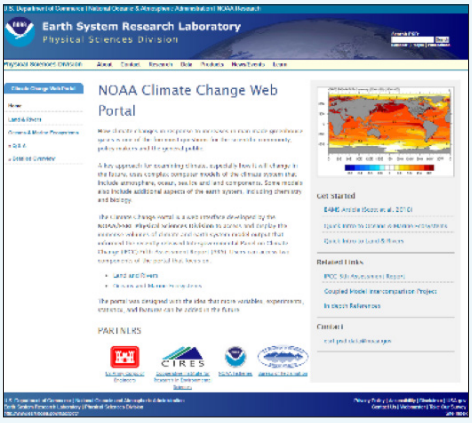
The KNMI Climate Explorer also provides a high level of data choice which, in the face of very limited user guidance, requires higher technical skill than most other portals. This portal features advanced parameter selections (see above) while most other portals favour more restricted pre-defined sets of parameter options (or they do not offer a user choice at all). Such freedom of choice can serve technically experienced and/or specialist data users well. Meanwhile, it can cause confusion for non-technical/novice data users (and possibly the misuse of climate data).

INSIGHT: Climate information portals can provide great freedom of data choice to meet an increased range of informational needs. With a view to meet the needs of decision makers, if providing high degrees of choice accompanying user guidance to assist non-technical/inexperienced users through such choices should also be provided. This can ensure usefulness is maintained for those with differing skill levels and resources.

3.1.14 ESRL CLIMATE CHANGE WEB PORTAL

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Visualisation platform for CMIP3, CMIP5 and CORDEX outputs as well as observational datasets	○ University-based institute	• Global	• Terrestrial	○ 1-3
	○ Government department	• Regional	• Oceanic	• 4-6
	○ Multi-national collaboration	○ National		○ >6
	○ National meteorology office	○ Subnational		
	○ Research institute			
	• National agency			
	○ Not-for-profit initiative			

OVERVIEW



Year created: 2015
Headquarters: Boulder, USA

The Earth System Research Laboratory's Climate Change Web Portal (the ESRL Climate Change Portal) is hosted by the Physical Sciences Division at the National Oceanic and Atmospheric Administration. Portal development was undertaken by the U.S. Department of the Interior, the U.S. Army Corp of Engineers and the Cooperative Institute for Research in Environmental Sciences.

The ESRL Climate Change Portal is a map- and timeseries-based visualisation platform for CMIP5 data (globally and the contiguous U.S.) and as well as NCAR's CESM-LENS global climate datasets. The portal is divided into two sub-portals: "land and rivers" and "oceans and marine ecosystems".

This portal is characterised by the provision of numerous climate variables at the expense of derived indices and a wealth of data choices.

Provision of climate information

Data tools

The ESRL Climate Change Portal provides six data tools which draw on slightly different underlying climate data. Therefore, each data tool has been presented in terms of its output type, function, climate models and downscaling approaches, emission scenarios and timeframes and variables and indices (see table below). A total of 22 climate variables and 0 derived climate indices are available across all 6 tools.

The ESRL Climate Change Portal's tools provide numerous advanced data choices to the user. For example, users can select and visualise a range of data statistics such as the ensemble mean and 10th, 50th and 90th percentiles, standard deviations, linear trends and lag 1 autocorrelations. Additionally, 37 GCM outputs can be displayed individually. These data choices are in addition to traditional parameter selections (e.g. emission scenario, future time period and so on).

The ESRL Climate Change Portal also features scientific-format maps and timeseries using scientific abbreviations, symbols, colour legends and axis. The ease with which these outputs can be interpreted by non-technical/inexperienced users is therefore reduced.

Handling of uncertainty

The ESRL Climate Change Portal presents uncertainty in very sophisticated ways. This portal displays ensemble averages (mean and median) and spreads (10th and 90th percentiles) typical of other portals however also provides more advanced statistics such as standard deviations and standard anomalies to allow users to capture the degree of spread in data. While advantageous to technically adept users, their usefulness may not be so apparent to non-technical/inexperienced users. User guidance on the general concept of uncertainty in climate data is not provided.

The portal also fails to communicate that interpolation has been used to project data over a 1 degree by 1 degree grid (approximately 100km$^{2)}$. This process smooths coarse-scale GCM data for display purposes only. Downscaling methodologies are not used. However, this is not reported on the portal site. Especially concerning casual, time-limited and/or inexperienced data users, this risks inferring higher scientific quality in its underlying data and, in turn, data misuse.

Metadata

This portal provides its brief metadata via a slideshow describing broad data characteristics as well as via the portal's guidance buttons that are coupled to the various parameter dropdown menus on the visualisation platform. Metadata is provided by ways of text and more visually appealing tables. Original data sources are acknowledged and hyperlinked.

User guidance materials

The ESRL Climate Change Portal provides a very low level of user guidance. Each data tool contains a "Quick Intro" section which, structured as a slideshow, serves as the portal's main user guide. This guide focuses primarily on the portal's data content and uses a very high level of technical jargon, scientific abbreviations and symbols. Meanwhile, guidance buttons coupled to the platform's parameter dropdown menus are useful forms of guidance. However, beyond these two forms no other user

guidance is provided such as a glossary of technical terms or an FAQ section which would otherwise significantly reduce the barrier posed by the portal's technical framing.

Website design

The Climate Change Web Portal successfully displays the majority of its content in a small number of webpages. The data visualisation interface uses a consistent design format across all of its data tools and features intuitively placed parameter dropdown menus and guidance buttons in close proximity to the data viewer. Overall, this significantly reduces user click count creating a clear and easy of use portal in terms of design.

Main insights

Lack of derived climate indices

The ESRL Climate Change Portal provides numerous climate variables while providing no derived indices. Further still, the portal's climate variables are more complex than those provide on other portals. Many relate to complex atmospheric, oceanic and biogeochemical processes. With respect to portal users from decision making contexts, the complexity of the provided climate variables and the lack of derived indices can have reduced usefulness.

INSIGHT: Climate information portals can provide ranges of simple yet useful climate variables and numerous derived indices for decision makers. These have greater usefulness in climate decision making processes than complex scientific variables more suited to academic research.

Abundance of data choices

The ESRL Climate Change Portal provides an abundance of advanced data choices such as the ability to select output statistics beyond ensemble averages and percentiles, the ability to select different reference periods and display individual model outputs. Such advanced data choices may be beyond the skill of non-technical data users to successfully navigate since no accompanying user guidance is provided. This can cause user confusion. Such advanced data choices are usually omitted in other portals that target decision makers.

INSIGHT: Climate information portals can provide appropriate data choices for decision makers such as different emission scenarios, derived indices, future time periods and so on. Should advanced options be included, supporting user guidance explaining such options in detail can be highly beneficial.

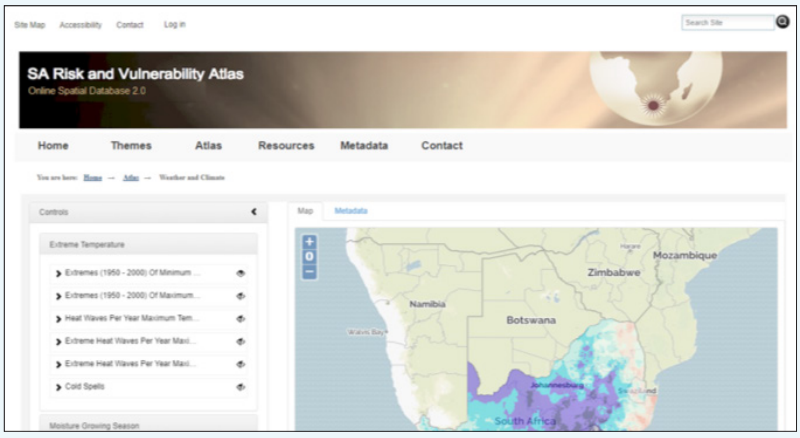
TOOL	OUTPUT	OVERVIEW	CLIMATE MODELS & DOWNSCALING	EMISSION SCENARIOS & TIMEFRAMES	CLIMATE VARIABLES & INDICES
Land and rivers: Map viewer	Maps	• Displays four user-defined interactive maps of historical observations and future projections. • Relative future changes. • Global and regional scale.	• Atmospheric variables use an ensemble of 37 GCMs. • Oceanic variables use ensemble of 27 GCMs. • GCM outputs interpolated to 1km^2. Uses CMIP5 datasets.	RCP4.5 & 8.5 1911-2005 1901-1950, 1956-2005, or 1979-2008	Air temperature, precipitation, daily max. temperature, daily min. temperature, sea surface temperature.
Land and rivers: Timeseries viewer	Timeseries	• Displays a set of two user-defined timeseries. • Compares absolute and relative future changes. • Hydrologic regions of the contiguous US.	Same as above.	RCP4.5 & 8.5 1901-2005	Air temperature, precipitation, daily max. temperature, daily min. temperature.
Oceans and marine ecosystems: Map viewer	Maps	• Provides same function as the land and rivers map viewer. • Relative changes. • Global and regional scale.	Same as above.	RCP4.5 & 8.5 1956-2005	Air temperature, precipitation, sea surface temperature (and other depths), sea surface salinity (and other depths), sea ice %, heat content, static stability, Ekman pumping (a range of ocean biogeochemical, wind and radiation variables).
Oceans and marine ecosystems: Timeseries viewer	Timeseries	• Provides same function as the land and rivers timeseries viewer. • Compares absolute and relative future changes. • Oceanic regions.	Same as above.	RCP4.5 & 8.5 User-defined between 1976-2099	Air temperature, precipitation, sea surface temperature, sea surface salinity, bottom temperature, bottom salinity, sea ice, mixed layer depth, net primary productivity.
Oceans and marine ecosystems: CESM-LENS map and timeseries viewers	Maps & timeseries	• Displays user-defined maps and timeseries for observations and future projections. • Atmospheric and oceanic variables.	• Uses a 30-simulation ensemble of the CESM-LENS GCM. • GCM output interpolated to 1km^2.	RCP4.5 & 8.5 Map viewer 1956-2005 Timeseries viewer Same as oceans and marine ecosystems timeseries viewer.	Map viewer Same as oceans and marine ecosystems map viewer. Timeseries viewer Air temp, sea surface temp., sea ice %, mixed layer depth, bottom temperature, net primary productivity
Raw data download	Raw data	-	-	-	-

3.1.15 SOUTH AFRICAN RISK AND VULNERABILITY ATLAS

DATA OFFERING	ORGANISATION	GEOGRAPHIC FOCUS	DOMAIN	DATA TOOLS
Visualisation platform for CMIP3, CMIP5 and CORDEX outputs as well as observational datasets	○ University-based institute	○ Global	• Terrestrial	• 1-3
	• Government department	○ Regional	○ Oceanic	○ 4-6
	○ Multi-national collaboration	• National		○ >6
	○ National meteorology office	• Subnational		
	○ Research institute			
	○ National agency			
	○ Not-for-profit initiative			

OVERVIEW

Year created: 2010
Headquarters: Cape Town, South Africa



The South African Risk and Vulnerability Atlas (the Risk and Vulnerability Atlas) was developed by the South African Science and Technology Department and in partnership with the South African Environmental Observation Network and the National Research Foundation.

The Risk and Vulnerability Atlas is divided into 9 socio-economic and environmental sections. Each section comprises a map-based interface to visualise a variety of associated datasets. The "weather and climate" section comprises the climate information portal examined here and is a map-based visualisation platform for observational climate datasets over South Africa only. The Risk and Vulnerability is the only portal not to provide information on future climate projections.

Provision of climate information

Data tools

The Risk and Vulnerability Atlas contains a map viewer as its single data tool with download options (see table below).

DATA TOOL	OVERVIEW	OUTPUT
Map viewer	• Statically displays a selection of observational climate datasets. • Point location information retrievable. • Overall limited interactivity; datasets are provided as is. • No options to explore user-defined time periods. • Displays clear metadata for each dataset.	Maps
Raw data download	-	Various formats

Climate data

The Risk and Vulnerability Atlas contains a restricted selection climate data compared to the other 14 portals with the major difference being the lack of climate projections data. The portal contains a selection of 15 observational climate datasets over South Africa relating to 4 climate variables and 5 derived indices covering temperature and precipitation changes. Additional climate impact variables concerning the moisture growing season, pertinent to South Africa, are also provided. All data runs from 1950 to 2000 and between 1-2km^2 resolutions.

Metadata

In a similar fashion to the CCKP, CLIPC and PREPdata, the Risk and Vulnerability Atlas provides metadata with respect to each (observational) dataset. Metadata comprises a short text-based abstract, data provenance and data download links.

User guidance materials

The Risk and Vulnerability Atlas provides no user guidance material such as a user guide, FAQ section, glossary and so on of the kind found commonly on other portals. It does give contact information for specific user enquiries. This gap in provision to some degree reflects the portal's limited amount of climate data and restricted functionality. This makes the portal quick to explore and easy to use.

Website design

The Risk and Vulnerability Atlas contains a number of functional issues which constrain ease of use. For example, in the map viewer, titles, captions, labels and unit symbols are missing which limits the ability of the user to successfully interpret visualised information. These issues are confounded by a lack of explanatory text across the portal's pages which on other portals are useful in explaining content, function and purpose to the user.

Main insights

Lack of future climate projections data

Observational climate data has utility for climate adaptation decision making on very short time horizons. However, this is the only portal not to provide climate projections data. A lack of future climate projections data prevents a wider range of informational needs (e.g. decision makers concerned with future climate change) from being satisfied and in turn makes it somewhat redundant to other more expansive climate information portals.

INSIGHT: With a view to meet an expanded range of decision maker needs and prevent redundancy, climate informational portals should aim to provide observational and projections data such that a sufficient range of data needs can be met and usefulness for decision makers increased.

3.2 PORTAL SUMMARY

This section synthesises and presents findings from across all 15 portals. This section provides an overview of their current data products. Particular similarities, differences and gaps in provision have been highlighted throughout this section.

Product types

The 15 portals deliver climate information using 4 broadly different approaches. They are either a visualisation platform, map-based visualisation platform, decision-support tool or climate data library and visualisation platform.

Portals tend to be map-based visualisation platforms (see table 2). These portals tend to display direct climate model outputs, typically from CMIP3 and/or CMIP5 archives, using prominently located interactive map-based visualisation interface which allows the user to select different climate parameters (e.g. variable, emission scenario, geographic location and so on) to create maps of climate change.

An equal number of portals are visualisation platforms, decision-support tools or climate data libraries and visualisation platforms (see table 2). Visualisation platforms use an interactive interface to display a range of data visualisations that have equal prominence on the portal site. These also typically display direct climate model outputs from CMIP3 and CMIP5 archives as maps and timeseries.

The decision-support tools (see table 2) (CCIA, Pacific Climate Futures and UKCP09) display more sophisticated data visualisations that can be more readily used in climate decision making processes. CCIA and Pacific Climate Futures focus on multi-variate tabulated model outputs of use in climate impact/risk assessments. UKCP09 displays probabilistic climate change projections using probability density functions, cumulative density functions, return plots and other related visualisations. Both approaches are particularly useful at presenting the range and likelihood of climate projections in a way that presenting direct climate model output as singular ensemble averages and spreads does not as effectively capture. The decision-support tools also use CMIP3 and CMIP5 outputs.

The climate dataset libraries and visualisation platforms (see table 2) (CLIPC, the IRI Climate Data Library and PREPdata) focus on enabling users to browse wider ranges of climate datasets such as in-situ and satellite observations, reanalysed observational datasets and CMIP3 and CMIP5 outputs. Options to further manipulate, statistically analyse and/or download climate data are often more prominent on these portals than visualisation tools.

TABLE 2 | CLIMATE INFORMATION PORTAL BY PRODUCT TYPE

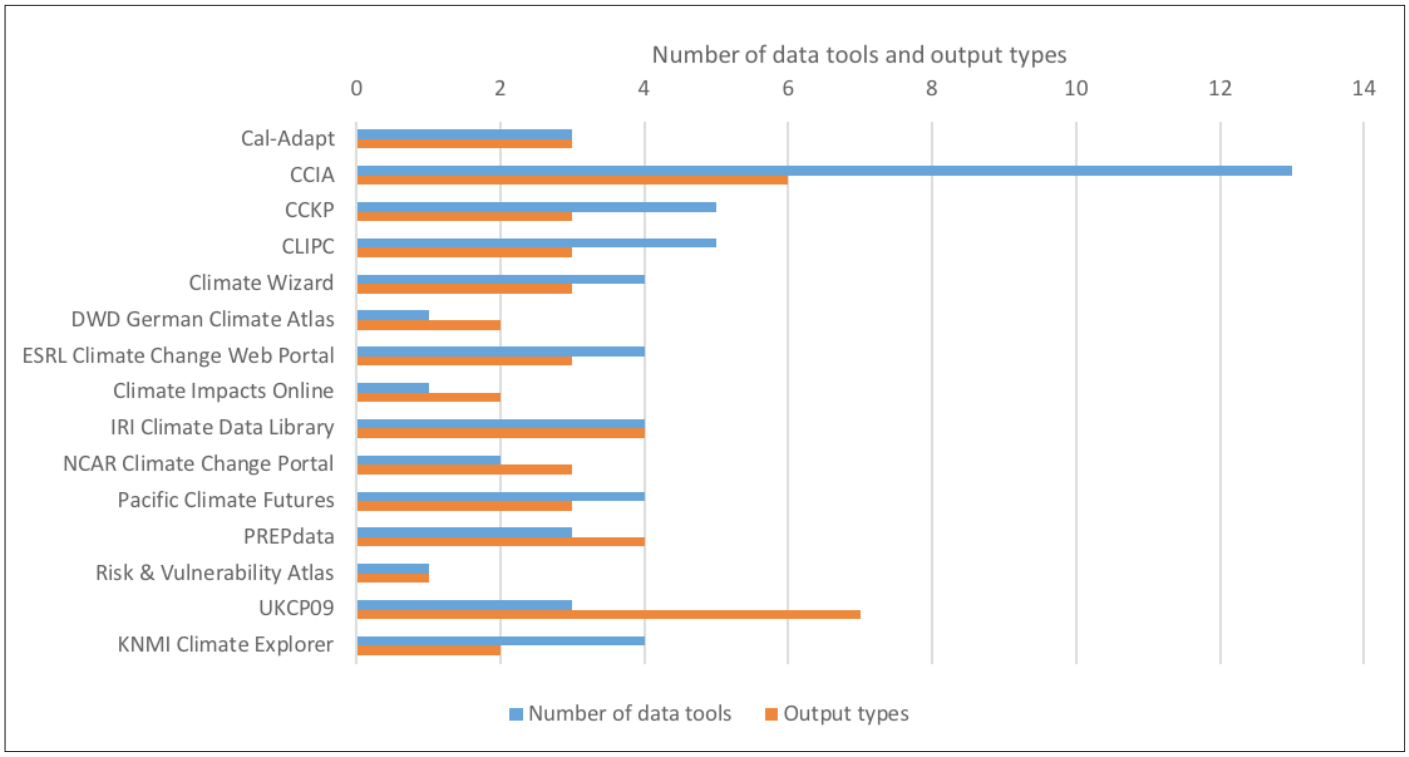
	VISUALISATION PLATFORM	MAP-BASED VISUALISATION PLATFORM	DECISION-SUPPORT TOOL	CLIMATE DATA LIBRARY AND VISUALISATION PLATFORM
Cal-Adapt	X			
CCIA			X	
CCKP		X		
CLIPC				X
Climate Wizard		X		
DWD German Climate Atlas	X			
ESRL Climate Change Portal		X		
Climate Impacts Online		X		
IRI Climate Data Library				X
NCAR Climate Change Portal		X		
Pacific Climate Futures			X	
PREPdata				X
Risk & Vulnerability Atlas		X		
UKCP09			X	
KNMI Climate Explorer	X			
Totals	3	6	3	3

Table 2 shows each portal in terms of the product type that it provides. Visualisation platform: interactive interface to display a range of data visualisations that have equal prominence on the portal site. Map-based visualisation platform: interactive interface to primarily display maps. Decision-support tool: display sophisticated data visualisations that can be readily used in climate decision making processes. Climate data library and visualisation platform: contain a library of climate datasets with options to analysis, visualisation and/or download data.

Data tools

Most portals provide 2-4 different data tools to explore their climate information (see figure 4). As one of the sophisticated decision-support portals CCIA is a stand out exception and provides up to 13 different data tools to the user providing both simple graphical displays of climate projections as well as more detailed application-ready climate information. In terms of output types, **most portals provide 2-4 different output types**. CCIA and UKCP09 are the exceptions here and, again as more sophisticated decision-support tools, provide a wider range of outputs types.

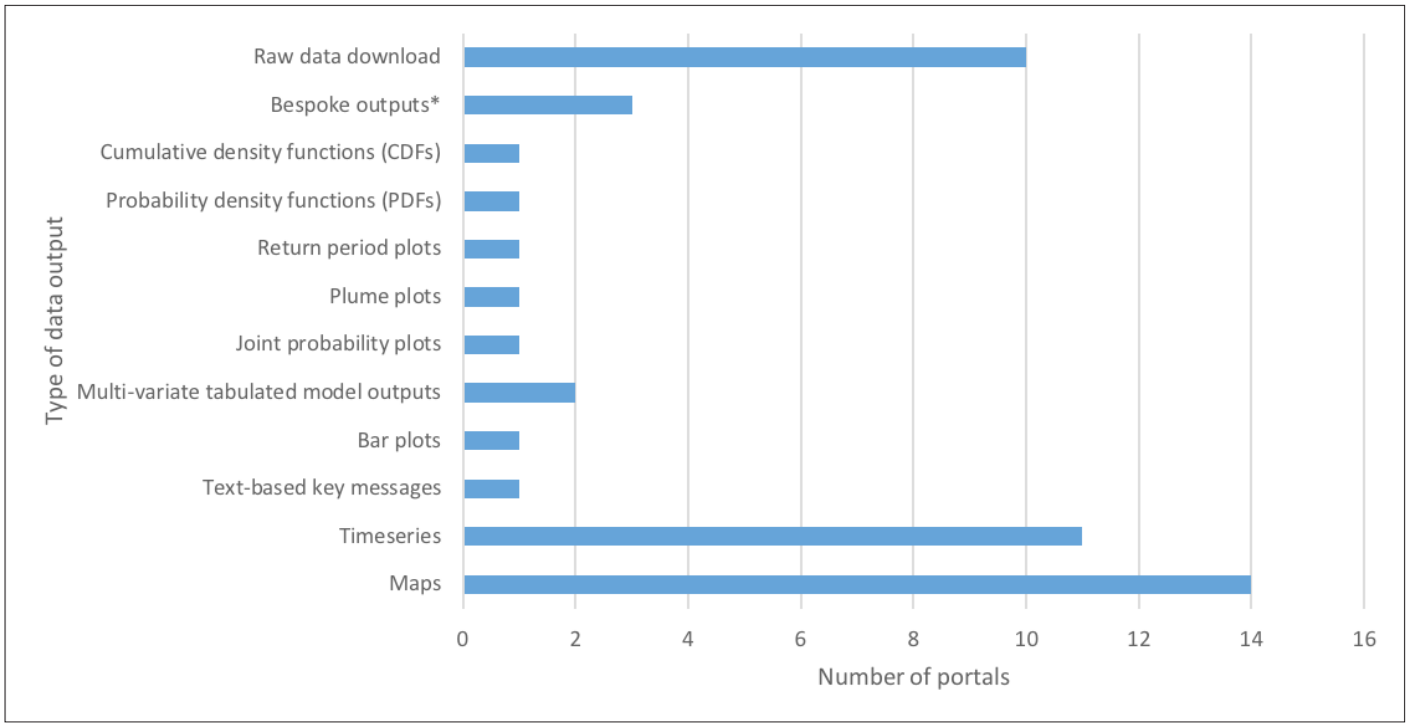
FIGURE 4 | PORTALS BY NUMBER OF DATA TOOLS AND OUTPUT TYPES THEY PROVIDE



Nearly all portals visualise climate data in maps and timeseries form with a large number allowing raw data download (see figure 5). This reflects the fact that many portals display direct climate model outputs that are arguably best visualised as maps and timeseries. As decision-support tools, CCIA, Pacific Climate Futures and UKCP09 present the majority of the more sophisticated output types such as PDFs and multi-variate tabulated model outputs (see figure 5). UKCP09 is notable in providing considerably more output types than data tools reflecting the versatility of this portal (see figure 4). A number of customised outputs – seasonal forecasts, climate information dashboards and statistical analysis tools - are also provided on across 3 portals. Seasonal forecasts, which provide short-term climate projections usually for the forthcoming 3 months, are provided on only 2 of 15 portals.

The visualisation of climate data in ways other than maps and timeseries represents a significant gap in provision. Additionally, data tools and outputs that answer the needs of climate decision makers operating on shorter time horizons (e.g. seasonal climate forecasts) is another gap relative to the abundant provision of maps and timeseries of end-of-century climate projections data.

FIGURE 5 | NUMBER OF DATA OUTPUTS PROVIDED BY EACH PORTAL EXAMINED



The 15 portals vary in terms of their geographic focus (see table 3). **Portals tend to provide climate information at global or national scales, or at national and sub-national scales together.** Cal-Adapt provides climate information over the State of California only (sub-national), and as such has the smallest geographic range of any portal. CLIPC and Pacific Climate Futures are unique in presenting climate information at regional scale (Europe and the Pacific region respectively) only.

The CCKP and the KNMI Climate Explorer cover the greatest geographical range; operating at global, regional and national scales. The KNMI Climate Explorer goes further still and enables the user to select any user-defined point location or geographic area of interest. All other portals either provide information at the global scale or focus on a particular region/country.

The provision of climate information across all 4 scales, at international, regional and national scales and at the sub-national scale alone is a possible gap in provision.

TABLE 3 | GEOGRAPHIC SCALE EXAMINED BY EACH PORTAL

	GLOBAL	REGIONAL	NATIONAL	SUB-NATIONAL
Cal-Adapt				X
CCIA			X	X
CCKP	X	X	X	
CLIPC		X		
Climate Wizard	X		X	
DWD German Climate Atlas			X	X
ESRL Climate Change Portal	X	X		
Climate Impacts Online			X	X
IRI Climate Data Library	X			
NCAR Climate Change Portal	X			
Pacific Climate Futures		X		
PREPdata	X			
Risk & Vulnerability Atlas			X	
UKCP09			X	X
KNMI Climate Explorer	X	X	X	
Totals	7	5	8	5

Climate models and downscaling

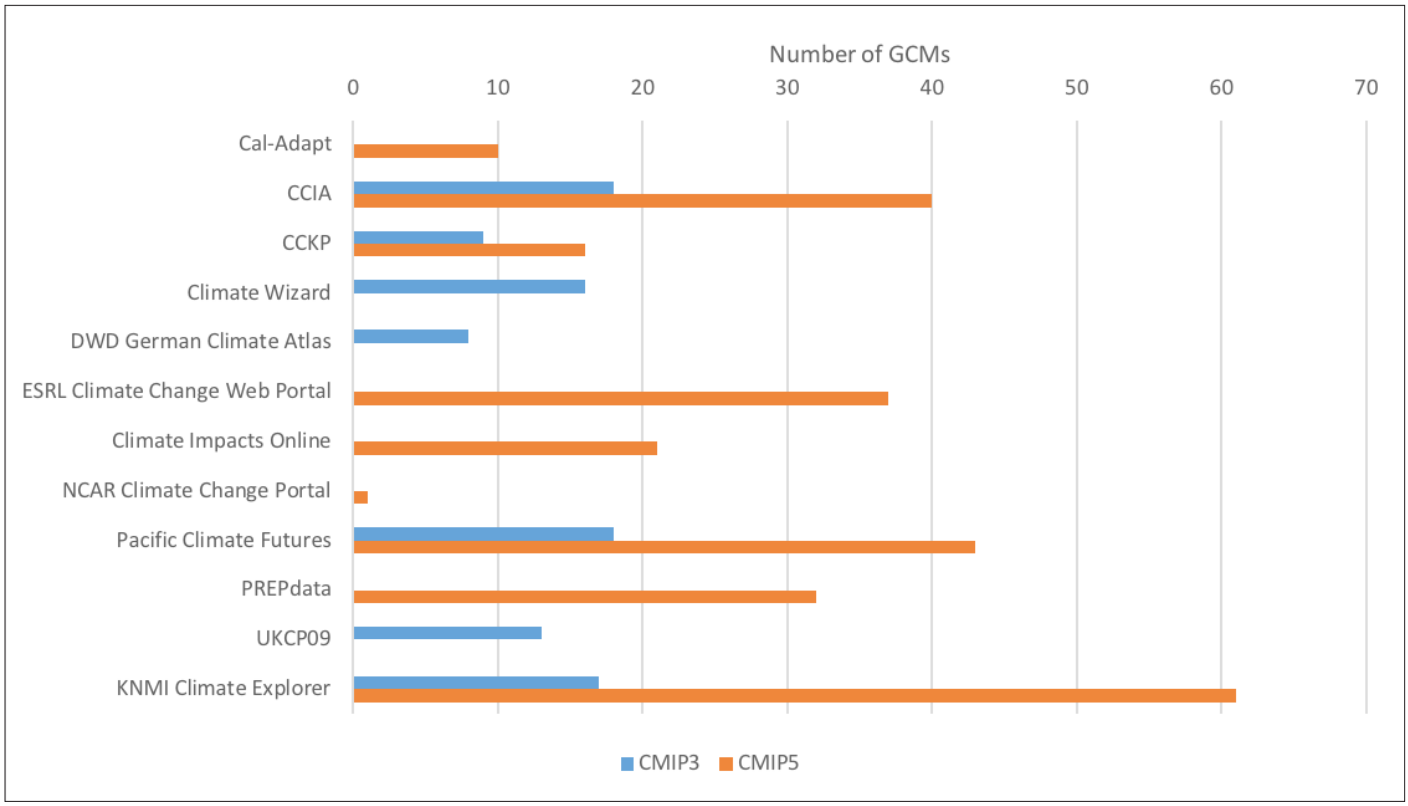
Nearly all the examined portals use CMIP3 or CMIP5 GCM data. Most portals use data from newer CMIP5 outputs (figure 4). As expected, more recently released portals appear to favour the use of newer CMIP5 GCMs while older portals still use the older CMIP3 data. Portals displaying both CMIP3 and CMIP5 data have often been updated into newer versions of the same platform.

The NCAR Climate Change Portal uses the fewest GCMs: NCAR's CCSM-4. The portal's data distribution agreement prevents the provision of any additional GCM output. At the other end, the KNMI Climate Explorer presents the full CMIP3 and CMIP5 multi-model ensemble of 24 and 68 GCMs respectively.

The Risk and Vulnerability Atlas is the only exception as it presents observational data only. CLIPC, the IRI Data Library and PREPdata contains numerous different datasets each containing different GCMs. These three portals have not been included in figure 6.

It is reasonable to assume that there will be a continued transition from CMIP3 to CMIP5 use (Hewitson *et al.*, 2017), and to the use of CMIP6 GCMs as they become available. Therefore, with a view to provide decision relevant climate data, the acquisition and inclusion of the latest GCM outputs from internationally verified sources is preferable. This can provide robust state of the art climate data that does not become redundant relative to other sources.

FIGURE 6 | NUMBER AND TYPE OF GCMS PROVIDED BY EACH PORTAL



Dynamical and/or statistical downscaling can be employed to derived local and regional scale climate data from GCM-scale outputs. There are a number of insights here:

- **Nearly all portals use a downscaling step to present information at finer resolution, more suitable for the national and sub-national scales that they cover.**
- **Across the 15 portals, about the same number of portals use dynamical downscaling as use statistical downscaling methods** (see table 4).
- **It is rare that a portal presents dynamically and statistically downscaled climate data.**

The ESRL Climate Change Portal is the only portal to present no downscaled climate projections data. The Risk and Vulnerability Atlas does not provide climate projections and so do not employ downscaling.

Downscaling methods used are also very conceptually diverse. This reflects the fact that in many cases downscaling efforts are carried out by the portal developers themselves or are drawn from an institution through which portal developers have an existing relationship. Methods range from more well known techniques such as the ENSEMBLES and CORDEX outputs through to less well known, or possibly entirely customised, methodologies such as the Weather Generator of UKCP09 or the unnamed statistical downscaling technique used in CCSM-4 of the NCAR portal. The variety of downscaling approaches found here supports those from the wider literature which highlight that downscaling is itself a research frontier (Hewitson *et al.*, 2017; Sigel *et al.*, 2016).

Downscaling methodology descriptions can be obscure for non-technical users. Technically detailed descriptions are often given from data provider perspectives. In other cases, portal websites forward users on to academic publications. Detailing downscaling approaches in this manner risks inferring higher skill from increased data resolutions, especially to non-technical or inexperienced data users. Meanwhile, the central characteristic of downscaling, that they still use underlying coarse GCM-scale processes and do not represent increased understanding of the climate system, is not always highlighted. Clear downscaling methodology descriptions that are accessible for non-technical and/or inexperienced data users represents a gap in provision.

Considering future portal development, the provision of downscaled data products from different sources is lacking in current provision and represents a significant gap. The transparent description of downscaling methodologies on portal websites, and guidance as to the appropriate use of downscaled data, is another significant gap.

TABLE 4 | CLIMATE INFORMATION PORTAL BY DOWNSCALING METHOD

	DYNAMICAL DOWNSCALING	STATISTICAL DOWNSCALING
Cal-Adapt	-	Localised constructed analogs
CCIA	CCAM	Delta Change
CCKP	-	Bias correction
CLIPC	Varies	Varies
Climate Wizard	-	Quantile mapping
DWD German Climate Atlas	ENSEMBLES	-
ESRL Climate Change Portal	-	-
Climate Impacts Online	STAR model	-
IRI Climate Data Library	Varies	Varies
NCAR Climate Change Portal	-	Custom methodology
Pacific Climate Futures	CCAM	-
PREPdata	-	Bias correction & LOCA
Risk & Vulnerability Atlas	N/A	N/A
UKCP09	HadRM3	Weather Generator
KNMI Climate Explorer	CORDEX	-
Totals	8	9

Emission scenarios

Most portals have transitioned to newer RCPs (reflecting the fact that most portals present CMIP5 GCMs) (see table 5). RCP 4.5 and 8.5 are the most used emission scenarios with A1B being the most used from the SRES family. Portals providing RCPs give at least 2 scenarios; typically, a low and high emission scenario to allow comparison to the user. Portals providing SRES scenarios tend to provide all 3 scenarios.

Less than half the portals provide access to a full suite of either SRES or RCP emission scenarios. Additionally, only 3 portals present all 7 scenarios from SRES and

RCP families. Likewise, for CMIP3 and CMIP5 data, portals providing both SRES and RCPs are those having been updated into newer versions. Once again, it is reasonable to assume the continued transition from older SRES to newer RCP scenarios.

Considering future portal development, the provision of a full suite of the most recently available emission scenarios represents a gap in provision yet serves advantages. It prevents portal redundancy with other sources and provides freedom choice to a greater extent than is currently provided by the majority of portals.

TABLE 5 | CLIMATE INFORMATION PORTAL BY EMISSION SCENARIOS (SRES AND/OR RCPS)

	SRES			RCP				TOTAL
	B1	A1B	A2	2.6	4.5	6.0	8.5	
Cal-Adapt					X		X	2
CCIA	X	X	X	X	X	X	X	7
CCKP	X	X	X	X	X	X	X	7
CLIPC	Varies depending on dataset							-
Climate Wizard	X	X	X					3
DWD German Climate Atlas		X			X*	X*	X*	1
ESRL Climate Change Portal					X		X	2
Climate Impacts Online				X			X	2
IRI Climate Data Library	Varies depending on dataset							-
NCAR Climate Change Portal				X	X	X	X	4
Pacific Climate Futures	X	X	X	X	X	X	X	7
PREPdata					X		X	2
Risk & Vulnerability Atlas	Historical observations only							-
UKCP09	X	X	X					3
KNMI Climate Explorer		X		X	X	X	X	5
Totals	5	7	5	6	8	5	9	

Observational data and timeframes

The portals tend to provide observational data back until the 1950s or approximately the 1900s (see figure 7). The DWD German Climate Atlas and the KNMI Climate Explorer give observational data as far back as 1880. The IRI Data Library is a stand out exception and provides observational data as far back as 1500 using tree ring proxy data. CLIPC and PREPdata supply numerous datasets from different sources meaning the extent of observational data varies dataset to dataset.

FIGURE 7 | CLIMATE INFORMATION PORTAL BY EXTENT OF OBSERVATIONAL CLIMATE DATA

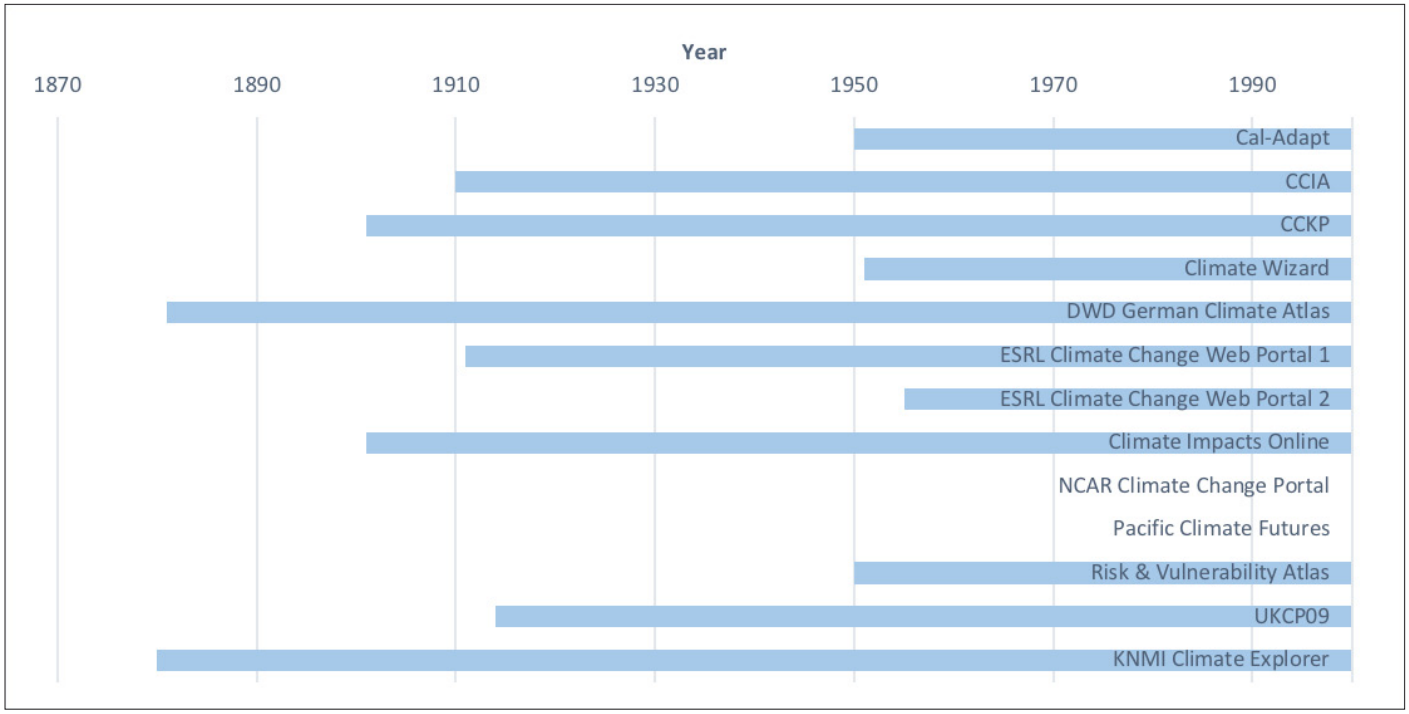


Figure 7: Note that NCAR and Pacific Climate Futures do not show observational data, only projections.

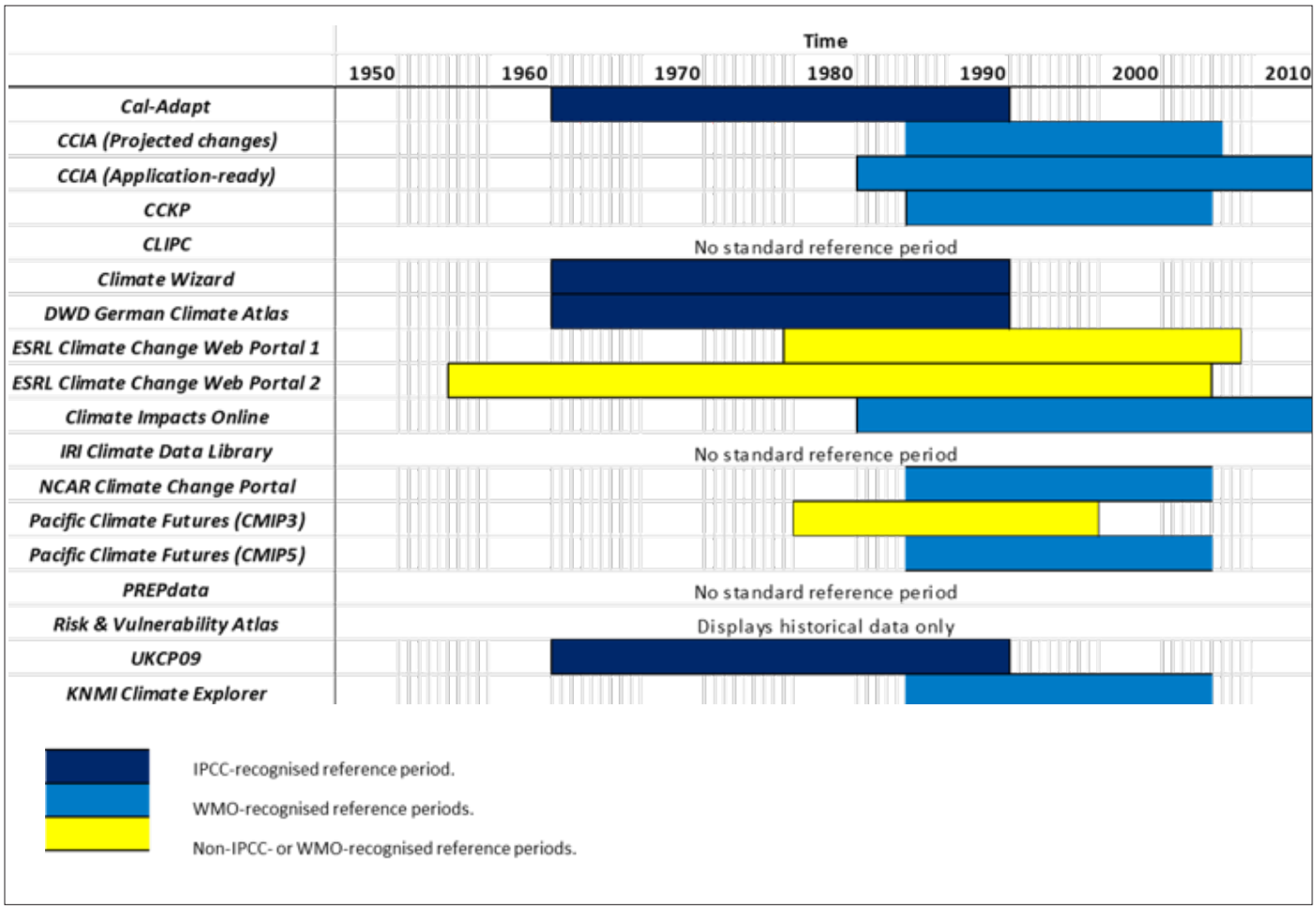
Portals tend to select official reference periods recognised by the WMO or IPCC (see figure 8; blue boxes); either the WMO-recognised 1961-1990 period (4 portals), the newer 1981-2010 period (2 portals), or the IPCC-recognised 1986-2005 period (5 portals). As one might expect, more recently created portals tend to use newer reference periods. Only the CMIP3 outputs of Pacific Climate Futures and the ESRL Climate Change Portal use reference periods different to those recognised by the WMO or IPCC (see figure 6; yellow boxes).

Some portals (CCIA, the ESRL Climate Change Portal and Pacific Climate Futures) use different reference periods depending on what data the user is exploring. Some portals enable significant user choice and allow the user to interactively choose their reference period of interest; either from pre-set options (the ESRL Climate Change Portal) or any range of years (Cal-Adapt and KNMI Climate Explorer).

CLIPC, the IRI Climate Data Library and PREPdata supply datasets containing a wide range of reference periods.

With a view to meet climate decision maker needs, portal developers should strive to use the latest internationally recognised reference periods as many other portals do. This upholds data currency and ensures consistency with other sources of climate data which can increase its usefulness in climate decision making process (e.g. climate risk and impact assessment). Providing users the freedom to select their own reference period is a niche quality of a few portals. This is advantageous as long as users have the technical skill, or are given guidance, to identify appropriate selections.

FIGURE 8 | CLIMATE INFORMATION PORTAL BY REFERENCE PERIOD EMPLOYED



In this figure: Dark blue: IPCC-recognised reference period. Light blue: WMO-recognised reference periods. Yellow: non-IPCC- or WMO-recognised reference periods. Note: CCIA uses two different reference periods across its projected changes and application-ready data; the ESRL Climate Change Portal uses two different reference periods across its "Land and Rivers" (portal 1) and "Oceans and Marine Ecosystems" (portal 2) portals; and, Pacific Climate Futures uses two different reference periods across its CMIP3 and CMIP5 datasets.

The 15 portals employ a diverse range of approaches to enable users to explore climate data over time. **Portals tend use either a 30-year or 20-year time interval to compute climate changes.** Climate Impacts Online and Pacific Climate Futures are the exceptions in using 10-year intervals.

Portals tend to offer at least 3 future time periods (typically an early-, mid- and late-century time period) to the user to view climate projections however it does range from 2 (Climate Wizard) to 16 (Climate Impacts Online) (see figure 9; 3 shades of blue).

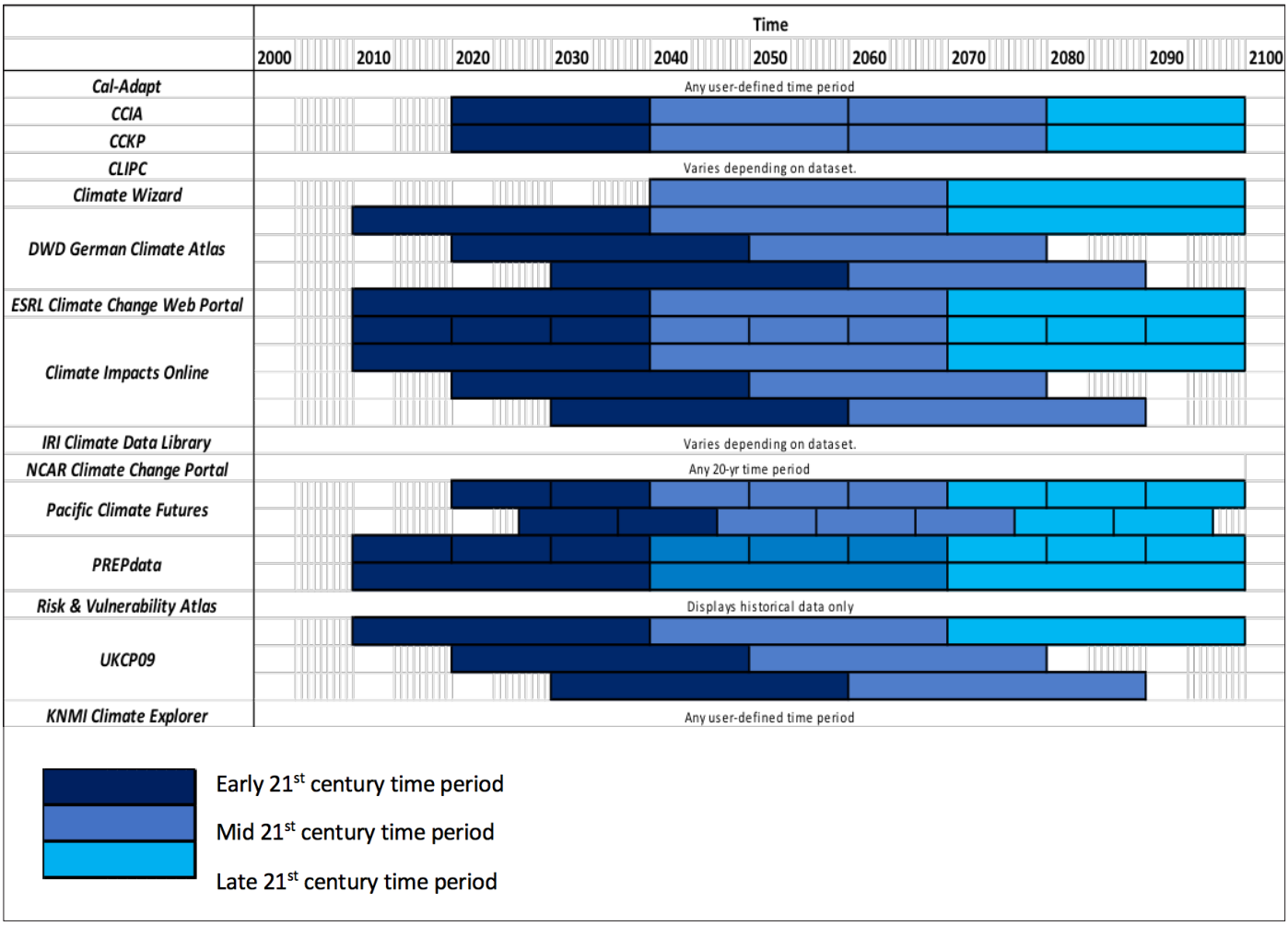
Some portals (4) overlap the time intervals they use to compute outputs as a means of providing data at finer time steps throughout the 21st century to the user (see figure 9). Overlapping enables these portals to present information at 10-year or 5-year time steps while still using robust 20- or 30-year time intervals.

Cal-Adapt and the KNMI Climate Explorer use an approach different to other portals. They allow the user to interactively select any user-defined time period to examine projections. While offering the greatest freedom of choice, this approach relies on users having the technical skill to identify and select suitable periods to prevent the misuse of provided information.

CLIPC, the IRI Climate Data Library and PREPdata supply climate datasets each covering a pre-set time period.

With a view to meet decision maker needs, overlapped time intervals that allow projections to be explored in small time steps can provide a large number of selectable future time periods for the user to explore projections.

FIGURE 9 | CLIMATE INFORMATION PORTAL BY CLIMATE PROJECTION TIME PERIOD



Offering a range of temporal averages is another way portals allow users to explore climate projections. Specifically, this enables users to assess seasonal differences in climate change. **Most portals enable the user to view projections with respect to (a range of) temporal averages** (see table 7). Furthermore, portals that do enable the user to view different temporal averages commonly provide the full range: monthly, 3-monthly and 6-monthly averages. Monthly and 3-monthly annual averages are most commonly provided.

TABLE 7 | CLIMATE INFORMATION PORTAL BY TEMPORAL AVERAGES

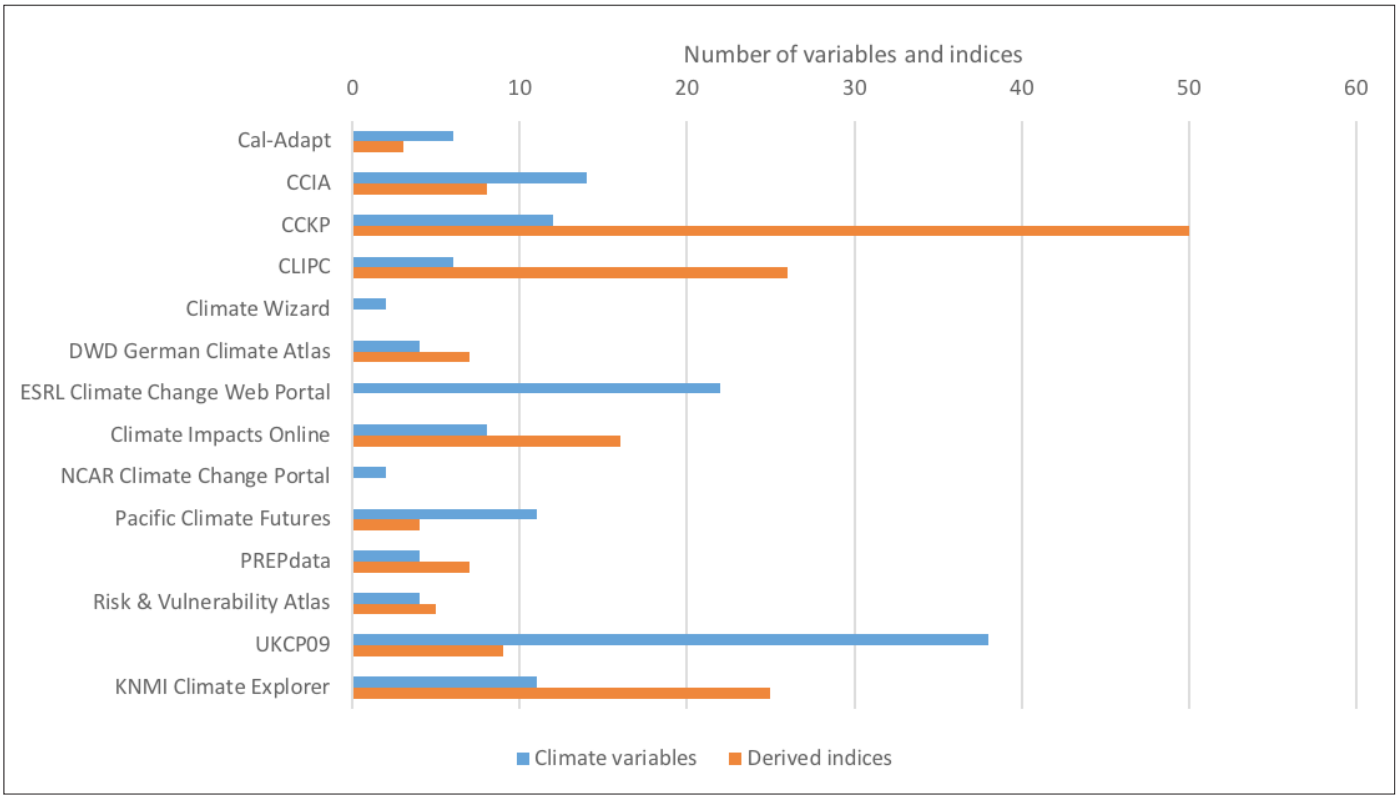
	MONTHLY	3-MONTHLY	6-MONTHLY
Cal-Adapt	X	X	X
CCIA	X	X	X
CCKP	X		
CLIPC		Varies depending on dataset	
Climate Wizard	X	X	X
DWD German Climate Atlas	X	X	X
ESRL Climate Change Portal		X	
Climate Impacts Online		X	
IRI Climate Data Library		Varies depending on dataset	
NCAR Climate Change Portal	X		
Pacific Climate Futures	X	X	X
PREPdata			
Risk & Vulnerability Atlas		Displays historical data only	
UKCP09	X	X	X
KNMI Climate Explorer	X	X	X
Totals	8	8	6

Climate variables and indices

Portals provide a range of climate variables and derived indices to users to explore climatic change. **Nearly all portals provide a selection of climate variables and derived climate indices** (see figure 10). **Most portals tend to provide between 1-20 climate variables while, of those providing derived indices, most give between 1-10.** UKCP09 is an exception which provides 38 climate variables as is the CCKP which provides up to 50 derived indices. The IRI Data Library takes a different approach to other portals and provides thousands of climate variables, indices and other quantities relating to advanced atmospheric, oceanic and biogeochemical processes on a dataset by dataset basis.

Types of climate variable vary across the examined portals and often relates to the pertinence of certain aspects of climate change in each portal's geographic domain. **All portals provide variables relating to temperature (e.g. daily min., mean and max. temperature) and precipitation (e.g. cumulative and/or annual average precipitation) (see table 8). Less than half the portals provide variables relating to oceans, water vapour and radiation, and only a few portals provide variables relating to wind.**

FIGURE 10 | CLIMATE INFORMATION PORTAL BY NUMBER OF CLIMATE VARIABLES AND INDICES



Types of derived climate indices also vary across the examined portals. **Again, most portals provide derived indices relating to temperature (e.g. heating/cooling degree days, summer days, ice days) and precipitation (e.g. wet days, dry spells, 1 in 20-year precipitation event)** (see table 9). **Only a few portals provide ocean- and wind-related indices. No portals provide indices relating to water vapour or radiation.** About half the portals also provide indices relating to climate impacts on socio-economic sectors, exposure and vulnerability. As for climate variables, the types of indices provided also relates to the pertinence of certain aspects of climate change in each portal's geographic domain. For example, Cal-Adapt (California) and CCIA (Australia) provide indices relating to wildfires.

TABLE 8 | CLIMATE INFORMATION PORTAL BY TYPES OF CLIMATE VARIABLE PROVIDED

	TEMPERATURE	PRECIPITATION	OCEANS	WATER VAPOUR	WIND	RADIATION
Cal-Adapt	X	X	X			
CCIA	X	X	X	X	X	X
CCKP	X	X				
CLIPC	X	X	X			
Climate Wizard	X	X				
DWD German Climate Atlas	X	X				
ESRL Climate Change Portal	X	X	X	X	X	X
Climate Impacts Online	X	X				X
NCAR Climate Change Portal	X	X				
Pacific Climate Futures	X	X	X	X	X	X
PREPdata	X	X				
Risk & Vulnerability Atlas	X	X				
UKCP09	X	X	X	X		X
KNMI Climate Explorer	X	X		X		X
Totals	14	14	6	5	3	6

TABLE 9 | CLIMATE INFORMATION PORTAL BY TYPES OF DERIVED INDICES PROVIDED

	TEMPERATURE	PRECIPITATION	OCEANS	WATER VAPOUR	WIND	RADIATION	OTHER
Cal-Adapt	X						Wildfires
CCIA	X	X	X		X		Wildfires
CCKP	X	X			X		Impacts & vulnerability indices
CLIPC	X	X	X				Ecosystem impact indices
Climate Wizard							
DWD German Climate Atlas	X						Sector specific impact indices
ESRL Climate Change Portal							
Climate Impacts Online	X	X					Impact indices
NCAR Climate Change Portal							
Pacific Climate Futures		X			X		
PREPdata	X	X					Impact, exposure & vulnerability indices
Risk & Vulnerability Atlas	X	X					Impact indices
UKCP09	X	X					
KNMI Climate Explorer	X	X					
Totals	10	9	2	0	3	0	8

4. INTERVIEW SERIES

4.1 METHODOLOGY

The Project Team began by conducting a desktop review to identify key points of contact for the selected climate portals. The climate portals selected for an interview were determined through a set of criteria (see p11). Once the key contacts were confirmed, the individuals were then contacted to schedule an interview. Prior to conducting the interviews, the Project Team curated a series of questions focused around the following components:

- Development of the climate change portal
- Barriers to portal implementation
- Evaluation and tracking of the climate data portal
- Next steps for the climate data portal

These questions were then compiled to create a formal interview guide, which was distributed to the interviewees prior to the scheduled interview. The interview process was used to identify the lessons learned from the information they provide, the usefulness of that information, as well as the types of information they intend to provide in the future. To date, a total of seven interviews have been completed, with each interview lasting 45 minutes to one (1) hour.

The following is a high-level synthesis of key findings from the seven interviews that have been conducted to date including PREPdata (United States), Pacific Climate Futures, Climate Change Australia (Australia), Cal-adapt (United States), KNMI Climate Explorer (Netherlands), DWD German Climate Atlas, and the Climate Change Knowledge Portal 2.0 (the World Bank Group). Observed commonalities, differences and preliminary recommendations emanating from these interviews are documented below. Table 10 shows key points from individual interviews, while Appendix 3 provides a sample interview guide.

4.2 COMMONALITIES

- In general, most of the climate portals interviewed to date have been developed through government funding and stakeholder consultations/workshops (except the KNMI Climate Explorer).
    - Interviewees noted that having a government-funded portal allowed them to have a sustainable source of funding rather than relying on multiple agencies for funding sources; a benefit for the development and implementation of the portal
- All portals interviewed had a means of collecting user feedback and have been integrated as part of the portal process.
    - Many of the interviewees identified multiple sources of feedback including built-in feedback mechanisms through the portal (e.g., comment boxes), surveys, webinars, and workshops.

- All interviewees identified the need for better communication with decision-makers and the need to help them interpret the technical data.
- All interviewees identified the need to engage stakeholders from the beginning of the portal development process in order to ensure the portal is successful, and that it is targeted to the stakeholders' needs.
- Most interviewees suggested that there is a need to provide training and outreach to help people understand how to use the portal and build a user base. Providing use-cases and developing guiding documents in plain language are critical.
    - As mentioned by PREPdata, having use cases provides the opportunity for someone to champion the portal and ensure it is useful.
- The interviewees also noted the need for alternative sources to explain the climate information presented on the portal (e.g., the DWD Climate Atlas YouTube video explaining percentile uncertainties).
- Data maintenance has been identified as a challenge given limited staff capacity. Limited analytical capabilities have also been identified as an area of weakness.
    - Many interviewees identified large data sets, limited server capacities, and a lack of cloud-hosting abilities as some of the main issues
- Most interviewees valued the partnerships (internal and external) that were made during the development and implementation of the portal, and stressed the importance of making these partnerships as early as possible in the development of the portal.
- Many interviewees also identified having staff turnover as a challenge for portal implementation and development, as well as internal capacity for specific aspects of the implementation of the portal (e.g., IT), leading to some portals relying on external partners for the development of different aspects of the portal, creating a challenge.

4.3 DIFFERENCES

- Certain interviewees highlighted the importance of communicating the complexity and uncertainties around climate change information for people's understanding.
    - Some of the interviewees noted that if end users are not aware of the uncertainties, it may hinder them from using the portal, however, if there are too many uncertainties and models to choose from, this might also hinder the user from using the portal.
- Cal-adapt suggested that providing information isn't enough, there needs to be a dedicated staff member whom people can call. Additional information is also needed to help people understand how to cope with climate change. They also mentioned that there's a need to work with more on-the-ground stakeholders rather than high-level partnerships to allow for more real users to be involved.
- PREPdata specifically targeted the ease of use, and getting people to play around with the platform to ensure that the portal is easy to navigate.
- DWD Climate Atlas emphasised that they pre-processed all of the IPCC scenario maps which allowed end users to have fast access. They emphasised that it's more important to have fast access to the information rather than having data on the fly.
- KNMI Climate Explorer was developed by a single individual, and did not have any external funding, nor any partners during the process.
- Some of the interviewees noted that it is beneficial to have less information on the page while others believe it is important to have all of the information on one page. While it may be a lot of information, this is the way that the climate information should be presented; and

- Some of the interviewees noted that there is still a wide range of expertise among the users, making it difficult to cater to everyone (i.e., some sectors require specific climate information for their projects which may not be transferrable or useful for another sector)

TABLE 10 | KEY FINDINGS FROM SPECIFIC PORTAL INTERVIEWS

PORTAL	KEY NOTES
PREPdata	• Funding: Portal initially funded by US government, now through multiple sources; no long-term sustainable funding • Intended Users: Resilience planners in government and industry • Consultation and Engagement: • Most Popular Features: The "Data Discovery" tab is the most used part of the platform. Ease of use was specifically targeted; tried to get people to play around with the platform to ensure that the portal was easy to navigate • Feedback, training and User Support: Feedback is provided through the portal, suggested dataset function, webinars and training, partnership networks to review the platform, google analytics, and in-person interviews • Barriers: External developer rather than in-house technology, data maintenance, no analysis option, communicating data to decision-makers • Lessons Learned: Need to provide training, promotion, and partnerships for people to understand how to use the portal and build a user base; use-cases are critical for someone to champion the portal • Future Upgrades: Template dashboards, creating web services for the portal, more learning/ shared knowledge space, providing training on how people can create insights from the data and the dashboards
Pacific Climate Futures	• Funding: Government-funded program but funding did not get extended because of changing political landscape which affected the uptake of the tool • Intended Users: Variable. Anyone can use the basic interface. Training is required for intermediate and advanced levels. Advanced level designed for those conducting climate change risk assessments • Consultation and Engagement: Lots of consultation with key partners but not a co-produced website; they ran workshops when portal was developed and after to get feedback, follow-up surveys but low return rate on evaluation surveys • Most Popular Features: "Projection Builder" is most popular tool • Feedback, training and User Support: User guides and FAQ documents are provided on the site. Online training is available for intermediate level users. In person training is available for Advanced level users. • Barriers: Datasets are too big, maintaining datasets, capacity of service staff, translating climate information, shifting political will • Lessons Learned: Need to put in a lot more effort on guidance materials so you can provide information to people along with guidance on how to use it, provide case studies, be upfront about complexity of climate data. If they were to develop a new portal, they would put in a lot of effort recruiting the right people, more effort on capacity-building, develop communication aids • Future upgrades: Portal developed prior to the Climate Change Australia portal. They plan on leveraging the Climate Change Australia experience back into the Pacific Climate Future portal and developing a new Pacific Climate Futures Portal

Climate Change Australia	• Funding: Also an Australian government-funded program. Climate Change Australia developed shortly after Pacific Climate Futures • Intended Users: Tools were categorised into 3 groups based on complexity and technical expertise or users • Consultation and Engagement: Learned from the Pacific Climate Futures that they needed to get a lot more input from key stakeholders but was not a co-produced website • Most Popular Features: Tool use varies. Most popular is the climate analogues because people relate to it easily as well as the data above and below thresholds. • Feedback, Training and User Support: They're running training courses now and also have a helpdesk; ran workshops when the portal was developed to get evaluations as well as webinars to show users how to use the particular tools. They've also run 2 online surveys but low return rate on the surveys. Need guidance documents with simple language so everyone can access and understand. Provide case studies so that those who want a particular assessment can see how it's been done with the datasets and tools • Barriers: Still a big range of expertise amongst users and a range of different implications of data projections, staff turnover, translating climate information, shifting political will • Lessons Learned: Be upfront about the complexity of climate data, if it's too simplified, the user will have no idea of the complexity, which might hinder them from using the portal. • Future Upgrades: They will leverage the learning from the Pacific Climate Futures back into the Climate Change Australia Portal
Cal-adapt	• Funding: funded by California energy commission (the research fund is generally constrained, they serve rate-payer needs, of natural gas, energy and utilities) but in a piecemeal fashion • Intended Users: Cal-adapt was scoped with 3 user groups in mind – researchers, planners/ decision-makers, general public. Cal-adapt has been relaunched (Cal-adapt 2.0) since it was initially released, and has been used to support California's climate change assessment • Consultation and Engagement: Google was a key partner and provided in-kind support in staff time • Most Popular Features: Most popular tool is the extreme heat tool because people understand it and understand what it feels like. • Feedback, Training and User Support: Stakeholders provided feedback via email on their website, and a user-needs workshop; they will be doing more of this engagement (e.g. through quarterly webinars and newsletters). Need a lot of public engagement to turn Cal-adapt into a planning tool; there is a disconnect between what people think it is and what can actually be done • Barriers: limited server capacity; previously, there was a lack of cloud-hosting abilities; insufficient funds to make it a local planning tool; failure to include subject matter expertise (e.g. meteorology) in funding stream. • Lessons Learned: Need to work with more on-the-ground stakeholders rather than high-level partnerships and have more real users involved. Should have had a dedicated staff for this work; providing information isn't enough, there needs to be someone people can call; having more data products can help meet users' specific needs; do not expect decision-makers to know how to interpret the data, need to help them interpret for decision-making; too much (funding) has gone to the interface, and too little in the analytical possibilities; also need to speed up response times. Need to help people to understand how to cope with climate change – their biggest gap Newsletter and guidance documents should be written in plain language • Future Upgrades: Being able to download data from the chart is now available. Huge plans for the future with 3 new grants in place for development

KNMI Climate Explorer	• Funding: No external funding; it was made for the developer's personal use, mostly for research. Initially developed in 1999 to visualise and report on El Niño; climate change information was added 5 years later. • Intended Users: Personal use by the developer. Does not think that this tool is suitable for decision-makers; intermediaries are needed to handle this technical information. • Consultation and Engagement: None. • Most Popular Features: Features were added because the developer thought it would be useful (e.g. mls instructions); it was an informal process • Feedback, Training and User Support: There is no documentation and was programmed with too much code, which is not maintainable. Feedback can be provided through user surveys; there are hotspots of users – e.g. Kenya, Ethiopia (lots of users). • Barriers: Pulls together data from 72 different servers, but there are often changes in location. • Lessons Learned: Be careful documenting uncertainties and communicating these and what they mean. You really have to know which data you can trust; need to talk to people with the expertise • Future Upgrades: Developer is looking for a new server; the data is getting too large – all data is daily and data sets are grainy; moving everything to the cloud would be ideal but expensive. Seeking to make upgrades to the portal to use more modern technology and make the network faster but will require moving lots of data; to move data faster, there is need for pre-processing of data
DWD German Climate Atlas	• Funding: Germany's MET Service was the sole funder and they used all of the information and projections generated by the MET Service • Intended Users: Public authorities (i.e. federal, regional and municipal levels of government), researchers, general public, etc. Wanted to provide users with information about past, present and future climate and provide visualisations for these. It was also about providing a portal in German so that anyone in Germany would be able to understand the information being presented. • Consultation and Engagement: Only involved federal environmental agencies during the development of the portal. The other users were involved only once the portal was complete. Since they did it all on their own, they're not dependent on other agencies or funding. They had sufficient resources and were able to do most things internally; one of the successes of their portal. • Most Popular Features: • Feedback, training and User Support: Includes different ways of explaining the data (i.e. YouTube video explaining percentile uncertainties, explanations of the maps in German) • Barriers: Processing visualisations on the fly took a lot of time. • Lessons Learned: Pre-process all of the IPCC scenario maps (they produced the background maps offline and then put it on their website to make it run faster). It's better to have fast access (i.e. pre-processed maps) rather than data on the fly • Future Upgrades: Right now, emission scenarios are based on the old SRES scenarios (A1B1). Want to use the new runs based on the RCPs (currently in process and will be updated in the next few months). Would like to add information for more sectors (i.e. urban and spatial planning providing higher resolution data; for climate adaptation and possibly water transportation). Want to link the website directly to their climate data portal. • Lessons learned: involve more core users from the beginning and with the portal development rather than simply at the end. It's important that you have information for the past, present and future climate (although a lot of info on one page). DWD believe this is the right way to present the data

Climate Change Knowledge Portal	• Funding: The portal was funded by the WB (which is a trustee of donors – including Canada). Later on, different countries would request specific data to be added, and would pay for the updates. • Intended Users: The World Bank (WB) was collecting different data from various sources and models to conduct vulnerability assessments, so the WB wanted to develop their own portal to ensure all their projects would be consistent with one another. The focus of the portal was to support WB projects (i.e. provide climate data, climate information, raise awareness, integrate climate information into decision making, demonstrate potential impacts, and to translate complex science for decision makers). • Consultation and Engagement: Many partnerships were created, including universities, research institutes, NGOs, the European Space Agency, NOAA. They used internal expertise to support the translation of data for different sectors. • Most Popular Features: The most successful products from the portal are the climate data (i.e., global projections), the GIS global databases, and the country-specific information (e.g., development statistics, adaptation actions, and climate information). • Feedback, training and User Support: WB receives up to 900 comments on the portal per week, and they do not have a dedicated person to maintain the feedback given – the re-vamp of the new portal (coming in August 2018) will aim to integrate the comments received, to decrease the amount of feedback they receive. Ease of use is very important to the WB, and this is the main reason for the upcoming re-vamp. A lot of the feedback given by users included complaints of not being able to find information easily. They track what users spend the most time on, they track by regions and countries of users, and the WB does informal consultation internally every 6 months to a year. Currently, they don't track sector-specific users, however, they are aiming to improve this. • Barriers: They experienced many challenges, including internal capacity for IT, server capacity, creating a simple interpretation of the data without hindering the uncertainties of the data, funding, and keeping up with the most up to date data (e.g., IPCC reports). • Lessons Learned: Key lessons learned include to have clear questions to answer in your portal, to have specific goals, to have a 5-year plan for future upgrades, to make the data transparent and ensuring that it is easy to understand, and to include guidance on uncertainties, timeframes, ranges of models, and trends. • Future Upgrades: In the future, the portal will have more streamlined downloading, and will include more guidance documents to reduce the number of questions received. This portal has developed over the 8 years of its existence and will be updated again by the end of the summer (2018). The portal is open sources, and has evolved to be a global good. The portal aims to provide more sector-specific data in the future (they have incorporated some sectors already, based on user group feedback).

5. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This report finds that climate information portals take a diverse range of approaches to the provision of climate data. This said, it is possible to identify a broadly typical climate information portal as a visualisation platform providing direct climate model outputs, usually CMIP3 and/or CMIP5 outputs, as well as one downscaled data product also typically derived from CMIP3 or CMIP5 outputs. Maps and timeseries are by far the preferred data visualisation techniques with portals commonly providing data download possibilities. Nearly all portals contain historical and future climate data, but few allow the user to explore historical data in isolation, where historical data is used only as a means to reference future projections. User guidance is predominantly given from a provider perspective with user guides, glossaries, and FAQ sections, readily explaining portal content and operation to the user.

This finding supports those of the existing literature in revealing that portals broadly present similar IPCC-style climate data products: maps and timeseries of end-of-century climate projections. While other portal aspects such as web design and user guidance materials vary significantly, their underlying climate data, their data tools and data visualisations remain broadly similar where further interpretation, analysis and evaluation is largely left to the user to undertake. In terms of providing decision-relevant climate information, most portals can be said to be useful however not as readily usable for decision makers, however, certain specific portals do not follow this trend.

CCIA, Pacific Climate Futures and UKCP09 are more sophisticated decision-support tools for direct use in decision making. These portals have undertaken interpretation, analysis and evaluation to convert direct climate model outputs into application-ready data and products. They present climate data in more sophisticated ways (e.g. multi-variate tabulated model outputs or probabilistic climate projections graphics such as probability density functions and cumulative density functions) which better enable the user to identify ranges and likelihoods of climate projections. By tailoring their data products in this way, they remove the user need for data management, analysis and evaluation; a need which often exists outside the skillset of non-technical users. Similarly, these portals often provide needs-based user guidance materials such as decision-trees, guiding principles and use cases. These guidance products work to foster the appropriate use of their climate data as well, providing overviews of portal content and operation assisting in the selection, interpretation and use of climate information. This report finds these portals are more usable, as opposed to useful, for decision making purposes.

Finally, certain portals exist as climate data libraries. The amount and type of climate data held on these portals far exceeds that of others examined here and covers paleo-climatic, in-situ and satellite observations, reanalysed datasets and climate model outputs typical of other portals. These portals' strengths lie in their abundance of climate data and so, in turn, have the potential to meet wider ranges of decision making needs

in addition to those associated with end-of-century climate modelling projections. However, these portals are very strongly data-oriented and tend to under-supply user guidance materials and web design. Therefore, this report finds these portals highly useful for experienced, technically skilled users which possibly straddle the boundary between decision maker and impact researcher.

RECOMMENDATIONS

Recommendations are grouped into two areas: user needs and communications, and data provision and management.

User needs and Communications

1. Explicitly identify and display the purpose, intended users and intended uses to avoid user confusion and avoid the misuse of climate information from a portal site.

2. Engage with real users to help ensure that the portal meets their needs, is accessible and includes the kinds of analytical capabilities that users are looking for (e.g. downloadable data and dashboards).

3. Use non-technical intuitive web design that is user- rather than data-driven. Many portals are structured around climate data itself and allow users to browse for datasets themselves (i.e. the climate dataset libraries), while the more intuitive user-friendly sites are designed from a user perspective and are structured around the insights that climate data is generating (i.e. the decision-support tool and visualization portals). Web design should minimize the number of clicks needed to access desired information and have a high level of intuitive interactivity e.g. sliders, drop-down menus and selection buttons. Ensure consistency across the portal in terms of: page design; units used for variables; colour-coding; etc.

4. Develop user guidance materials that employ user-appropriate language. This will allow users with varying degrees of expertise to understand portal content and operation. Also ensure user-appropriate labels on all products i.e. graph titles, axis labels, legends, etc.

5. Provide appropriate use guidance materials (e.g. site maps and decision trees to match user needs with suitable portal features, guiding principles on the appropriate use of climate data, use cases to suggest how to use data, FAQs and a glossary). These prevent the misuse of climate information in decision making and help users successfully navigate data options. Decision makers are not data experts and may not have the skill to identify data needs, navigate climate data and use it in appropriate ways unless guided. CCIA (Australia), Pacific Climate Futures and UKCP09 (United Kingdom) are examples of the provision of high quality appropriate use guidance materials. Cal-Adapt use cases are particularly well done and can be found in Appendix 2 of the report.

6. Provide explicit and transparent explanations of any downscaling methodologies that have been used. Downscaled data is still derived from GCM outputs and therefore still has inherent uncertainty associated with it. Rather, it better represents climate changes where local factors (e.g. topography, coastlines etc.) are also accounted for. Many portals do not explicitly highlight this fact. Providing

such higher resolution data risks inferring reduced uncertainty and higher data quality to non-expert data users and, in turn, risks the misuse of climate data.

7. Ensure that a user feedback mechanism is supported and/or built into a climate data portal to have a clear pathway of communication with data users and portal developers.

8. Continual engagement and training is essential to continuously improve the portal by collecting user feedback and helping users understand how to use the portal, its tools and how to interpret the data. Where possible, ensure that there are dedicated staff working a Support Desk for the portal and helping end users.

9. Understand and develop a clear set of questions that the user might ask of the portal. Develop the portal layout and interface in response to these questions, and develop guidance for the user to answer the specific question. This can then be used in the creation of a FAQ page.

Data Provision and Management

10. Consider categorizing the data for different user groups (e.g. creating tiers of information for basic, intermediate and advanced users, specific sectors) to help tailor the information to their specific needs.

11. Consider integrating data that has been endorsed by government or other trusted data sources as the majority of other portals do so.

12. Climate information portals are most effective as decision-support tools, minimizing technical data choice through provision of decision maker-relevant information, presenting climate data aligned with decision maker needs.

13. Avoid an over-abundance of data options that are inappropriate for decision makers. For example, the ability to explore changes in advanced atmospheric, oceanic and biogeochemical quantities, advanced statistical analysis options, freedom to manually change projection reference periods, or freedom to select paleo-climate data may be beyond the technical skills of non-expert users and can lead to confusion.

14. Conversely, providing abundances of appropriate data choices can maximise a portal's ability to meet a range of climate decision maker needs. This can mean provide, for example, numerous derived indices alongside climate variables, the ability to assess seasonality (e.g. monthly, 3-monthly, 6-monthly temporal averages) and the ability to explore projections across numerous 21s^{t} century time periods (e.g. 5- or 10-year time steps).

15. Uncertainty is often presented as singular averages and spreads from multi-model ensembles of direct climate model outputs which do not reveal clustering, spreads and likelihoods of ranges of climate projections. Data visualizations that reveal these aspects can be more useful to decision makers as a tool to inform higher quality climate decisions rather than discouraging action. CCIA, UKCP09 and Pacific Climate Futures provide good examples of how portals can handle uncertainty in sophisticated ways.

16. Portals which include multiple funding streams may be limited in what climate information is provided on the portal. Having a government-funded portal allows for sustained funding and improvement over time.

17. Use a 3, 4, or 5-year plan for future direction of the portal, and constantly update the portal based on the new models/science that emerge with time (e.g., IPCC reports).

6. NETWORK MAP

a	Cal-Adapt	Berkeley CA
b	CCIA	Canberra, AUS
c	CCKP	Washington DC
d	ESRL	Swindon, UK
e	Climate Wizard	Arlington VA
f	DWD German Climate Atlas	Offenbach, GER
g	ESRL	Boulder CO
h	Climate Impacts Online	Potsdam, GER
i	IRI Data Library	New York NY
j	NCAR	Boulder CO
k	Pacific Climate Futures	Canberra, AUS
l	PREPdata	Washington DC
m	SA Risk and Vulnerability Atlas	Cape Town, SA
n	UKCP09	Exeter, UK
o	KNMI Climate Explorer	De Bilt, Netherlands

7. REFERENCES

Bennett V. and Groot A. (2015). *CLIPC: User Expectations.* Swindon, UK: Climate Information Platform for Copernicus. Retrieved from: https://www.ecmwf.int/sites/default/files/elibrary/2015/13521-clipc-user-expectations.pdf. Last accessed: 18th July 2018.
Brasseur G. and Gallardo L. (2016). Climate services: Lessons learned and future prospects. Earth's Future, 4(3), 79-89. https://doi.org/10.1002/2015EF000338

Bureau of Meteorology and CSIRO (2011). *State of the Climate 2010*. Melbourne, VIC, Australia: Bureau of Meteorology. Retrieved from: http://www.bom.gov.au/state-of-the-climate/documents/CSIRO-State-of-Climate-2010.pdf. Last accessed: 18th July 2018.

Bureau of Meteorology and CSIRO (2014). *State of the Climate 2014*. Melbourne, VIC, Australia: Bureau of Meteorology. Retrieved from: http://www.bom.gov.au/state-of-the-climate/documents/state-of-the-climate-2014_low-res.pdf?ref=button. Last accessed: 18th July 2018.

Cal-Adapt (2018). Frequently Asked Questions. Available online at: http://cal-adapt.org/help/faq/. Last accessed: 18th July 2018.

Clarke J., Whetton P. and Hennessy K. (2011). *Providing application-specific climate projections datasets: CSIRO's Climate Futures Framework*. In Chan F., Marinova D. and Anderssen R. (eds.), Proceedings of the 19th International Congress on Modelling and Simulation (MODSIM2011), Perth, Australia. Retrieved from: http://www.mssanz.org.au/modsim2011/F5/clarke.pdf. Last accessed: 18th July 2018.

Climate Services Partnership (2018). What are climate services? Available at: http://www.climate-services.org/about-us/what-are-climate-services/. Last accessed: 18th July 2018.

Groot A., Betgen C., Dubois G., Roth E., Dhenain S., Swart R. and Mañez M. (2015). CLIPC Deliverable (D -N°: 2.2): *User requirements part 2 Climate (impact) data requirements of different user groups.* Swindon, UK: Climate Information Platform for Copernicus. Retrieved from: http://www.clipc.eu/media/clipc/org/documents/deliverables/clipc_deliverable_2.2__final.pdf. Last accessed: 18th July 2018.

Hammill A., Harvey B. and Echeverria D. (2013). *Understanding Needs, Meeting Demands: A user-oriented analysis of online knowledge brokering platforms for climate change and development.* Winnipeg, Canada: International Institute for Sustainable Development. Retrieved from: http://www.iisd.org/pdf/2013/understanding_needs_platforms.pdf. Last accessed: 18th July 2018.

Hansen J., Zebiak S. and Coffey K. (2014). Shaping global agendas on climate risk management and climate services: an IRI perspective. *Earth Perspectives*, 1(13), 1-12. https://doi.org/10.1186/2194-6434-1-13

Hewitson B., Waagsaether K., Wohland J., Kloppers K. and Kara T. (2017). Climate information websites: an evolving landscape. *WIREs Climate Change*, 8, 1-22. https://doi.org/10.1002/wcc.470

Hewitt C., Mason S. and Walland D. (2012). The Global Framework for Climate Services. *Nature Climate Change*, 2, 831-832.

Hoar T. and Nychka D. (2008). *Statistical downscaling of the Community Climate System Model (CCSM) monthly temperature and precipitation projections.* Boudler, CO, USA: National Center for Atmospheric Research. Retrieved from: https://gisclimatechange.ucar.edu/sites/default/files/users/Downscaling.pdf. Last accessed: 18th July 2018.

Houtkamp J., Riviere I., Groot H., Janssen S. and Jong A. (2016). *From Research Data to Web-Based Policy Tools: User-Centered Design Techniques in the Development of the AgMIP Impacts Explorer*. In Sauvage S., Sánchez-Pérez JM. and Rizzoli A. (eds.), Proceedings of the 8th International Congress on Environmental Modelling and Software, Toulouse, France. Retrieved from: http://www.iemss.org/society/index.php/iemss-2016-proceedings. Last accessed: 18th July 2018.

Intergovernmental Panel on Climate Change (2013). *Summary for Policymakers.* In T. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

KNMI Climate Explorer (2018). Starting Point. Available online at: https://climexp.knmi.nl/start.cgi. Last accessed: 18th July 2018.
Lemos M., Kirchhoff C. and Ramprasad V. (2012). Narrowing the climate information usability gap. Nature Climate Change, 2, 789-794. https://doi.org/10.1038/NCLIMATE1614

Mason S., Kruczkiewicz A., Ceccato P. and Crawford A. (2015). *Accessing and using climate data and information in fragile, data-poor states.* Winnipeg, Canada: The International Institute for Sustainable Development. Retrieved from: https://www.iisd.org/sites/default/files/publications/accessing-climate-data-information-fragile-data-poor-states.pdf. Last accessed: 18th July 2018.

Maurer E., Brekke L., Pruitt T. and Duffy P. (2007). Fine-resolution climate projections enhance regional climate change impact studies. *Eos Transactions*, 88(47), 504. https://doi.org/10.1029/2007EO470006

Morand A., Douglas A. and Richard J. (2015). *A Survey of Climate Information Needs Among Users in Ontario, Canada.* Prepared by the Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR) for Environment Canada. Retrieved from: http://www.climateontario.ca/doc/Survey/ClimateInformationNeedsSurveyResults-OCCIAR.pdf. Last accessed: 18th July 2018.

National Center for Atmospheric Research (2018). Climate Change Scenarios: frequently asked questions. Available online at: https://gisclimatechange.ucar.edu/faq. Last accessed: 18th July 2018.

Pierce D., Cayan D. and Thrasher B. (2014). Statistical Downscaling Using Localized Constructed Analogs (LOCA). *Journal of Hydrometeorology*, 15(6), 2558-2585. http://dx.doi.org/10.1175/JHM-D-14-0082.s1

Sigel M., Fischer A., Zubler E. and Liniger M. (2016). *Dissemination of climate change scenarios: a review of existing scenario platforms.* Zurich, Switzerland: Federal Office of Meteorology and Climatology MeteoSwiss. Retrieved from: https://www.meteoschweiz.admin.ch/content/dam/meteoswiss/en/service-und-publikationen/publikationen/doc/TR257_Sigel.pdf. Last accessed: 18th July 2018.

Swart R., de Bruin K., Dhenain S., Dubois G., Groot A. and von der Forst E. (2017). Developing climate information portals with users: Promises and pitfalls. *Climate Services*, 6, 12-22. http://dx.doi.org/10.1016/j.cliser.2017.06.008

UKCP18 (2018). UKCP18 Project Announcement. Available at: http://ukclimateprojections.metoffice.gov.uk/24125. Last accessed: 18th July 2018.

United Nations Framework Convention on Climate Change (2015). *Paris Agreement:* FCCC/CP/2015/L.9/Rev.1. Retrieved from: https://unfccc.int/documentation/documents/advanced_search/items/6911.php?priref¼600008831. Last accessed: 18th July 2018.

Vaughan C. and Dessai S. (2014). Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework. *WIREs Climate Change*, 5(5), 587-603. https://doi.org/10.1002/wcc.290

8. APPENDICES

APPENDIX 1. CLIMATE INFORMATION PORTALS INITIALLY IDENTIFIED IN THE JURISDICTIONAL SCAN (those in bold selected for further analysis)

PORTAL NAME	WEBSITE LINK
APEC Climate Center	https://sso.apcc21.org/
Arctic Climate Research at the University of Illinois	https://thepolarhub.org/resource/arctic-climate-research-university-illinois
AWhere	http://www.awhere.com/
Cal-adapt	http://cal-adapt.org/
Canada Centre for Climate Modelling and Analysis	https://www.canada.ca/en/environment-climate-change/services/climate-change/centre-modelling-analysis.html
Canadian Climate Change Scenarios Network	https://www.ec.gc.ca/sc-cs/default.asp?lang=En&n=FE6B6E6B-1
CCAFS Downscaled GCM Data Portal	https://ccafs.cgiar.org/downscaled-gcm-data-portal#.WqlzzcPwaUk
Centre for Climate Change Research (CCCR)	http://cccr.tropmet.res.in/home/index.jsp
Climate-Adapt	http://climate-adapt.eea.europa.eu/
Climate Change Adaptation in Asia and the Pacific	http://www.asiapacificadapt.net/
Climate Change in Australia	https://www.climatechangeinaustralia.gov.au/en/
Climate Change Knowledge Portal	http://sdwebx.worldbank.org/climateportal/
Climate Change Hazards Information Portal (CCHIP)	http://cchip.ca/
Climate Guide (Finnish Adaptation Platform)	http://ilmasto-opas.fi/en/
Climate Information Portal (CIP)	http://cip.csag.uct.ac.za/webclient2/app/
Climate Information Portal for Copernicus (CLIPC)	http://www.clipc.eu/
Climate Wizard	http://www.climatewizard.org/
Climatic Research Unit	http://www.cru.uea.ac.uk/
CliMond	https://www.climond.org/
CLIMsystems	http://www.climsystems.com/
Copernicus Marine Environment Monitoring System	http://marine.copernicus.eu/
CORDEX East Asia	http://cordex-ea.climate.go.kr/cordex/
Downscaled CMIP3 and CMIP5 Climate and Hydrological Projections Archive	https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html
DWD German Climate Atlas	https://www.dwd.de/EN/ourservices/germanclimateatlas/germanclimateatlas.html
Earth System Grid Federation	https://esgf.llnl.gov/
Earth System Research Laboratory Climate Change Web Portal	https://www.esrl.noaa.gov/psd/ipcc/
EDENext Data Portal	https://www.edenext.eu/data-portal

European Climate Assessment and Data set (ECA&D)	https://www.ecad.eu/
European Space Agency Climate Change Initiative open data portal	http://cci.esa.int/
GERICS	http://www.climate-service-center.de/
Giovanni	https://giovanni.gsfc.nasa.gov/giovanni/
Global Framework for Climate Services	https://www.wmo.int/gfcs/
IPCC Data Distribution Centre	http://www.ipcc-data.org/
IRI/LDEO Climate Data Library	http://iridl.ldeo.columbia.edu/index.html?Set-Language=en
IS ENES Climate4impact Portal	https://climate4impact.eu/impactportal/general/index.jsp
Climate Impacts Online	http://www.climateimpactsonline.com/
Klimaat Portal	https://nl.climate-data.org/location/137520/
Klimatilpasning	http://www.klimatilpasning.dk/
KMNI Data Centre	https://data.knmi.nl/datasets
KNMI Climate Explorer	https://climexp.knmi.nl/start.cgi
Med CORDEX	https://www.medcordex.eu/
NCAR's GIS Program Climate Change Scenarios GIS Data Portal	https://gisclimatechange.ucar.edu/
Nevada Climate Change Portal	http://sensor.nevada.edu/nccp/
NOAA Climate.gov	https://www.climate.gov/
NOAA Geophysical Fluid Dynamics Laboratory (GFDL)	https://www.gfdl.noaa.gov/
Ontario Climate Change Data Portal	http://www.ontarioccdp.ca/
Pacific Climate Futures	https://www.pacificclimatefutures.net/en/
Pacific Climate Impacts Consortium	https://www.pacificclimate.org/
Partnership for Resilience and Preparedness (PREPdata)	https://www.prepdata.org/
Regional Clearinghouse Database	www.clearinghouse.caribbeanclimate.bz
Senorge	http://www.senorge.no/aboutSeNorge.html
South African Risk and Vulnerability Atlas	http://sarva2.dirisa.org/
State Meteorological Agency of Spain	http://www.aemet.es/es/
Global and Regional Adaptation Support Platform (ci-grasp)	http://pik-potsdam.de/cigrasp-2/
The Satellite Application Facility on Climate Monitoring (CM SAF)	http://www.cmsaf.eu/EN/Home/home_node.html
UK Climate Projections 2009	http://ukclimateprojections.metoffice.gov.uk/
USGS Data Portal	https://cida.usgs.gov/gdp/
UNDP Climate Change Country Profiles	http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/
Wisconsin Initiative on Climate Change Impacts	https://www.wicci.wisc.edu/
WoodforTrees.org	http://www.woodfortrees.org/
World Clim	http://worldclim.org/version2
World Meteorological Organisation's World Weather & Climate Extremes Archive	https://wmo.asu.edu/

APPENDIX 2. CAL-ADAPT ADAPTATION INITIATIVE USE CASES

- **California Investor-Owned Utilities** participating in the **U.S. Department of Energy's Resilience Partnership** used Cal-Adapt to support vulnerability assessments:
  - **PG&E:** used Cal-Adapt's extreme heat tool to explore intensity and duration of projected mid-century heat waves.
  - **SoCalEdison:** used Cal-Adapt in conjunction with spatial overlays of infrastructure and as a basis for exploring uncertainty.
  - **SDG&E:** used Cal-Adapt to support a comprehensive GIS-based vulnerability study.
- Moving beyond vulnerability assessments, **California Investor-Owned Utilities** have used Cal-Adapt to support **on-the-ground resilience efforts:**
  - **SDG&E:** Used Cal-Adapt 2.0 to support climate-resilient design of a compressor station in Blythe, California, to investigate implications of climate re: SDG&E's Design Standards, and to explore climate dimensions of system hardening projects.
  - **SoCalEdison (SCE):** Data available on Cal-Adapt 2.0 improved analyses regarding projected climate (e.g., Mesa Substation Project in Monterey Park, California); plans to integrate climate projections into existing planning models.
- **General Planning Guidelines** (2017 update), §65302(g)(4), **direct local governments to Cal-Adapt** as resource to support assessment of climate-related vulnerabilities and development of adaptation policies;
- The Governor's Office of Planning and Research (OPR) is interested in supporting General Planning through custom Cal-Adapt tools designed to fulfil statutory requirements related to climate change adaptation;
- *Planning and Investing for a Resilient California* (January 2018), which provides adaptation guidance from the Technical Advisory Group established by **OPR directs state agencies to Cal-Adapt as a source for peer-reviewed, state-sanctioned data depicting** projected climate risks and for map overlays to facilitate planning and investment;
- In March 2017, the **State Water Resources Control Board (SWRCB)** Approved a Resolution (no. 2017-0012) on "Comprehensive Response to Climate Change" **directing staff to consult "the most current data available through Cal-Adapt";**
- Caltrans' Transportation Adaptation Planning Grant Program, to distribute $20M to local and regional agencies for adaptation planning, points to Cal-Adapt as a tool to support applicants;
- The California Department of Public Health used climate risks portrayed by Cal-Adapt as the foundation of work to "Build Resistance Against Climate Effects" (BRACE) by preparing local and county-level public health departments for projected risks;
- The **California Government Operations Agency** (GovOps) **leveraged Cal-Adapt's publicly available Applications Programming Interface (API)** to develop an automated tool supporting incorporation of adaptation into Sustainability Roadmaps;
- The **United States Forest Service (USFS)** has already used Cal-Adapt for planning at least one **fuel treatment** (Tatham Ridge Project) **with future climate conditions in mind;**
- Cal-Adapt is named as a resource by landmark legislation (SB 379) that requires integration of climate-related risks in local hazard mitigation plans;
- Safeguarding California (2017 update) notes that Cal-Adapt "is at the forefront of resources for specific communities to understand how climate change will raise temperatures and exacerbate extreme heat events, drought, snowpack loss, wildfire, and coastal flooding";
- OPR's Adaptation Clearinghouse (a.k.a. **ICARP**, or Integrated Climate Adaptation and Resiliency Program), development of which was mandated by SB 246, **refers users to Cal-Adapt for exploration of local climate risks** through high resolution climate projections.
- EPC-15-081 used the API thus: *Regarding the Cal-Adapt temperature data, I tried some different things but what has ended up working best with our approach to date is to use the API to pull down the temperature data at the 50 selected "stations" (or whatever set of latitude-longitude coordinates we eventually end up with). These are then saved in a local database, processed and exported to the Sandbox - so we don't do this live and we don't have to do this too often. I think the main reason I ended up with this solution was that it avoided the need to locally process the rather large files. But the flexibility of the API seems really nice - this approach has worked out well so far.*

APPENDIX 3. SAMPLE INTERVIEW QUESTIONS

Interviewee:
Date:

Lead-in and Icebreaker

Question 1: Can you describe the over-arching context under which the climate data portal was created? What was the purpose of its creation? *For example, specific purposes could include: (1) to create awareness only, (2) to develop and test climate models, (3) to support the development of climate adaptation strategies, (4) to provide data to a particular type of user, (5) for commercial purposes.*

Portal Development

Question 2: Were specific user groups identified in the development process? If so, how involved were they in the tailoring and/or development of the portal? *For example, a user could be from a different country but collaborating through data transfer or multi-governmental initiatives (such as in Europe). Potential user groups: academic researchers, boundary organisations (intermediaries), practitioners and decision-makers, climate scientists, etc.*

Question 3: During the development of your climate portal, were you able to establish partnerships externally or internally? Based on your lessons learned from partnerships, if you had to create another portal, what would you do differently?

Question 4: Can you please describe how the portal was funded? Did it require contributions from multiple organisations/governments or was it led by one particular agency?

Barriers to Implementation

Question 5: What were some of the barriers to the climate data portal being implemented? Specifically, what were those more technical and those non-technical?

Question 6: What factors existed to facilitate portal implementation? In other words, if you had to do it again and "re-produce" the portal from the start, what would you recommend should be in place to facilitate implementation?

Evaluation and Tracking

Question 7: Have you carried out any evaluations of the climate data portal? If so, how were they undertaken and what sort of information did you learn from the evaluations? *A few examples could include: (1) Survey format, (2) asking users in a workshop, (3) contracted services or hiring an external organisation to obtain feedback, (4) Built-in feedback mechanism into the portal directly.*

Question 8: Were specific metrics identified for use of tracking portal utility and success? If so, what are some specific examples of these metrics created? *A metric could be broad or specific, as long as it ties directly to demonstrating the utility of the data portal. For instance, a metric could be: (1) No. of data downloads by unique portal visitors, (2) No. of unique users of the portal, (3) No. of sectors represented by portal users, etc.*

Question 9: What types of climate data products have been most successful in your portal? Have these been tailored specifically to particular types of users and/or sectors?

Question 10: How effective was the display, layout and set-up of the data portal for end users? In your evaluations, was "ease of use" flagged as an important piece for end users?

Next Steps

Question 11: Do future upgrades or improvement plans exist for the data portal? If so, can you describe what these look like in more detail?

Question 12: From your perspective, what are some key lessons learned from the production, operation and maintenance of the data portal? *For example, a lesson learned could be that fewer data products may be more valuable and easier for decision makers to understand and thus should be provided as a starting point when the data portal is produced, and only expanded once these initial products are considered complete and in good shape. Another lesson learned could focus on how the data portal is laid out – did the design initially implemented work for types of users targeted?*

Question 13: What are your preferred, suggested or recommended methods of translating complex climate data for decision-makers?

APPENDIX 4. COMPARISON OF PORTAL STRENGTHS AND POTENTIAL IMPROVEMENTS

Climate Change in Australia

Strength- Comprehensiveness: CCIA is one of the most comprehensive portals examined. It includes information on observed and future climate change, general climate change topics, impacts and adaptation and provides raw data for download. Additionally, CCIA (like Pacific Climate Futures and UKCP09) based on extensive background reports that contain all of the information presented on the portal. CCIA therefore provides a wealth of climate information on a range of topics to meet user needs.

Strength- Extensive user guidance materials: CCIA provides one of the most extensive portfolios of user guidance materials across the 15 portals examined here. Rather than provide a central user guide, CCIA places walkthrough and explanatory text across its data tools and outputs to train users. Key terms within these are useful highlighted to enable users to quickly reach desired content. The portal features a "Climate Campus" providing some of the most extensive information on general climate change topics from across all 15 portals. For more advanced users, the "Publication Library" is available to access technically detailed information on the portal's climate data. The portal also features expansive FAQ and glossary section. These together provide a wealth of guidance materials to the user.

Strength- Appropriate use guidance materials: CCIA provides multiple needs-based guidance resources which help users appropriately use the portal's data tools and outputs. CCIA employs a decision tree (like UKCP09) and a tool rating system (like Pacific Climate Futures) to help direct users to information suitable for their needs. CCIA also contains extensive guiding principles on the use of its climate data as well as a pop-up disclaimer and other cautionary notes to educate users on the appropriate use of climate information. These features ensure that users needs are answered using appropriate pieces of climate data from the portal and, in turn, helps prevents data misuse.

Strength- Application-ready data and outputs: CCIA focuses on providing application-ready data and outputs an achieves this is a number of ways. Firstly, the portal employs a model evaluation process on CMIP5 models to identify a sub-set of 8 models (and their outputs) deemed to perform well over Australia. Secondly, direct climate model outputs are tailored and presented as multi-variate tabulated model outputs in line with users' definition of "best" and "worst" cases for the system they are studying impacts for. Then, a representative model wizard selects models (and their outputs) that best represent such changes. This reduces user effort and ensures underlying data is suitable for decision making purposes.

Strength- Handling of uncertainty: Multi-variate tabulated model outputs handle uncertainty in a sophisticated way. Using a colour-coded matrix to display the degree of model agreement and the extent of climate change in the underlying projections in a table enables the users to more effectively grasp the spread, clustering and likelihood of climate projections. This type of data visualisation can better reveal ranges of projections compared to multi-model ensembles displayed as singular averages and spreads.

Potential Improvement - Website Clarity: Does not utilise a prominent visualisation interface like many other portals. Instead, the portal walks users through various parameter selections to compute and display outputs. This approach increases the reliance on less intuitive and less aesthetic explanatory text. CCIA is also information-rich with useful climate information distributed across many website sections. This can reduce website clarity, especially to casual, time-limited and/or novice portal users. Extensive user guidance does work to mitigate against this to some degree however.

UK Climate Projections 2009

Strength- Application-ready data: UKCP09 provides tailored application-ready data (similar to CCIA and Pacific Climate Futures). Probabilistic climate change projections convey climate futures in terms of the likelihood of occurrence as opposed to displaying direct climate model outputs. Likelihood of occurrence can better align with decision maker problem framings and encourage a consideration of ranges of possible climate futures. Other portals tend to display direct climate model outputs with the ranges of climate projections reduced to singular ensemble averages and spreads. Additionally, the various outputs of the User Interface are publication-ready and can be easily exported for use.

Strength - Appropriate use guidance materials: UKCP09 features a site map and decision tree which work to match user needs with suitable portal features. Guiding principles, which UKCP09 recommends the user reads first, also educate the user on how it's information can, should and should not be used in climate decision making processes. These features are also prominently positioned on the portal site. In this way, the appropriate use of UKCP09's climate data in decision making processes is a central theme.

Strength - Handling of uncertainty: UKCP09 employs one of the most sophisticated handlings of uncertainty from all 15 portals examined here. In UKCP09, probability is a measure of the degree to which a particular climate projection is consistent with the information used in the analysis. Quantifying uncertainty in terms of probability (i.e. likelihood of occurrence) enables users to better identify (and plan for) ranges of climate outcomes in a way that is more obscure when presenting direct climate model outputs. This also enables users to identify the actual plausibility of climate projections. Furthermore, users can explore climatic changes at user-specified probability levels (e.g. 50% probability of occurrence) and the probability levels of user-specified thresholds of climatic change (e.g. 2°C warming). This handling of uncertainty can align more directly with decision maker problem framings and needs.
Strength - Extensive user guidance materials: UKCP09 provides extensive user guidance and includes a user guide, an extensive interactive glossary (with definitions appearing as the user hovers their cursor over them), an FAQ section, educational pieces on general climate change topics and 7 interactive online training modules on climate change in general and portal content and operation. Contact details are also provided for specific user enquiries. In a similar manner to CCIA, UKCP09 provides some of most comprehensive user guidance portfolios among the 15 portals examined here.

Potential Improvement - Website clarity: UKCP09's User Interface tool walks users through parameter selection screens to produce outputs. This approach is more text-heavy and less aesthetic than those portals that use large visualisation interfaces to display climate projections. This can mean immediate clarity and ease of use is reduced; especially for first-time users. Nevertheless, the extensive user guidance portfolio of this portal does work to maintain some, albeit less immediate, clarity.

Pacific Climate Futures

Strength - Application-ready data and outputs: Pacific Climate Futures is grounded in an extensive climate model evaluation that has evaluated GCM outputs and downscaled projections for performance over the Pacific region. Additionally, the Pacific Climate Futures tool employs a "representative model wizard". This feature selects climate projections that best represent the climate changes of interest to the user. In turn, plausible climate projections are given as opposed to also displaying outputs from models that do not perform well under the parameters selected. This reduces the user effort required for data management, selection and analysis and ensures users deal with application-ready data only.

Strength - Appropriate use guidance materials: Pacific Climate Futures features a tool rating system (like CCIA) which differentiates its tools for different skill levels (basic, intermediate and advanced) recommends users undertake training to access more complex tools. Employing this system effectively guides heterogeneous users to suitable portal content and mitigates against the misuse of climate information. Pacific Climate Futures also features guiding principles and cautionary notes on the use of its climate data (similar to CCIA). These features work to ensure that users extract climate data that is appropriate for their needs.

Strength - High temporal resolutions: For CMIP5 projections, Pacific Climate Futures uses a 10-year overlapping time interval to compute and present its climate projections data. This enables projections to be explored in 5-year time steps; the finest time step across all 15 portals. Furthermore, projections can be explored in terms of monthly, 3-monthly, 6-monthly and annual averages enabling the user to assess seasonality with much freedom.

Strength - Handling of uncertainty: Pacific Climate Futures uses multi-variate tabulated model outputs to visualise its climate projections data. These emphasise the degree of model agreement and likelihood across the multi-model ensemble for ranges of climate change. This is achieved via a colour-coded matrix that reflects the number and percentage of models in agreement. Rather than reducing the multi-model ensemble to a singular average and spread, the tabulated outputs enable the user to better assess the range and plausibility of certain projections as a means to navigate uncertainty.

Potential Improvement - Website clarity: Pacific Climate Futures does not utilise a prominent visualisation interface like many other portals. Instead, the Climate Futures tool walks users through various parameter selections to compute and display outputs. This approach increases the reliance on less intuitive and less aesthetic explanatory text. This can reduce website clarity, especially to casual, time-limited and/or novice portal users. User guidance does work to mitigate against this to some degree however.

Cal-Adapt

Strength - Intuitive web design: Cal-Adapt employs effective data tool design. The use of interactive sliders, large parameter selection buttons, high resolution outputs and highlighted call-out boxes effectively summarise its visualised data. More generally, the portal features the consistent and aesthetic positioning and formatting of portal elements. In turn, Cal-Adapt supports intuitive use and so assists users to find suitable climate information for their needs. This also decreases the need for overly extensive user guidance materials.

Strength - Model evaluation process: Cal-Adapt is based an extensive model evaluation which identified 10 CMIP5 models with high performance over the State of California. This reduces the user need for data management and reduces uncertainty by removing outputs from poorly performing models. In this way, Cal-Adapt reduces the data choices to provide more application-ready data and, in turn, supports the use of decision-relevant climate data.

Strength – Highly interactive: Cal-Adapt features highly interactive map and timeseries viewers. These tools feature, for example, interactive calendars to select temporal averages of interest, an interactive map to select geographic locations of interest and employ sliders to allow users to freely select time periods of interest. These enable climate projections data to be explored with greater freedom compared to other portals that often favour pre-defined options in these areas.

Potential Improvement - Lack of appropriate use guidance materials: Cal-Adapt features an FAQ section as its main form of user guidance which covers portal content, operation, wider climate change topics and explains key terms. However, more advanced user guidance on the appropriate use of climate data is largely absent beyond high-level statements. By not providing this form of guidance, Cal-Adapt relies on the user's abilities with handling climate data to ensure appropriate use. This represents a gap in provision.

PREPdata

Strength - User feedback mechanism: PREPdata employs a user feedback mechanism to open up provider-user dialogue. This feature acts like a discussion forum in which users can submit requests for new types of climate data, suggest datasets of their own for inclusion, highlight portal bugs and fixes and so on. PREPdata and users can then interact with each other on posts to open further discussion and/or provide updates on progress. This helps with the user-driven needs-based curation of climate datasets and other information (e.g. background resources) to ensure user needs continue to be satisfied. More generally, PREPdata (along with Cal-Adapt) as one of the more public facing portals examined here. It also encourages social media sharing and for users to get in touch with the portal developers to a greater extent than the majority of other portals.

Strength - Website clarity: PREPdata features some of the most aesthetic and easy to use design elements across all 15 portals; reflecting its recent launch. The use of a large high resolution map viewer provides clarity for users exploring datasets. Furthermore, the consistent and strategic use of an orange, blue and white colour scheme, text sizes, fonts and formats and other features work to increase website clarity and ease of use.

Strength - Dashboard tool: PREPdata provides a unique feature: a dashboard tool (see table below). This tool allows users to synthesise climate information (e.g. text, tables, charts, images and other elements) into personalised dashboards for a given geography or topic of interest. The dashboard resource bank serves to showcase climate preparedness activities in other communities as well as act as a collection of use cases on how users can create dashboards.

Strength - Provision of metadata: PREPdata provides dataset-specific metadata on each dataset in its library. Metadata is accessible from within the map viewer interface as the user selects datasets of interest. Metadata comprises a short yet information-rich text-based abstract detailing key characteristics as well as data provenance and links to external download locations. This style of provision is similar to the effective metadata provision of the CCKP, CLIPC and the South African Risk and Vulnerability Atlas.

Strength - Multiple data sources: Many portals are data visualisation platforms for climate data from single research programs and/or data is acquired from single sources; typically CMIP3/5 archives. PREPdata, as an institutional partnership and climate data library, is free to provide data from multiple sources. PREPdata also provides downscaled climate datasets from more than one source and which use more than one downscaling method. This is a common gap in provision on other portals.

Potential Improvement - Handling of uncertainty: PREPdata presents uncertainty in terms of the ensemble mean and spread (25^{th} and 75^{th} percentiles) in timeseries form. No additional educational materials on the concepts are provided. Accessing PREPdata's timeseries can be a challenge for the user as they are not displayed or accessible from the main map viewer and are instead displayed when the user selects to further explore an individual dataset meaning the portal's uncertainty information is considerably hidden in overall portal architecture. This inaccessibility can be problematic for the users seeking such information and further problematic for inexperienced users who may be unware of the importance of uncertainty information.

Climate Change Knowledge Portal

Strength - Geographical data coverage: The CCKP provides climate data at international, regional and national scales where the majority of other portals usually take a narrower geographic domain. This can obviously increase usefulness to a wider range of users. Strength - Large number of variables and derived indices: The CCKP features 12 climate variables and 50 derived indices. This portal provides the highest number of derived indices across all 15 portals examined here. Supplying large numbers of derived indices can increase the usefulness of portals for decision makers.

Strength - Intuitive design: The CCKP is structured by geographic location and uses a selection cascade from global to regional and then national areas of interest. The map interface itself is also prominently positioned and accessible on the portal's main landing page over auxiliary features. This structure can clearly guide users to relevant climate information. The portal also features the intuitive and consistent use of similar page layouts, fonts, sizes and headings to foster clarity.

Strength – Metadata: The CCKP effective and highly comprehensive metadata compared to most other examined portals. The map interface features a clear "Show Metadata", "Show Source", and "Show Data Description" buttons which enable the efficient retrieval of dataset-specific metadata. Furthermore, a full list of metadata is provided in a dedicated "Metadata of the CCKP" guide. No other portal provides a dedicated metadata guide.

Potential Improvement - Appropriate use guidance material: A user guide, site map and interactive guidance button on the map interface guide users on portal content and operation. However, the CCKP provides limited guidance materials relating to the appropriate use of its climate information. In turn, the portal relies on the technical skills of the user to know their data needs and successfully identify relevant data and use it appropriately.

Potential Improvement - Handling of uncertainty: The CCKP conveys uncertainty using ensemble averages and spreads that are visualised in the map interface when using non-downscaled projections data. When viewing downscaled data, only individual model outputs are displayed with no ensemble averages or spreads given. No auxiliary information, such as general guidance on the concept of uncertainty, are provided.

Climate Impacts Online

Strength - Transparency of downscaling methods: Climate Impacts Online features clear and relatively non-technical explanations of the downscaling methods used to create its climate data by detailing the model chain linkages between direct GCM output and forcing of the STARS impact model. Explicitly communicating downscaling methods in this manner can help guide users on how, and how not to, use such climate data in decision making processes. This is gap in provision across some other portals.

Strength - Website clarity: Climate Impacts Online features an interactive map viewer as its main landing page. From here, the majority of portal features (e.g. climatic observations, projections, parameters selections and so on) are easily accessible in a centrally location on the portal. This design is intuitive and reduces user click counts and the need for extensive user guidance. Additionally, the

map viewer is very large and uses relatively fine display resolutions which aids visual interpretation of its climate projections. A consistent red-black colour palette and other formatting creates visual consistency. Together these characteristics foster clarity and ease of use.

Potential Improvement - Limited appropriate use guidance: Climate Impacts Online provides climate information with a view to inform specific adaptation options in sectors. However, it provides little explicit guidance as to how its data can be incorporated into such decision making processes or how to do so in appropriate ways (e.g. via guiding principles or decision trees). Therefore, the portal relies on user skill to recognise where data can be appropriately incorporated.

Climate Information Portal for Copernicus

Strength - Extent of climate data: CLIPC provides up to 493 datasets covering a range of data types and verified sources. This is considerable more datasets than the majority of portals examined here and helps the portal meet an expanded range of user needs.

Strength - Handling of uncertainty: CLIPC, where possible, accompanies each dataset with an expert-based assessment of uncertainty and confidence. This visually conveys confidences level to the user by way of a colour-gradient spectrum from low to high. Specific sources of uncertainty are also identified helping the user differentiate between uncertainty due to incomplete knowledge, unpredictability and stochasticity. This represents a sophisticated presentation of uncertainty compared to graphical presentations of multi-model ensemble averages and spreads.

Strength - Glossary section (user guidance): CLIPC features a high quality and extensive glossary section to guide users on technical terminology and abbreviations. The user can usefully hover their cursor over terms to more quickly reveal definitions. Additionally, three pre-existing glossaries (from the IPCC Data Distribution Centre and EUPHORIAS and Climate4Impact projects) are synthesised into one. This helps create consistency with other climate information sources.

Potential Improvement - Website clarity: CLIPC's data tools feature high levels of scientific jargon, unit symbols and abbreviations. For example, the map viewer lists datasets in original scientific-format (e.g. "TXx MON EURO4M MESANv1 EUR-11 1989-2010") and so use extensive scientific abbreviation and numbering that relate to underlying modelling processes. Similarly, timeseries outputs in the map viewer also feature scientific modelling abbreviations and unit symbols. A number of functional issues also exist such as colour legends not appearing automatically when data is visualised, units appearing absent or inconsistent (e.g. temperature datasets displaying ˚C or K). These features work to reduce website clarity for non-technical, and especially first-time, users which can disincentivise portal use.

Potential Improvement – Metadata: CLIPC provides broad metadata descriptions its main landing pages and dataset-specific metadata descriptions are available as the user selects them within the map viewer. However, metadata features high amounts of technical jargon, scientific abbreviations and symbols and generally appears to provide information more suited to technically adept researchers than less specialist decision makers.

Potential Improvement - Appropriate use guidance: CLIPC features user guidance materials that mainly focus on portal content and operation (e.g. video tutorials on data tools). However, CLIPC does not engage with the appropriate use of its climate data and, through a lack of appropriate use guidance materials, maintains that it is the user's responsibility to select and use suitable data.

NCAR GIS Program Climate Change Scenarios GIS Data Portal

Strength - Visually comprehensive data tool: The NCAR Climate Change Portal's map viewer presents an interactive map, timeseries and annual cycle graphs of climate projections data in a single centrally located interface on the portal website. This data tool is information-rich and features intuitively positioned parameter dropdown menus (with guidance buttons). This enables al of the portal's climate data to be accessed from one data tool which aids ease of use.

Potential Improvement - Small extent of climate information: The NCAR Climate Change Web Portal provide outputs from a single GCM: the CCSM-4 (part of the CMIP5 archive). Additionally, 2 climate variables are provided and 9like Climate Wizard)

downscaled data covers the contiguous USA only. Providing a reduced amount of climate data means a reduced range of informational needs can be met compare to other portals. This risks redundancy.

DWD German Climate Atlas

Strength - Visually comprehensive data tool: The DWD German Climate Atlas' Atlas tool is an information-rich data visualisation tool. Maps and timeseries of both historical observations, climate normals (reference periods) and future projections are all visualised at once. Further still, projections are broken down into percentiles (15th, 50th and 85th) and are viewable as absolute values or relative changes and under a variety of annual averages. This effectively presents large quantities of climate information using a consistent visualisation platform and assists users with comparisons across different climate projections and to historical observations.

Potential Improvement - Inconsistencies: The DWD German Climate Atlas contains a number of functional issues constrain ease of use. The Atlas, although under construction at the time of writing, contains a lack of maps and timeseries for RCP projections. This a significant gap in content meaning only changes under the A1B scenario are presented. Additionally, K is the unit used for its maps of climate normals and future projections while ˚C is the unit used for its timeseries. Inconsistencies such as these can cause user frustration and reduce the efficiency with which users can acquire meaningful insights.

Potential Improvement - Limited user guidance materials: Outside of this portal's data visualisation little additional content is provided. A small "Explanations" section serves the portal's user guidance function. It provides text-heavy guidance on portal content and operation. Guidance buttons distributed across The Atlas tool interface do usefully link to the user guide area. However, no other forms of user guidance such as use cases, FAQs, a glossary for technical terms or others are provided.

Potential Improvement - Lack of problem identification: Linked to its lack of user guidance materials, this portal does not state its purpose, intended use or intended users, which most other portals do (e.g. using text on their main landing page). This means it is down to user effort/skill to identify if the portal is appropriate for use. This can create user frustration and confusion and can disincentivise use in favour of those that more clearly identify purpose, intended users and uses.

Climate Wizard

Strength - Appropriate use guidance: Climate Wizard provides a series of guiding principles on the appropriate use of climate projections data (i.e. "Use and misuse of Climate Wizard" section) that, for example, remind users that areas of severe model disagreement should not be for climate-related decision making. Such expert-based recommendations help to assist non-specialist users as to the appropriate use of Climate Wizard's climate data.

Strength - Transparency over downscaling methods: Within this section on appropriate use, the downscaling methodology employed is also described. Moreover, this section explicitly highlights that while actual climatic changes for smaller geographic areas (in this case the contiguous USA) are better represented, they are still based on coarse-scale GCM processes. Again, this fosters the appropriate use of climate data.

Potential Improvement - Extent of downscaled climate information: Relative to Climate Wizard's non-downscaled data which has global coverage, downscaled model outputs only cover the contiguous USA. Climate Wizard was one of the first portals of its kind to be launched but, nevertheless as a global portal, the small extent of its downscaled projections makes it somewhat redundant to other sources that now provide more expansive downscaled data products.

Potential Improvement - Lack of climate variables and indices: Climate Wizard only provides climate projections with respect to 2 variables: average annual temperature and precipitation with no derived indices. Again this relates to the portal's age compared to newer platforms, but nevertheless makes it more redundant for decision makers given other portals provide more expansive selections.

IRI/LDEO Climate Data Library

Strength - Wealth of climate data: The IRI Data Library contains a wealth of climate data from paleo-climatic, in-situ and satellite observations, reanalysed datasets and climate model outputs plus others. This represents a more expansive variety of climate data compared to most other portals that typically provide direct climate model outputs only. This can increase portal usefulness for a wider range decision making challenges.

Strength - Seasonal climate forecast tool: The IRI Data Library provides a seasonal climate forecast tool. This generates short-term climate projections over 3-month and 6-month periods based on a probabilistic assessment of historical climatology at different locations globally. Across all 15 portals, only the IRI Data Library and the KNMI Climate Explorer provide such a tool that aims to short-term climate decision making needs. This represents a significant gap in provision.

Potential Improvement - Very high technical skill: The IRI Data Library targets users of higher technical skill than the majority of other portals. The acquisition of specific datasets of interest, via searching by distinguishing features, and the ability to statistically analyse them, via applying advanced statistical functions, are the primary features of this portal. This contrasts others that tend to favour the visualisation of climate data. This approach requires very high technical skill from the user. Furthermore, supplying such a wealth of climate data can be advantageous. However, in the face of highly technical user guidance materials, this relies on the user's skill at browsing, selecting and analyzing datasets appropriately. This may have less usefulness for non-technical users from decision making contexts.

Potential Improvement - Website clarity: The IRI Data Library features technically advanced dataset-specific metadata however does not provide summary metadata on the overall data composition of the portal. Furthermore, datasets are presented in terms of distinguishing characteristics (e.g. data source, type, institution etc.); characteristics which often relate to technically advanced properties. A needs-based presentation of data is not a strong focus. This can reduce website clarity for non-technical, inexperienced and/or first-time portal users.

Potential Improvement - Technically advanced user guidance materials: The IRI Data Library provides a series user guidance material (e.g. tutorial sections (and videos), glossary, FAQ section). These guidance pieces appear to target users with very high technical skill as they overlook many specialist climate science concepts and terms that other portals choose to explain. They themselves also feature extensive scientific terminology, abbreviations and so on. A limited amount of very technically advanced user guidance materials are provided relative to other portals.

KNMI Climate Explorer

Strength - Climate data variety: The KNMI Climate Explorer provides 10 climate datasets covering CMIP3 and CMIP5 outputs, downscaled CORDEX outputs and a range of in-situ and reanalysed observational datasets. A seasonal forecast tool (like that of the IRI Data Library) also provides short-term climate projections. The provision of such a range of climate information can allow a wider range of user needs to be met. Most other portals tend towards the provision of long term climate projections data (typically CMIP3/5 outputs).

Potential Improvement - Technical user guidance: The KNMI Climate Explorer provides some data-oriented user guidance materials but also emphasises its intended use as a scientific tool for climate analysis whereby users should verify themselves that selected data is suitable for their purposes. In turn, user guidance materials themselves assumes a high level of technical skill and are strongly data-oriented.

Potential Improvement - Website clarity: The KNMI Climate Explorer features scientific-format maps and timeseries that use many conventions of the climate science research community in their figure titles, captions, labels and so on. These are characterised by technical jargon, scientific abbreviations and symbols. These characteristics, with are not accompanied by user guidance material, can be unclear to non-technical or inexperienced users.

Potential Improvement - High technical skill: The KNMI Climate Explorer provides a high level of data choice and enables advanced parameter selections (e.g. free choice of reference period, advanced statistics). Other portals often favour more restricted pre-defined sets of parameter options. Such freedom of choice can serve technically experienced and/or specialist data users well. Meanwhile, it can cause confusion for non-specialist data users (possibly from decision making contexts).

ESRL Climate Change Web Portal

Strength - Website clarity: The ESRL Climate Change Web Portal uses a small number of webpages to display the majority of its content. "Land and Rivers" and "Oceans and Marine Ecosystems" portals, and their respective map and timeseries viewers can be easily switched between. The data visualisation interface itself also uses a consistent (albeit scientific) design format in terms of maps, titles, axes, legends and so on. Intuitively placed parameter dropdown menus coupled with guidance buttons that are in close proximity to the data viewer provide further clarity.

Potential Improvement - No derived indices: The ESRL Climate Change Portal provides no derived indices while providing an abundance of advanced climate variables that relate to complex atmospheric, oceanic and biogeochemical processes. These mix can be less useful for users seeking to incorporate climate data into decision making processes.

Potential Improvement - Scientific format of outputs: The ESRL Climate Change Portal features data visualisations that remain in scientific format; using titles, axes labels, unit symbols and other technical jargon similar to data presentations from the academic literature. Given the portal does not provide accompanying user guidance, these features can be confusing for non-technical or inexperienced users.

Potential Improvement - Transparency over downscaling methods:** The portal uses interpolation to project direct GCM outputs over a 1 degree by 1 degree grid (approximately 100km2). This process smooths coarse-scale GCM data for display purposes only. Importantly, downscaling methodologies are not used. However, this is not reported on the portal site. This risks inferring higher scientific quality in its underlying data and, in turn, data misuse (especially concerning casual, time-limited and/or inexperienced data users).

Potential Improvement - Very limited user guidance: The ESRL Climate Change Portal provides very limited user guidance. A "Quick Intro" section for each data too (structured as a slideshow) serves as the portal's user guide and focuses primarily on the portal's data content. High levels of technical jargon, scientific abbreviations and symbols are used here. Guidance buttons coupled to the visualisation interface's parameter dropdown menus provide guidance over the options available. However, beyond these two forms no other user guidance is provided such as a glossary of technical terms or an FAQ section. These would otherwise significantly reduce the barrier posed by the portal's scientific format.

South African Risk and Vulnerability Atlas

Strength – Metadata: The Risk and Vulnerability Atlas provides metadata with respect to each (observational) dataset (i.e. dataset-specific metadata). Metadata comprises information-rich short text-based abstracts detailing key characteristics, data provenance and data download links.

Potential Improvement - Lack of future climate projections data: The Risk and Vulnerability Atlas contains a selection of 15 observational climate datasets over South Africa covering 4 climate variables and 5 derived indices on temperature and precipitation changes. This is the only portal not to provide climate projections data Functionality is further restricted by the map viewer, the portal's single data tool, and the reduced number of variables and indices compared to some other portals. In short, a restricted range of user needs can be met which makes it somewhat redundant to other portals examined here.

Potential Improvement - User guidance materials: The Risk and Vulnerability Atlas contains the least user guidance information across any of the 15 portals examined here. Portal contact information for specific user enquiries is the only guidance option available. This gap in provision to some degree reflects the portal's limited amount of climate data and restricted functionality.

Potential Improvement - Website clarity: The Risk and Vulnerability Atlas contains a number of functional issues which constrain ease of use. For example, in the map viewer, titles, captions, labels and unit symbols are missing which limits the ability of the user to successfully interpret visualised information. These issues are confounded by a general lack of explanatory text across the portal's pages which on other portals are useful in explaining content, function and purpose to the user.