



Climate information websites: an evolving landscape

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The climate change agenda is populated by actors and agencies with different objectives, values, and motivations, yet many seek decision scale climate information to inform policy and adaptation responses. A central element of this network of activity is the climate information website (CIW) that has seen a rapid and organic growth, yet with variable content and quality, and unfettered by any code of practice. This builds an ethical–epistemic dilemma that warrants assessment as the presence of CIWs contribute to real-world consequences and commitment. This study considers the context of CIW growth, and reviews a representative sample of CIWs to draw out key issues for consideration in CIW development. We assess content, function, and use-case value through a dual approach of a typology and user experience narratives to evaluate the general efficacy of a CIW. The typology reveals strong contrasts in content, complicated interfaces, and an overload of choice making it difficult to converge on a stable outcome. The narratives capture user experience and highlight barriers that include navigation difficulties, jargon laden content, minimal or opaque guidance, and inferred information without context about uncertainty and limits to skill. This illuminates four concerns: (1) the ethics of information provision in a context of real-world consequences; (2) interfaces that present barriers to achieving robust solutions; (3) weak capacity of both users and providers to identify information of value from the multimodel and multimethod data; and (4) inclusion of data that infer skill. Nonetheless, results provide a positive indication of a community of practice that is still maturing. © 2017 The Authors. *WIREs Climate Change* published by Wiley Periodicals, Inc.

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INTRODUCTION

The availability of climate information websites (CIWs) has expanded rapidly as global awareness of systemic climate risks is mainstreamed into decision- and policy-making. The 2015 agreement of the 21st Conference of the Parties (COP21) was a milestone in this regard, and established challenging yet necessary targets,¹ including consideration of the impacts at 1.5°C warming. Even though the possibility of achieving these goals may be open to question,² this growing concern has been matched by an accelerating demand for scale-relevant climate

information that is likely to continue. Central to this is the understanding that data do not necessarily equate to the relevant information, but that data may contain some relevant information if interpreted appropriately. The challenge for the CIW is to facilitate this. The demand for relevant climate information, coupled with the proliferation of CIWs, makes it important to evaluate the quality and delivery of information used by the decision-making and policy communities, which frames efforts on actionable adaptation measures.

It is recognized that information sought for climate-related decisions goes well beyond data about the physical climate, and could be considered to include information on impacts, adaptation, vulnerability, and a host of socioeconomic factors. The focus here is on climate data and projections. This is in part to constrain the scope to pragmatic levels, but more because climate data are often a first hurdle for users, and the uncertainty and diversity of online climate data offerings presents a substantial barrier to finding decision-relevant information about climate variability and change. As such, ‘information’ as used here refers to the information from data products about the physical climate.

The landscape of CIWs is continually evolving and includes a strand of commercialization of services which introduces additional dynamics, while the principal drivers of future development are likewise shifting from the producers to the users’ expressions of information needs.³ The diversity, number, and the continued growth of CIWs preclude an exhaustive treatment of all available CIWs. The focus of this study is to review the general efficacy of current CIWs by drawing lessons from a representative sample with a range of implementation designs, content, and geographic coverage. A dual approach of metrics and narrative experience is used to evaluate the state of the CIW landscape, and so provide a review of the dominant nature of current online offerings.

For both comparative and pragmatic purposes, the selection of CIWs is focused on those using English language (noting that some of the selected CIWs are hosted in countries with non-English national languages). It is recognized that there is a non-English set of CIWs not represented here, and no comprehensive survey of how many non-English CIWs exist has been attempted.

CONSIDERING THE OPERATIONAL CONTEXT OF CIWs

The most robust climate change information is arguably represented by the Intergovernmental Panel on

BOX 1

HETEROGENEITY: STRENGTH AND WEAKNESS

The landscape of CIWs is characterized by extreme diversity of form and function. This reflects the evolution of unique initiatives that seek to provide tailored information to a diversity of user communities, a complex resource of multimodel, multimethod, and multigeneration climate change data with variable visibility and access, and disparate motivations from organizations and institutions hosting CIWs.

The strength lies in that while CIWs are relatively immature, they are evolving in line with the climate research and the decision-makers’ growing awareness of information needs. This heterogeneity constructively explores alternate avenues where no single approach will be optimal and exposes issues that the community can wrestle with.

The weakness is that adaptation action is becoming a central focus in many sectors, creating an immediate and growing demand for information to inform and frame these actions. Thus, the danger is that the heterogeneity of CIWs will either contribute to continued uncertainty or lead to choices based on messages of low robustness or limited value.

Climate Change (IPCC) assessment reports.⁴ However, these reports present mostly high-level messages that are not well aligned with the heterogeneity of information sought at adaptation decision scales. Reflecting this, the formats and content of CIWs positioned to provide this information are exceptionally diverse, ranging from the simple delivery of maps and numbers based on different generations of global climate models (GCMs), through to an eclectic mix of spatial disaggregation methods and downscaling techniques.

The objectives of providers are usually stated in the CIW in very broad terms and the common paradigm is about providing a service (although this is often limited to providing access to research products) and the apparent perspective is that the provider is filling a real need (Box 1).

However, the target audience, if it is even stated by a CIW, is often weakly defined (and arguably ill-conceived) using very broad language to frame its intentions. Examples drawn from the prominent text on different CIWs (as of January 20, 2017) include: (1) providing access to data (cordex-ea.climate.go.kr); (2) ‘enhance the use of climate research data’

(climate4impact.eu); (3) ‘establishing the foundation for climate services’ (ccaafs.cgiar.org); (4) ‘transition farmers into an era where decision-making does not come from best guesses’ (www.awhere.com); and (5) ‘enable improved assessments of the regional climate responses to global climate change’ (cccr.tropmet.res.in) and ‘enables technical and nontechnical audiences alike to access leading climate change information’ (www.climatewizard.org).

This is an implicit recognition that users come to CIWs with exceptionally diverse decision contexts and in an effort to maximize the exposure the CIW necessarily needs to leave the target broadly defined. However, this point needs to be considered alongside an individual user’s capacity to evaluate the added value of a CIW’s content for their unique decision context. As is illustrated through the use-case scenarios reported on later, much is presumed by the CIW of the user’s capacity.

Nonetheless, the loose framing of the target audience is, in the authors’ experience of engaging with users, very much secondary to the user’s reason for choosing to access a CIW. The basis of using one or other CIW, in the absence of any preexisting experience with or knowledge of a CIW, is commonly through internet searches based on related keywords. The efficacy with which a presumed answer is (quickly) attained is seemingly a strong motivation for using a particular CIW. Some users of the authors’ own CIW (cip.csag.uct.ac.za) often refer to valuing the ease with which a question can be answered, despite not knowing how robust that answer may actually be. As such, it is likely that there is a weak relation between a CIW’s stated target audience and the background of those using the CIW, unless the users have other motivations (e.g., institutional loyalty and perceived authority) for selecting a specific CIW.

It is worth noting that a user’s search for information does not necessarily equate with what is the actual needed information; ‘need’ is a complex concept that is intrinsically dependent on understanding the context and nature of systemic vulnerability, thresholds, impacts, and adaptation options, and a user’s awareness of these. These disconnects between provider and user, content and application, need and context, raise a critical ethical–epistemic dilemma.⁵ Value judgments based on perceptions of user contexts are made by climate scientists about the relevance and usefulness of the presented data and information, while other users (scientists and non-scientists alike) equally make value judgments about the robustness of climate information for their decision scale and context. At the same time, value

judgments are also being made by a community of boundary organizations⁶ on what and how to deliver to user communities. The combined result is a heightened potential that adaptation measures may be poorly aligned with actual defensible information with the possibility that they may contribute to maladaptation under a future climate.

This dilemma is characterized by data from physical climate research often being delivered as information, and based around the assumed needs of a poorly defined and diverse ‘user’ community. The concept of ‘uncertainty’ is critical in this context, applicable to both the incomplete climate history and the projected future climate, and if addressed by a CIW it often conflates multiple sources of error and bias with a time-evolving and irreducible component of natural variability.^{7,8} This uncertainty, as presented in most CIWs, typically receives a mixed treatment, and may draw on a number of approaches that include simply assessing the spread of data,^{9–11} or else attempting to constrain these to a likelihood outcome.^{12,13}

There is thus a challenge to examine contradictions between data sets and the inherent decision scale limitations of climate projections.¹⁴ This is often poorly addressed, or else the messaging of uncertainty may itself be inadequate.¹⁵ Because of the potential real-world consequences, there is a strong need to establish principles of practice and principles of product in the delivery of climate information by CIWs. There is an emerging discussion on this particular topic,^{16,17} but given the absence of any governing authority or enforceable code of conduct for CIWs, the responsible provision of online disseminated information will necessarily remain subject to a recognition of the issues by the CIW community.

The activities of online resources are nominally encompassed by the broader term ‘climate services’ and while this has some measure of formal definition¹⁸ it remains an evolving concept.¹⁹ Historically, the development of climate services has been dominated by a developed country perspective due to resources and capacity, yet it is continually challenged by shifting epistemologies²⁰ that are rooted in the diverse experiences of the decision community.²¹

At its heart, climate services and the embedded CIWs are forced to wrestle with a reality that data are a mix of signal and error, in the context of a specific application where the temporal or spatial requirements may exceed the information content of the data. Furthermore, not all information is relevant to a decision and relevance is not automatically significant. Rather, context defines relevance while need

BOX 2

THE PROBLEM OF INFORMATION CHAINS

The present state of the construction, dissemination, and communication of climate information may be articulated as follows.

A predominance of structured supply chains in which research data (chasing ever higher resolutions) is progressively transferred and translated between next-users, where the impacts, adaptation, and vulnerability (IAV) communities potentially overinterpret the robustness of the data's information content, and where the products are often inadequately communicated, scale inappropriate, and at times contradictory. These activities are being operationalized through a plethora of dissimilar portals by self-authorized boundary organizations that have little or no accountability, and where assumptions are complicated by ambiguous or opaque terminology.

determines significance.²² For example, annual rainfall is relevant to water resource management, but of limited significance to flood events which require information on rainfall intensity and duration. Hence the multiplicity and heterogeneity of use-case contexts preclude simple generalizations of information, which in turn limits the breadth of value that any single CIW can likely provide.

A helpful concept here is that of the 'next-user' which is aligned with the idea of organizational linkages or boundary chains.^{23,24} While the concept of a linear supply chain linking climate science through to decision-maker is intuitive, the more normative nature is that of networks or webs of individuals and organizations.²⁵ Next-users reflect the potential connectivity of individuals and organizations—those actors engaged in the transfer of knowledge between science and society.^{26,27} Everyone connects to a 'next-user' and are themselves 'next-users': on one end an atmospheric physicist may connect to the developer of climate models who supports the climate change modeler who produces the climate projection data; from another end a policy maker connects to a technical advisor who speaks to an impacts modeler who draws from a disseminated information product of climate projections. This is complicated by the tension between a positivist epistemology in the physical climate sciences and the value-based approach of the social sciences—both

perspectives bringing their own dimensions to the ethical–epistemic dilemma (Box 2).

Yet, this process is a core element supporting value judgments for adaptation actions that seek to manage socioecological risk in a development framework. The potential for negative outcomes thus places a notable ethical responsibility on CIWs to consider the consequences of their presence and of their formulation of information in the context of society's accelerating agenda for climate change action.

The diversity of contexts surrounding decision scale information precludes custom solutions in all cases, and so necessitates a measure of generalized content in CIWs. Herein lays the challenge: how to assess the appropriateness of generic online services for an individualized application?

AN APPROACH TO ASSESS THE CIW LANDSCAPE

There is no canonical solution for how climate change information should be disseminated as it is the individual use-case that frames the required information. To some degree, this is reflected in the diversity of approaches adopted by CIWs which complicates the design of any assessment framework (yet paradoxically some CIWs also imply a perception of being able to provide a 'one-stop-shop'²⁸).

Metrics of CIW characteristics which can be commonly applied are desirable as they are to some measure objective. Yet, metrics are only able to assess a finite subset of a portal's efficacy. Thus, the diversity of CIWs also necessitates an additional narrative approach, even though this is labor intensive and pragmatically limits the number of portals that may be assessed in this manner. However, the combined approach of a typology classification based on metrics and lessons learned from use-case narratives, offers both a quantitative and qualitative lens to better understand the landscape of CIWs. Together these expose key lessons and messages for consideration in the evolution of future CIWs.

A total of 42 CIWs are assessed in this study. By intention, the list was constructed around those CIWs that have good visibility, would likely be encountered in a user's search for data and information on climate change, and which are clearly intended to support users seeking physical climate information for decision-making. These CIWs were initially selected based on the authors' awareness and experience of the climate services landscape and from discussion with other scientists engaged in CIWs.

The list was further adapted with online searches using keywords, and finally filtered to be logistically pragmatic, and is thus not exhaustive of the landscape, nor is it intended to be as the landscape is continually evolving. The final 42 sites are considered to provide a fair sampling of English-based CIWs at the time of the assessment (recognizing that non-English sites are not included here, as discussed earlier) and are listed in Table 1.

Developing a Typology of CIWs Using Different Criteria

The metric approach uses a set of criteria to build a typology of CIWs. These criteria were evolved through a number of assessment trials and were developed in discussion with a broader group of people involved in climate research, climate services, and capacity development, and who span the social, impact and adaptation, and physical climate sciences. All participants in this discussion have solid experience with engaging multisectoral decision-makers, especially in relation to the water, food, and urban sectors, as well as with multicultural decision contexts.

The criteria are aimed at the following overarching questions: Who is providing the service? What are the geographic domains of focus? Who are the target users? What is the content being delivered? How is the content communicated? As there is a plethora of similar data products based on multiple models, methods, and scales, and as these present practical challenges to the user and contribute to perceptions of uncertainty, the number of data products presented is important to capture. For criteria that are not simple yes/no answers or where the answer is simply a number, a static set of 'option' categories are established. The scope of these categories needs to cover the entirety of possible answers and inevitably leaves a tension between being specific enough to say something of value, and general enough to apply across the diversity of CIWs. This is exacerbated by the different uses of terminology, and the sometimes opaque jargon and structure employed by a CIW. Table 2 lists the criteria and the category criteria that require some measure of subjective judgment to answer, as discussed below.

The target audience criterion aims to get a sense of the spread of CIWs' intended next-users, though the muddled nature of next-user definitions makes classifications complex. While one CIW may identify the next-user as the IAV user community, another may refer to development practitioners and yet another to the water sector. However, both

development practitioners and next-users in the water sector might also be considered part of the IAV user community, depending on how they use the information. At the same time, water sector next-users could also be government officials, as is identified on some websites. With this diverse terminology, the limited clarity of definitions and the overlap between possible categories, the development of the criteria is a balancing act between the specific and the generic, and entails a number of subjective interpretations about how different groups use the terminology.

The criterion to capture the different types of providers has similar challenges. A central question here is what motivates the establishment of the CIW? For example, whether it is a government agency responding to perceptions of user needs, researchers promoting the use-value of their research, or a funding agency requirement to disseminate research results. Motivations are not mutually exclusive and boundaries are essentially fuzzy. For example, there are research institutes whose researchers have strong links to a university, but whose funding is mainly from government departments and/or national development agencies. Conversely, one may have a university-based research group that shares some of its work freely through a CIW, but who also provides a commercial consultancy. Many CIWs fit several categories and this necessitates more generic options for the criteria but with a loss of detail.

The criterion of how CIW content is presented identifies options that include interactive information, static information, and raw data. However, we recognize that information is interpreted through a personal lens shaped by factors that include professional background, value systems, and subjective preferences. Hence a 'raw data' option might mean something very different for a climate scientist compared to a social scientist. Thus, it is important to articulate each of the options as unambiguously as possible yet recognize a degree of fuzzy boundaries.

As this discussion of typology criteria illustrates, the classification of CIWs requires a delicate and necessarily subjective balancing between specificity and generality. It further requires acknowledging, and working with, a diverse and weakly defined terminology with overlaps in categorizing elements. The adopted typology approach is the authors' selection of criteria based on the experience of many hours working with the diversity of CIWs. Despite these limitations, there is nonetheless a clear emergent profile of the 'who, where, to whom, what, and how' characteristics of the CIW landscape.

TABLE 1 | Overview of the 42 Climate Information Websites (CIWs) Reviewed in the Typology with the Six Included in the Narratives Highlighted with an Asterisk

Climate Information Website	Link
Arctic Climate Research at the University of Illinois	http://arctic.atmos.uiuc.edu/
aWhere	http://www.awhere.com/
Canada Centre for Climate Modeling and Analysis	http://www.ec.gc.ca/ccmac-ccma/
CCAFS Downscaled GCM Data Portal*	http://ccafs.cgiar.org/
Centre for Climate Change Research (CCCR)	http://cccr.tropmet.res.in/
Climate Change in Australia	http://www.climatechangeinaustralia.gov.au/
Climate Change Knowledge Portal*	http://sdwebx.worldbank.org/
Climate CHIP	http://www.climatechip.org/
Climate Data Online	http://reg.bom.gov.au/climate/data/
Climate Information Portal (CIP)	http://cip.csag.uct.ac.za/
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/
CORDEX East Asia	https://cordex-ea.climate.go.kr/
Downscaled CMIP3 and CMIP5 Climate and Hydrological Projections Archive	http://gdo-dcp.ucllnl.org/
Earth System Grid Federation	http://esgf.llnl.gov/
EDENext Data Portal	http://www.edenextdata.com
European Climate Assessment & Data set (ECA&D)	http://www.ecad.eu/
European Space Agency Climate Change Initiative (esa cci) open data portal	http://cci.esa.int/
Giovanni	http://giovanni.sci.gsfc.nasa.gov/
IPCC Data Distribution Centre (DDC)	http://www.ipcc-data.org/
IRI/LDEO Climate Data Library	http://iridl.ldeo.columbia.edu/
IS-ENES Climate4impact portal	https://climate4impact.eu/impactportal/
KlimafolgenOnline	http://www.klimafolgenonline.com/
KNMI Data Centre	https://data.knmi.nl/
KNMI Climate Explorer	http://climexp.knmi.nl/
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	http://www.gfdl.noaa.gov/
Ontario Climate Change Data Portal	http://www.ontarioccdp.ca/
Pacific Climate Futures	http://www.pacificclimatefutures.net/
Pacific Climate Impacts Consortium Data Portal	https://www.pacificclimate.org/
Regional Clearinghouse Database*	http://clearinghouse.caribbeanclimate.bz
South African Risk and Vulnerability Atlas*	http://sarva.dirisa.org/
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/
USGS Geo Data Portal	http://cida.usgs.gov/gdp/
Wisconsin Initiative on Climate Change Impacts	http://www.wicci.wisc.edu/
WoodForTrees.org	http://woodfortrees.org/

Most CIWs offer only climate and climate derivative data and information products. A few CIWs (e.g., see Narrative in Table 6(a)) do offer some ancillary information on socioeconomic data and context, and tools and guidelines for vulnerability and impact analysis and adaptation decision-making.

TABLE 2 | Typology Approach: Criteria Used in Assessing the 42 Climate Information Websites (CIWs)

Criterion	Type of Answer
Country in which climate service provider headquarter/main office(s) is based	Country name(s)
CIW provider types	Category options
Access control (log-in or registration required)	Category options
Target group (explicit next-user)	Category options
Geographic domain of data/information focus	Region/country name
How data/information are presented/provided	Category options
The number of GCMS presented	Number
SRES scenarios applied	Yes/No
RCP scenarios applied	Yes/No
The number of dynamical downscaling products presented	Number
The number of statistical downscaling products presented	Number
GCM and downscaling results separately accessible	Yes/No
Personal judgment: do they point explicitly to the fact that downscaled data are based on GCM output?	Yes/No
Personal judgment: Can a decision-maker get the information he/she needs and is he/she able to maneuver this portal?	Yes/No/With some difficulty

For this stage of the assessment, three researchers accessed the 42 sites between September 2015 and May 2016. Two researchers each independently accessed each CIW and assessed the criteria related to the types of service providers (*Types of Providers* section), and given the often ambiguous nature of these criteria then did so again collectively to resolve any discrepancies if their answers for any criterion differed. A third researcher, with a climate science and modeling background, undertook an additional assessment of the types and number of data products included in CIWs (*Types of Data Included in CIWs* and *Dynamical vs Statistical Downscaling* sections).

A Narrative Approach

If any criteria-based typology is likely to fail, it is in reflecting the *experience* of navigating the specific components of this online landscape. The user experience is, of course, paramount to the added value of a CIW. For this reason, a second method of narratives is used to complement the typology and explores a limited set of websites through the lens of use-case scenarios.

It may be argued that external actors charged with making decisions should be the basis of the narrative assessment of the CIWs. This is problematic given the vast diversity of decision contexts, decision-maker communities, and different value systems between sectors and cultures. Such an approach would be difficult and challenging to design and beyond the scope of this review (quite aside from the

problem of finding the range of external users engaged with decision-making who are willing to allocate the substantial time required). Instead, the narrative assessments were undertaken by junior researchers who are (1) from different disciplines spanning the physical and social sciences, (2) collectively have experience across multisectoral stakeholder engagement with decision-makers (including rural and urban contexts), and (3) come from cultural backgrounds that include both developed and developing nations (Africa and Europe). While the choice to use junior researchers as assessors also introduces a human factor, it is argued that the assessor's self-awareness of potential bias and the breadth of their collective experience and cross-culture exposure offer a way to better manage the bias and achieve a more comprehensive conclusion than is possible using external sector-specific decision-makers.

The four junior researchers, each with different disciplinary backgrounds and varying levels of experience, took on the role of different next-users. Following group discussion of potential bias and of taking consideration of lessons learned from stakeholder engagements, each accessed the same set of CIWs to build a narrative of their experience in attempting to construct the requisite information to meet each of the three use-cases (Table 3).

The use-case scenarios are necessarily limited in scope compared to the breadth of real world use-cases. Nonetheless, while alternative scenarios could always be constructed, these choices are considered

TABLE 3 | Use-Case Scenarios Used to Illuminate Key Lessons from the Experience of Constructing Climate Change Information from Online Services

Use-Case Scenarios Perspectives Taken by Narrators		
In my role as a Peace Corps member I would like to work with local residents to develop climate change adaptation responses, and therefore need to understand current climate vulnerability and vulnerability to future climate change	Water demand in the city is expected to exceed supply by 2019. In order to conduct long-term planning in my role as water management official, I need to understand how climate change may impact future water availability	In my role as an agricultural extension officer, I am tasked with understanding possible changes in the climate and to use this information to develop more resilient strains of maize seed for the climatic circumstances of the future

adequate to illuminate the leading lessons that emerge from an engagement with the CIWs.

Each of the four researchers spent on average 1.5 to 2 h per CIW applying the use-case scenarios to five selected CIWs (see the CIWs marked with an asterisk in Table 1), documenting their experience throughout. These written narratives were then collated and summarized into a single narrative per CIW to represent the key aspects which emerged through accessing and navigating the CIW. One additional CIW, a commercial service, was only assessed by one researcher (Table 6(f)). The narratives were compiled during June and July 2015 and further in February 2016.

THE TYPOLOGY OF WEBSITES

The geographic spread of the institutions hosting each of the 42 CIWs (Figure 1) illustrates dominance by the economically developed world, with North America accounting for the largest share, followed by Europe, Australia, and New Zealand. These reflect the emergence of CIWs from countries with strong capacity, and hence introduce a dominance of perspective from developed countries.

Types of Providers

Table 4 presents the breakdown of the types of providers. The main providers are governments, researchers, and multinational entities, with commercial and not-for-profit entities playing a smaller role (Table 4, Line A–H). The limited role of commercial actors is further reflected in the accessibility of data and information (Table 4, Line I–L). Only two climate services required payment, while all others offer their data and information free of charge. Roughly half of the services do not have any registration requirements and in most cases where an account has to be created an overview of the accessible information is given up front.

The CIW content is presumed to be linked to the provider's perceptions of the target next-user(s) and to the availability of data. However, a large portion of the services do not specify the next-user (Table 4, Line M), which may indicate either that the provider has not clearly identified its audience, that the service is aimed at anyone or simply that it has not been articulated on the CIW. More than half of the services do aim at a specific next-user, with researchers being the most common target group (Table 4, Line N). While some services have a rather narrow target group, such as the agricultural sector, others appear to target multiple groups of users containing, for example, government officials, the media, NGOs, and development practitioners.

The potential next-users of climate data and information thus range from researchers who would apply the data in impacts modeling to NGO practitioners who are completely new to climate change science yet have to plan a climate change adaptation project. As such, these different next-users are likely to require very different information and guidelines, and as emphasized at the outset of this article, establishing the appropriateness of generic CIWs for these individual, context-driven applications poses a key challenge.

The diversity of next-users accessing CIWs necessarily results in a search for data and information for a variety of locations and scales. Nearly half (19) of the assessed CIWs provide global data (as opposed to serving a geographical domain due to institutional interests or mandate). In the remaining cases, North America is the dominant focus (9), while Africa and the Arctic, and the subregions of the Pacific Islands, the Caribbean, the Mediterranean, Southern Africa, South Asia, and East Asia are each addressed by one dedicated CIW. Only two of the assessed CIWs include a focus on Europe as a whole, while Germany and the Netherlands each have a dedicated CIW. Hence the breadth of information

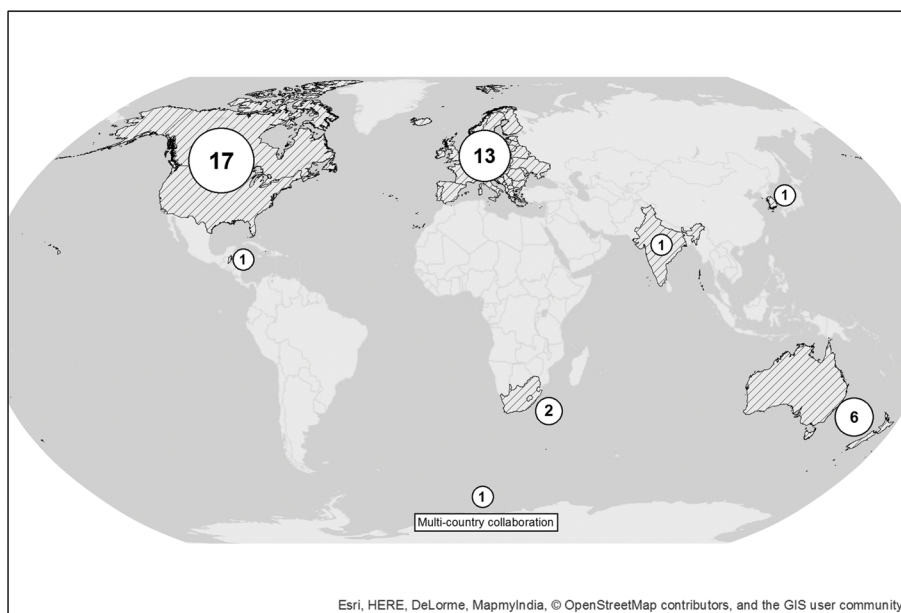


FIGURE 1 | Geographic distribution of the 42 climate information websites assessed in this study.

available to a next-user will depend on his or her geographical focus area.

As also illustrated in the *Narratives* section, the type of data or information encountered by next-users and the way in which it is presented plays a central role in shaping their experience, and likely, the application of the data and information. The type of data or information provided on the CIWs, and its representation, varies. The majority (32) allow for access to raw data downloads (e.g., in ASCII or NetCDF files) that are generally most appropriate to other researchers. Of these, a small subset of CIWs restricts the distribution to raw data only (11). However, approximately three-fourths of the CIWs also contain, or solely focus on, visualized data in the form of maps, graphs, or tables. Among them, more of the CIWs are designed to be interactive (19), that is, next-users can navigate the data by making input choices (e.g., emission scenarios and GCMs) compared to those with static content (13) where next-users have to select from a predeveloped set of maps, graphs, and tables. Two CIWs offer both interactive and predeveloped static representations of the data, while there is only one CIW offering interactive, static, and raw data.

Types of Data Included in CIWs

Relevant climate data necessarily includes the past and the future, the former being essential to define baselines and natural variability. The foundation for projections is the GCM, of which the coupled model

intercomparison projects CMIP3 and CMIP5 archives represent the primary multimodel resource that uses a consistent experiment design for all models. These form the core of the third, fourth, and fifth IPCC assessment reports. CMIP3 is based on the emission scenarios from the Special Report on Emission Scenarios (SRES)²⁸ while CMIP5 uses atmospheric concentrations and land-use change from the representative concentration pathways (RCPs).²⁹ These two GCM archives span an evolution of climate models,³⁰ which show an increase in the numbers of models, spatial resolution, size of ensembles, and model sophistication from CMIP3 to CMIP5.

Building on this foundation of GCM data are multiple downscaling and spatial disaggregation methods to develop higher spatial resolution and which seek to be more relevant to adaptation decision scales. Added to this are alternative techniques for spatial disaggregation (which are sometimes confusingly referred to as ‘downscaling’), for example, through bias correction and the delta approach.³¹ Statistical downscaling¹⁴ and dynamical downscaling are available through the emerging coordinated multimodel downscaling experiments.³² This diversity of data types presents a significant challenge to a nonexpert. However, that diversity stems from the fact that the development of climate projections for decision scales remains a critical and evolving research frontier, often confounded by the debate as to the degree of added information from downscaling.^{33–36}

In view of the ongoing evolution of model sophistication and model resolution, there is reason

TABLE 4 | Understanding Types of Information Providers

Criteria		Criteria Options	Number of CIWs	
CIW provider type [†]			Total	Collaboration
A		Multi-National Collaboration/Centre	9	N/A
B		National Agency/Institute/Centre	10	2
C		National Meteorology Office/Bureau/Weather Services	5	1
D		University-based Research Institute/Centre/Group/Unit	12	5
E		Research Centre/Institute	7	5
F		Commercial	4	1
G		Not-for-profit initiative	3	1
H		Government Department	1	1
I	Access control	Not required	20	
J		Required for some/all data access but overview available upfront	18	
K		Required for some/all data access and no information available upfront	2	
L		Payment required	2	
M	Target group	Not specified	17	
N		Researchers	14	
O		Government officials (including planners and policy/decision-makers)	10	
P		Impacts, adaptation, and vulnerability user community	6	
Q		NGOs/International agencies/Development practitioners	4	
R		Specific or multiple sectors	3	

Line A–H (provider type): some services are run by consortia consisting of multiple actors. Thus, we differentiate between the total number of providers of a certain type (total) and the number of times a certain provider type acts as the sole agency; Line I–L (access control): log-in or registration requirements for data/information access; Line M–R (target group): note that the target groups that were only identified by three or less CIWs have not been listed. These include educators, students, private sector, media, GIS users, and technical and nontechnical users. Also note that many CIWs identified more than one target group.

[†] Classification of CIW provider types is inherently fuzzy (as we measure multiple nonnumeric dimensions) as discussed in *Developing a Typology of CIWs Using Different Criteria* section and a more detailed definition of these is: (A) *Multinational Collaborations/Centres* are entities that include actors from various countries (e.g., the Earth System Grid federation). (B) A *National Agency/Institute/Centre* that is strongly linked to a government department. For example, a government agency like the USA National Oceanic and Atmospheric Agency (NOAA) or a government/state owned entity such as the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). (C) *National Meteorology Office/Bureau/Weather services* are clustered separately to (A) since they share a very precise role as the national weather service provider with existing mandate complementary to climate change. (D) A *University-Based Institute/Centre/Group/Unit* is part of an academic educational institution. (E) *Research Centres/Institutes* (e.g., the Ruby Coast Research Centre) represent entities that are neither part of an academic institution nor strongly linked to a government department. (F) *Commercial* is simply where a CIW imposes a charge for full or partial access, and is not one of the preceding types. (G) *Not-for-profit initiatives* include independent, self-funded CIW providers (e.g., Wood for Trees), nongovernmental organizations (e.g., The Nature Conservancy), and informal collaborators (e.g., CLIMond). (H) *Government departments*.

to favor the use of data from more recent generations of models. Likewise, as the policy community and international negotiations are shifting to the RCP scenarios, the use of CMIP5 is arguably preferred over the older CMIP3 data based on SRES scenarios.

Figure 2 shows the breakdown of CIWs in terms of the type of data products offered. GCMs and downscaling methods are counted such that the same model in different versions, resolutions or coupled to different submodels are treated as two different models. Figure 2(a) shows the number of GCMs presented by CIWs, and that approximately a quarter of the CIWs focuses on historical climate information and do not include any model projections. Among the remaining services, 15 of 32 with model data include

an extensive set of GCMs (more than 15) and thus facilitate an investigation of intermodel spread. In contrast, five climate services offer only a single GCM.

It is apparent from Figure 2(b) that CIWs are more able to provide output from multiple GCMs than they are for output from multiple downscaling methods. This is not unexpected as the CMIP archive offers ready access to GCM data whereas downscaled products are both less readily available and a challenge for many organizations to generate (due to computational and resource constraints).

Likewise, the number of CIWs offering only SRES-based output is limited and indicates a focus by CIWs to include the more recent RCP-based results. It is notable that CIWs which offer output

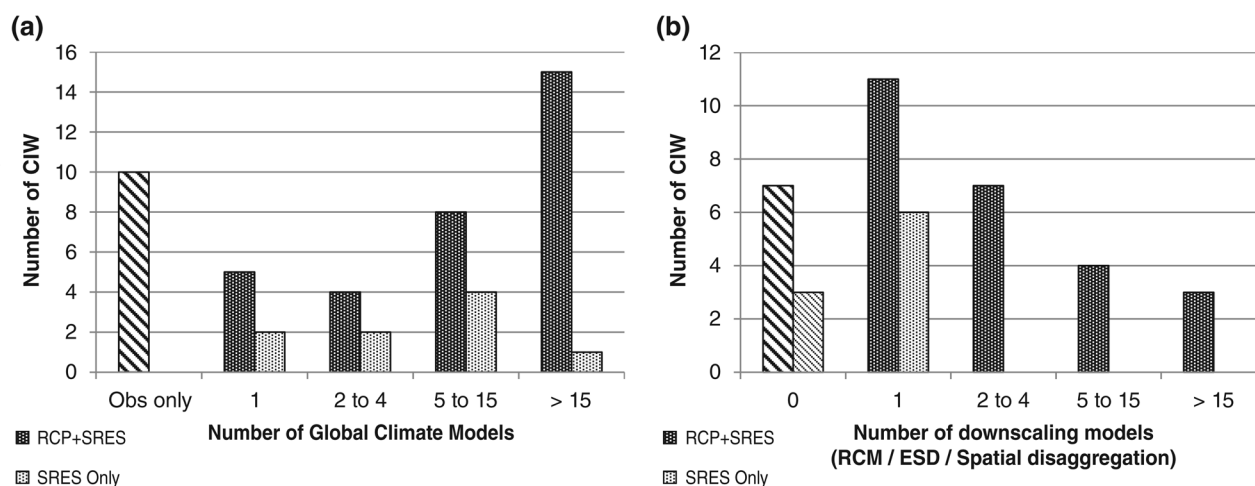


FIGURE 2 | The number of climate information websites (CIWs) in relation to the number data/information products offered. In each pair of bars, the right bar is the number of sites with only SRES-based products. The global climate models (GCMs) are shown in panel (a) and include the number of CIWs that offer only historical information (left-most bar). Downscaled (statistical or dynamical) methods are shown in panel (b), where the bars for zero downscaling methods indicate instead the number of CIWs with only GCM products.

from more than one downscaling method do not include downscaling from SRES-based GCM output, indicating that extensive downscaling ensembles tend to concentrate on the more recent RCP forcing scenarios. In terms of the emission scenarios included in the CIWs, 36% of the CIWs use both SRES and RCP scenarios, 19% only RCP, 19% only SRES, and remaining only have historical data.

Dynamical Versus Statistical Downscaling

The breakdown between dynamical and statistical downscaling (pattern scaling and bias correction techniques are included under statistical methods) is shown in Figure 3, where the tendency is clearly for CIWs to favor either regional climate models (RCMs) or statistical methods, but not both. Only one of the surveyed services offered information from both dynamical and statistical downscaling. This result reflects the fact that, unlike for GCMs, downscaling has as yet no comprehensive archive equivalent to CMIP. Consequently, accessing downscaling output is necessarily reliant on the CIW's competency to undertake downscaling themselves or to develop a relationship with one or more downscaling research groups to access such data. In coming years, the CORDEX program³² is working towards changing this situation.

The type or method of downscaled information included by a CIW was not always clear. In one case, downscaled data were included without any explanation of how the downscaling was implemented and in another case it was unclear whether some of the

information products actually represented downscaled products or not.

Transparency About How Data Products Are Constructed

Adams et al.³⁷ argue for an ethical framework for climate services and consider transparency a 'core element intrinsic to the production of climate services.' This is important as a simple explanation of the different steps involved in reaching a downscaled information product may enable the next-user to be aware of associated uncertainties and robustness of the climate information. In the spirit of this approach, the transparency with which the service providers communicate the modeling chain producing downscaled climate data is assessed. For this, a subjective judgment is used to answer two questions: Does a CIW provide downscaled data separate to the GCM data (as opposed to simply the outcome of a GCM/downscaling combination), and is there a clear explanation of how these are constructed? These results are necessarily subjective about what constitutes an adequate explanation, but nonetheless reflects a consistent assessment of the provision of supporting explanatory materials about the construction of the included downscaled products.

Table 5 provides a simple breakdown of this assessment. Of the CIWs providing explicit individual downscaled data products (24 in total), just over half (13) were judged to be transparent with respect to explaining the modeling chain. Moreover, linking

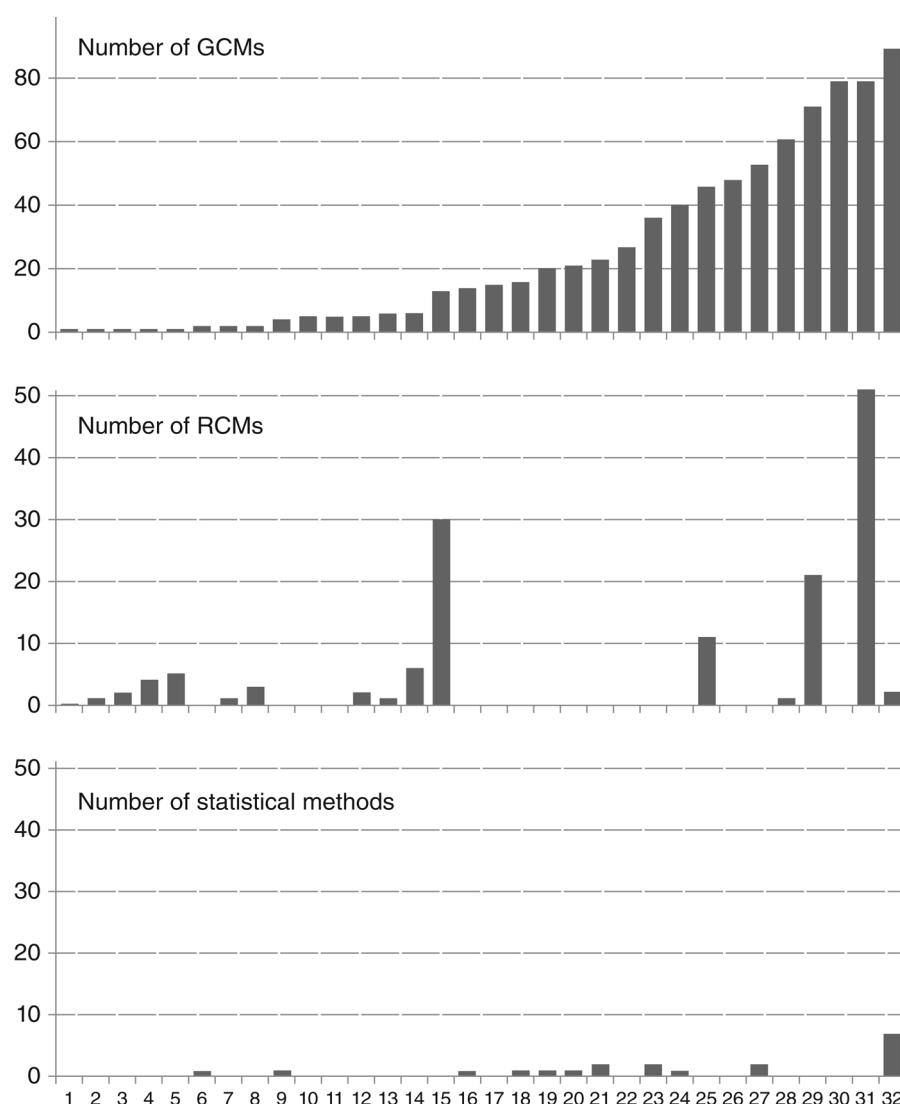


FIGURE 3 | Relationship between the number of global climate models (GCMs, top), regional climate models (RCMs, middle), and statistical downscaling methods (bottom) on the climate information websites (CIWs) which included discrete information on these data sets (32 of 42 CIWs). The x-axis represents the 32 CIWs, with the same ordering in all three panels and ranked by the number of GCMs incorporated on the CIW. This includes two additional CIWs where the number of statistical methods and/or number of RCMs were unclear. Note that the same model in different versions, resolutions or coupled to different submodels, is counted as different models.

the transparency question with that of the separate availability of GCM and downscaled data reveals that only five CIWs are compliant in this respect, while six CIWs neither offer the data separately nor are judged to be transparent about the modeling chain.

Overall Perceptions

To summarize this criteria approach, a final question is posed. This is a question that is quite undeniably no more than a perception based on experience, but nonetheless interesting as a qualitative message.

TABLE 5 | Number of Climate Information Websites (CIWs) in Relation to the Transparency About the Included Downscaled Data

Are downscaled data available separately to the GCM data?	Yes	5	5
	No	8	6
Is the modeling chain explained explicitly?			
		Yes	No

TABLE 6 | Summary Messages from the Narratives of Four Nonexperts Applying Three Use-Case Scenarios with Six Climate Information Websites (CIWs)

(a) Narrative 1			
Geographic domain	Regional	Interface (static or interactive)	Interactive
GCM raw data	No	GCM postprocessed or downscaled	Yes (method unclear)
Experience summary			
<i>There is a straightforward and welcoming climate data interface, but a lack of obvious pathways to the desired information, and a multitude of interesting yet potentially distracting information. The lack of clear guidance on how to maneuver among the choices provided, and the inconsistent presentation of data from different models makes confidence around the extraction of robust messages hard to come by.</i>			
Edited content from the individual researchers narratives			
<ul style="list-style-type: none"> On accessing the website I am faced with a somewhat overwhelming amount of IAV-related information and tools. Though the IAV focus is enticing, in that they are speaking 'my language,' the vast amount of information makes it somewhat difficult to locate the actual climate information. I am, for example, given the option of 19 different vulnerability assessment tools—phew, where do I go from here? On my locating the climate information part of the website, I am encouraged as the layout is straightforward and welcoming, and there are a lot of degrees of freedom in the search options. There is a lack of clear guidance on how to robustly choose among the various options. I therefore randomly select a file set and an image pops up. After some exploration and trial and error, I end up getting some quite specific messages, based on one model, one future scenario. There are no guidelines with regards to the extent to which these are robust messages. I decide to have a quick look at the projections from the other model they provide, just to see if the messages are relatively similar. I am immediately put off, as the variables that I am now choosing between differ from those offered for the other model. This is frustrating, where can I find guidance? I move on... 			
(b) Narrative 2			
Geographic domain	Global	Interface (static or interactive)	Options for raw data download only
GCM raw data	No	GCM postprocessed or downscaled	Yes (bias correction)
Experience summary			
<i>Having located the nonapparent climate information section, one is overwhelmed by options, and without substantial reading time the extensive supportive material does not make for easy maneuvering in the jargon-laden landscape of options. Technical challenges and unfamiliar data file formats further alienate the user.</i>			
Edited content from the individual researchers narratives			
<ul style="list-style-type: none"> It is positive that the website is being offered in English, French, and Spanish, yet the location of the climate information section of the website is not immediately apparent and extensive searching is followed by a general sense of confusion as I locate and enter the climate section. I am overwhelmed with the amount of options I must choose to be able to get the climate data. Without intimate knowledge of climate terminology and modeling slang, accessing data is a guessing game. Supporting materials are of little support. Having skimmed through the different pages, all of which are under the Spatial Downscaling Section, I am afraid I am none the wiser with regards to what file sets to look at. In the absence of clarity, I randomly choose a set of options, however, my computer struggles and I now realize I may have chosen a data set that is too big for my computer to handle—I have to completely reload my browser to continue working. When the computer finally downloads the data the download provides me with file formats that I do not know how to use ... I give up. 			
(c) Narrative 3			
Geographic domain	Global	Interface (static or interactive)	Interactive
GCM raw data	No	GCM postprocessed or downscaled	Yes (interpolated to 0.5°)
Experience summary			
<i>The multitude of data entry points and data displays breed confusion, yet the easily accessible multimodel comparison and averaging is encouraging, despite not fully grasping why such comparison and averaging is important. Despite clear messages regarding data being nonapplicable at a local scale, the site tempts one to extract local scale messages with relative confidence simply because it is possible.</i>			

(continued overleaf)

TABLE 6 | Continued

(c) Narrative 3			
Edited content from the individual researchers narratives			
<ul style="list-style-type: none"> I immediately see that the CIW has a big focus on impacts and adaptation, but does it actually have climate data? It turns out there are several entry points to climate data, each of which displays the data differently. I can access graphs that compare data from multiple models for a specific location. But, the value of comparing data by generating averages over multiple models is not necessarily apparent. In further search for climate data I identify another entry point, an easy to use interface that allows for comparison of four models through four simultaneously displayed maps. For each of the four maps I can choose one out of five models, one out of three emission scenarios and one out of five time periods. This is quite easily accessible and not too overwhelming to start with! The maps are accompanied by information on the data presented, provided in an easy, nontechnical language, and emphasizing the need to not overinterpret the maps while highlighting that they are not applicable for highly localized projections. Seeing that I want to use the information for adaptation planning at the local level, this last part is discouraging. However, through the maps it is possible to identify my town of interest, and I can explore what messages the projections are providing for my location. I spend just over an hour on the portal, and through my investigation I find that there is no clear message with regards to rainfall projections for my location, but that temperatures will increase throughout the year, likely around 1–1.5° by 2040. Now, is this a robust message? I will not deny that I feel quite confident because in comparing all five models I found that they all gave me the same direction, and generally similar degree, of change for temperatures. 			
(d) Narrative 4			
Geographic domain	Regional	Interface (static or interactive)	Mostly Static
GCM raw data	No	GCM postprocessed or downscaled	Unclear
Experience summary			
<i>Opaque and messy, with a technically challenged search engine featuring an overwhelming multiplicity of data files in a variety of formats. Repetitive text and endless mouse-clicking providing pathways to a multitude of pdf file maps, discouraging the narrator from considering multiple lines of evidence.</i>			
Edited content from the individual researchers narratives			
<ul style="list-style-type: none"> The CIW is initially visually appealing, and I am immediately drawn to the case studies, which are said to demonstrate how the website can be used. However, on reading a case study the relevance to using the CIW information is not clear. All the information applied in the study was accessed from elsewhere! I move on. I find a data search engine. It takes me to a map and asks for a keyword. I am a little confused as to what to write, so I just type in 'maize' as this is the crop I am interested in. I am immediately directed to a paper resource and find the link to download. I realize this is not a paper after all, and realize that I am taken to a data set with a map that is pulling data from another database. I get very confused as to what I am looking at and which attributes to choose. In another search, I get over 100 results, and I feel overwhelmed by the number of data files. In addition, many files are in GIS format, which I am not able to open or use. To add to the confusion, the information given to describe the different data files is inconsistent and at times incomprehensible. Overwhelmed and somewhat discouraged I try looking through other parts of the website, and discover a section on dynamically downscaled projections. Through a lot of clicking, reading of repetitive text and looking at pdf file maps I get the sense that these are projections downscaled from six different models, for a number of different variables and time periods. Seeing that they are providing projections from six models I should probably download the maps for each of the models (annual and for each season) and compare them to see the extent to which they agree. This means comparing six maps for annual projections and six maps for each season, a total of 30 maps. If I am to do this with the five climate variables that are provided, this would mean looking through a total of 150 maps! Being uncertain about the extent to which it is responsible to draw out local scale projections from the maps, it does not seem worth the effort. 			
(e) Narrative 5			
Geographic domain	Global	Interface (static or interactive)	Interactive
GCM raw data	Yes	GCM postprocessed or downscaled	Yes (method unclear)
(continued overleaf)			

TABLE 6 | Continued

(e) Narrative 5

Experience summary

Immediately accessible climate data, presented through an intuitive design, and encouraged by the ease of access to local scale messages, yet a nonsensical disparity in the presentation of GCM and downscaled information makes for potentially poor data choices.

Edited content from the individual researchers narratives

- I am encouraged by the immediate access to the climate data, with no need to search around.
- I turn to the User's Guide, which turns out to be a 16 page pdf document. While this discourages me a little, it turns out to be easy to read and straightforward, while at the same time touching on complicated aspects such as model ensembles and uncertainty.
- I find that the data itself is categorized in a logical way, and the design is intuitive. Having had a peak at the historical data, I then look at the GCM projections tab where I am presented with an interactive map where I can zoom in and find my town—and get graphs displaying projections for my exact location. I am feeling positive about this portal—this is easy so far! With this information, is it actually necessary to look at downscaled information? I decide to have a look. Again there is a map and graphs, though here it does not seem possible to engage with the map at all, and the interface and options provided are different from those provided for the historical and GCM data.
- While this is downscaled data there is no reference to place or scale—is this for the country as a whole? My immediate reaction is to stick with the data under the GCMs, as the way the data is displayed there is better for my purpose—there I can see the data spatially and get data for my specific location!

(f) Narrative 6

Geographic domain

Global

Interface (static or interactive)

Interactive

GCM raw data

Yes

GCM postprocessed or downscaled

Yes (interpolation to 0.5°)

Experience summary

Beyond the apparent hindrances associated with the required fee, one is also discouraged by the need for technical know-how and the time and learning efforts required before analysis of data is possible.

Edited content from the individual researchers narratives

- I need to purchase and download a license. Luckily, there is a free trial option! I have to fill in a whole lot of details in order to send a request, and I am told that I can expect to be contacted in 1–2 business days. It takes a few weeks before I hear back.
- The 'about' section of the website turns out to be very informative, the language makes it easy to read and makes me feel like I have enough understanding to use this portal.
- When it comes to downloading the software I face challenges. I get an error message telling me the program can start because rtl170.bpl is missing. I try to do the same thing a few times, and get the same message again and again. With help from our IT person I manage to download and get it up and running.
- The software icons and tabs seem to have some very exciting attributes on offer. I explore the various Youtube videos that are provided as guidance, but what is showing on the Youtube video is not a match to what happens on my screen.
- While I have spent a lot of time now without getting very far, I do feel this is software that I will be able to learn to use. However, the effort and time it takes seems out of proportion to what I am looking to achieve.

The tables illustrate the user experience, including key attributes of the CIW, a composite summary of the leading messages and selected quotes from the researchers' narratives.

The question posed was 'Is it likely, as an expert judgment, that a decision-maker would obtain the information sought and likely be able to navigate this CIW?' In most cases (25), it is concluded that decision-makers (at least in terms of our experience with decision-makers in developing countries) are not likely to successfully navigate the site and access the information they are looking for, while for eight CIWs they may be able to with some difficulty. Of the remaining, nine CIWs were deemed to perform well, in that it was judged that there was adequate

clarity to enable decision-makers to likely achieve a measure of success.

NARRATIVES

The user's experience in using a CIW is paramount; users come to a website with an application context and time constraint in which to obtain what they seek. In a competing landscape of CIWs, it is easy to allow barriers to force a change to another

internet search engine-identified option, or simply accept a suboptimal solution in the interest of time. Hence understanding the efficacy of a CIW necessitates a user experience perspective. Max-Neef³⁸ in his book 'Human Scale Development,' provocatively argues that one can read and study everything that is written on the phenomenon of love, but one can never truly understand love without falling in love. This is a strong metaphor for how some CIW providers may be at a disadvantage in understanding the decision-makers experience unless they have personally accessed and 'used' a CIW with the background, context, and knowledge of a nonexpert.

Thus, there is significant value in characterizing this experience by providing a narrative detailing the experiential barriers, frustrations, and positive factors. The six narratives (Table 6(a)–(f)) are developed from the experiences of four nonexperts who have a limited understanding of the nuances inherent in CIW content. While these are not perfect representatives of the diversity of users, their inexperience with CIWs enables creating an illustrative view aimed at gaining a sense of the leading issues that users would typically experience, and for pinpointing some of the key challenges faced by next-users in their search for climate data and information.

Central Experiences

Each narrative in Table 6 begins with a summary from the composite narrative experiences of the four researchers in their attempt to apply each of the three use-case scenarios (see Table 3). Following this, we show selected quotes from each of the four researcher's narratives to illustrate how they reacted to using the CIW to complete the tasks. All access was undertaken from South Africa which represents a medium bandwidth limited situation.

Common Lessons Learned Through the Narratives Process

The above narrative summary reflects the primary issues encountered, while each source narrative also produced some unique experiences not included here. Nonetheless, there are a number of common issues emerging that are pertinent to the practical and ethical implications of the CIW content and how CIWs present climate information. These issues can be considered in terms of practicality and appropriateness.

From a practical perspective, the overall message is that all the CIWs grossly overestimate the ease of use. The following lessons are dominant:

1. Much is assumed of the user's familiarity with terminology.
2. Navigation is complicated with complementary data often spread across multiple sections of the CIW, testing the user's patience and raising frustration.
3. There is often a lack of clarity about what is being displayed, either in terms of explanations of how it was generated, or how robust the information may be taken to be.
4. The choices presented are multiple and often confusing.
5. Guidance is commonly minimal, unclear, or hard to find.
6. Different avenues through the CIW structure can lead to different outcomes.
7. There is a presumed degree of (significant) technical skills by the user.
8. In many cases, the level of effort required by the users is in contrast with the expectation that the CIW will simply deliver information.

In many cases, the immediate consequence of the experience was frustration, leading to uncertainty about the robustness of the information obtained. The overriding issue is that much is presumed of the users' technical abilities, their conceptual understanding and familiarity with jargon, and awareness of the implications of choices and options. While those active in the research community may well be able to overcome these challenges, for many operating in the consultancy, advisory, and decision-making realm of adaptation these challenges are likely to greatly inhibit the chances of success, or else lead to users making inappropriate conclusions (Box 3).

Turning to the question of content, the issues are perhaps more subtle, and may also be of significantly more concern in some cases. This issue revolves around the question of what may be inferred from the data, and what is left unsaid or unaddressed. Leading points of concern that are highlighted by the narratives approach (and which are not exposed by the metrics/typology approach) include:

1. More often than not the expected cautionary flags about limits to the information are either not present, or incomplete, with the result that overinterpretation is implicitly encouraged.
2. In numerous cases, GCM data are postprocessed in a way that encourages overvaluing the data, and are most commonly seen in a practice of interpolating GCM data to finer

resolutions. The implied message is that resolution equates to skilful information, which in this case it most certainly does not.

3. The plethora of choices offered (perhaps thinking that more is better) along with weak guidance on how to manage uncertainty requires the user to subjectively constrain the options to something manageable—at times by semi-random choices. The net consequence is that users evaluate only a finite set (and possibly a suboptimal set) of relevant outcomes for their use-case.
4. The heavy use of climate terminology and modeling jargon, without easily accessible guidance on *how* to choose, is discouraging at best, and at worst leads to bad choices.
5. Contradictions and differences abound, not only as a result of which data are selected or whether considering GCMs versus some post-processed product, but also according to which pathway is followed in accessing the data. These are largely unexplained or at best conflated under the general label of uncertainty.
6. Guidance seldom goes into the issues of scenarios, such as the implications of the shared socioeconomic pathways (SSPs)³⁹ or the different emission RCPs that delineate possible futures.
7. There is minimal explanation of how the downscaling or spatial disaggregation has been applied, requiring significant trust that the assumptions implicit in a downscaling method are understood and accommodated in a user's interpretation of information.
8. Little to no attention is paid to the atmospheric processes governing the climate system. This is a CIW deficiency by omission, yet is a fundamental element to constructing rigorous information, and which many use-case scenarios can respond to. Hewitson et al.¹⁴ present a framework for constructing robust information and identify understanding of changes in climate processes as one of the core foundations. For example, the message that frontal systems are moving poleward, or convective rainfall intensity is increasing, or seasonal boundaries are shifting, all imply a regional climate consequence that many users can respond to in their use-case.
9. There are inherent dangers from the implied authority of sophisticated interfaces and the relationship between the quality of the interface and the quality of the information content is not necessarily strong.

BOX 3

AN (UN)AWARENESS OF CONSEQUENCES

CIWs evolved in large part from data services in the research community. As demand has grown, and as the research community increasingly sought to bridge the science–society divide, new initiatives have emerged to interface with decision-makers and has created a plethora of portals.

These are marked by two general characteristics: (1) they connect the user to the raw data with associated (unrealistic) expectations that the inherent jargon and concept are understood and/or (2) they build an interface that infers skill but shields the user from understanding the intrinsic limitations of the information.

Both cases reflect an organic growth of CIWs with weak cognizance of real-world consequences that their actions may potentially instigate, especially in developing and economies in transition countries where the capacity deficit magnifies the risk that the CIW will contribute to misaligned adaptation actions.

Managing this requires stronger partnerships between provider and user such that each informs the other, capacity is mutually developed and coexploration of information is maximized.

SUMMARIZING THE CURRENT STATE OF THE CIW LANDSCAPE

The overarching impression is that CIWs have yet to mature, and are mostly focused on providing access to a deluge of data rather than serving as a filter to robust and relevant information, thereby supporting informed use.

More specifically, the plethora of CIWs form a complex landscape wherein any single CIW contains only a subset of data and information products, communicated in diverse forms with variable quality content. A few CIWs do well, but no CIW is close to being able to be considered a generic one-stop-shop, nor is that necessarily desirable. Outside of a niche activity where a CIW may serve a very tightly defined use-case, it is difficult to conceive how one CIW can be a generic resource which satisfies all needs.

In terms of usefulness, a preliminary conclusion is that using a CIW to find information products

which may be defensibly appropriate to the use-case perspective requires significant effort, and the inherent limitations in the CIW content and guidance materials are significant barriers for the nonexpert. In essence, despite the diversity available, all CIWs present hurdles that hinder next-users from completing a process of exploration through to a defensible conclusion. For the user, this leaves unanswered questions about the degree of added value and quality that any given CIW provides and undermines confidence in the derived outcome.

Emergent Issues

Two core issues emerge from the current state of affairs: (1) dangers and implicit ethical questions from the use of CIWs, even when developed with the best of intentions, and (2) the question of what this means for building capacity to use climate information as part of adaptation planning.

Regarding the first core question, Adams et al.³⁷ articulate the need for principles of practice and principles of product among climate information providers and these clearly apply to CIWs. While CIWs legitimately respond to a very valid need for information from decision-makers, at the same time there is a likely danger of users overinterpreting the information content of the data (e.g., when users interpret GCM data which has simply been interpolated to a higher resolution). If this leads to adaptation and policy decisions, and to financial investment and infrastructural development, then real world consequences for society and human security are at stake. Thus the provision of climate information without clearly communicated qualifiers, guidance, and explanations to enable reasonable checks and balances, is an ethical–epistemic problem which the CIW community needs to seriously consider.

Second are the implications for capacity development. The reality is that users of CIWs are nonexperts in the interpretation and/or construction of decision scale climate information. This is complicated by the fact that CIWs seek to operationalize the dissemination of data and information (with complex and nuanced uncertainty) that is derived from continually evolving research. Recognizing a propensity for individuals to be overconfident in their competency despite being nonexperts,^{40,41} how do we develop user capacity to maximize adoption of appropriate information? Hewitson⁴² argues that developing skills is not enough, but that experiential learning that leverages foundational skills is required. This suggests that capacity development for the

responsible use of CIWs needs to be a partnership between skill development and coproduction⁴³ or coexploration²¹ activities. This poses the key challenge of deciding how far CIWs (and the researchers providing the underpinning science) need to extend their support and understanding of user contexts to match the existing skill capacity of users versus the degree to which users need to develop skills to use CIWs.

Evolving CIWs

The authors of this study host a CIW,^b which has broad usage in Africa and was included among those assessed in this paper. The results of this assessment have stimulated a much closer examination of the motivations for our CIW and how best to develop the platform. The underlying questions raised by this are: (a) What constitutes information? (b) What should be the process through which a user develops decision-scale information?

The first question is intuitive, yet difficult to articulate in the context of a CIW being accessed through the lens of an exceptionally diverse set of interests—where ‘information’ is taken as ‘information for my application.’ This suggests that the initial development should be to focus on how to identify robust signals of climate change relative to natural variability and sources of error. This is the challenge of distillation (discussed below) and provides a foundation to address the second question: How to best facilitate a user’s lens on the data?

The distillation concept involves constructing defensible climate information from the multimix of data sources (each having relative scale-dependent skill), and to do so with the decision scale and decision context in mind in order to understand what is relevant and significant. For example, GCM data are not skilful in capturing local rainfall under complex topography, yet GCMs are skilful in representing synoptic scale processes. Conversely, downscaling can add value in regions of complex topography, but also introduce new sources of uncertainty. Thus, distillation is the concept of constraining the breadth of projections from multiple data sources, through an understanding of how the characteristics of different sources relate to user requirements for information.

This reframes the focus to (1) develop new techniques to distil multiple data sources which can potentially inform decision scales and (2) develop appropriate interfaces that help users to understand the complexity, filter noise, and distil the information content for their use-case and decision context. This

is codependent on evolving user community awareness that, rather than seeking an idealized or highest resolution data product, first considers building a narrative of possible future climate which is strongly based on defensible evidence.

CONCLUSIONS AND RECOMMENDATIONS

It is tempting to be prescriptive about how CIWs should evolve, yet the diversity of context and application precludes specific statements; rather it is desirable that the existing heterogeneity of innovation continues. Inherently, such innovation will require increased cohesion of a community of practitioners that integrate providers of CIWs into a broader sphere of climate service activities and establish good practice. This community is at present emergent, although somewhat fractured in structure. For example, formally there is the global framework for climate services operating under the auspices of the World Meteorological Organization, engaging most strongly with national meteorological services. In contrast is the climate services partnership (CSP), an informal, interdisciplinary, and global network of climate information users, providers, donors, and researchers who host the International Conference series on Climate Services. The CSP has already authored a document¹⁶ framing principles of practice and product that includes CIWs. Similar is the climate knowledge brokers (CKB) group, an alliance of knowledge brokers specializing in climate information. The next step for these communities is to begin to integrate and establish more foundational frameworks and principles to steer the evolution of CIWs within climate services.

These emerging communities of practice face a significant challenge—to broaden their activities to cohesively establish an evolving information ecosystem essential for supporting decision-makers to be able to robustly contextualize climate information in regard to place, time, and vulnerability. This includes: engaging in development of complementary nonclimate information products (socioeconomic in particular) relevant to the management of complex socioecological systems; fostering research for developing distillation methodologies to integrate multi-scale, multimodel, and multimethod climate data; and building a knowledge base of guidance materials for capacity development to help decision-makers manage the complexity of issues such as bias correction, model selection, matching socioeconomic drivers with concentration-driven climate simulations,

climate uncertainty, coproduction and coexploration of information, data distillation, limits to information, and more.

The CIW is arguably a central vehicle to achieve much of the above, especially where the user demand greatly outstrips the climate services' human capacity. However, there are important limitations to CIWs through which dialog and coexploration between user and scientist is not possible. The limited or nonexistent interaction is compounded by any inadequacy of guidance material that is accessible to the skill level of users—most especially when it comes to distilling messages across disparate data sets. In this regard, as Adams et al.¹⁶ point out, it is appropriate to consider which framing considerations will best help to advance CIWs (and are equally applicable to the broader climate services). Three broad areas can be identified as:

1. *The ethics of information.* The act of providing information into an environment of adaptation investment and action carries serious responsibilities. Adams et al.³⁷ consider a framing of honesty, transparency, and humility, and go into detail on principles of practice and principles of product. However, there is no binding authority able to mandate a code of conduct and the borderless nature of the internet effectively permits any form of CIW to exist with no accountability. How CIWs evolve thus depends on community agreement and on user awareness of responsible practice by both users and providers. To achieve this requires greater visibility and discussion of these issues in the literature of the relevant academic and practitioner communities, as well as structures to facilitate this dialog. Both of these are emergent, and in this way CIWs may evolve a community of peer accountability, while users gain an enhanced awareness of what to expect and demand of a CIW.
2. *The interface to the information.* As is readily apparent from the assessment, an overriding experience of the CIWs is how difficult it is to navigate the sites and how users thus make compromises in order to achieve a result. Central to this problem is that, in general, current interfaces maximize options of choice and data sets with no structured approach to filtering—simplification is needed. Distillation is key to achieving this, but likewise there is a need to evolve methods to identify problems in the data and structure the interface to help users focus

on which information credibly serves their needs, and especially to provide guidance on how to use the resources of different CIWs responsibly.

3. *The defensibility of the information.* This is intimately coupled to the issues in (1) and (2), and speaks to the responsibility of the CIW to guard against data being inferred as information when that is not warranted. This is an integrity issue, but is also predicated on the CIW evolving the capacity to identify and understand the information limits of the data and to use this understanding to design their delivery and communication.

The CIW landscape is prolific and makes a substantial contribution to closing the gap between science and the decision-maker who wrestles with adaptation investments and policies. At the same time, there are deep issues embedded in current practices that raise concerns about real-world consequences tied to the current generation of CIWs. Thus, we would make three priority recommendations. First, that the disparate communities of practice engage more in greater dialog with each other and with the diverse user communities (including building bridges across cultural, regional, and language barriers) to develop a cohesive body of practice that is as responsive to the evolving bottom-up needs as it is formalized through top-down institutional structures. Second, and specifically in regard to the climate information component of CIWs, is the need to develop distillation

methodologies to bridge the confusion arising from the varied messages of different data products. Third is for user guidance materials to be developed on the application of the growing resource base, appropriately targeted to the different capacities of user communities, along with commensurate capacity development that is needed equally within both the provider and user communities.

In conclusion, the emergent community around climate services and the increasing recognition of the issues highlighted in this article suggest that there are substantial opportunities for CIWs to mature and valuably contribute to more robust climate services.

NOTES

^a Examples include the following websites, archived on July 11, 2016 on

- WayBack Machine (<https://archive.org/web/>)
- Cornell University: “New website is ‘one-stop-shop’ for climate change info” (<http://tinyurl.com/gof4t9z>)
- NOAA: “Water resources dashboard provides ‘one-stop-shop’” (<http://tinyurl.com/z8nlrtl>)
- UK Government: “One-stop-shop for adapting to climate impacts” (<http://tinyurl.com/jedafrh>)

^b <http://cip.csag.uct.ac.za>

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