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Identifying research priorities to advance climate services

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ABSTRACT

Climate services involve the timely production, translation, and delivery of useful climate data, information, and knowledge for societal decision-making. They rely on a range of expertise and are underpinned by research in climate and related sciences, sectoral applications (e.g., agriculture, water, health, energy, disasters), and a number of social science fields, including political science, sociology, anthropology, and economics. Feedback and engagement between these research communities and the communities involved in developing and/or using climate services is thus critical, ensuring that climate services are built on the best available science and providing researchers with guidance regarding priority challenges in the development of climate services that should warrant their attention.

This paper reports the results of an international survey to gauge community perspective on research priorities for climate services, highlighting several areas in which respondents agree on the need for future work. The survey results indicate an overarching interest in research that can better connect climate information to users, particularly around the communication of climate information, the mapping of climate information needs, and the evaluation and prioritization of capacity building efforts. They also reveal significant interest in climate research to advance the skill of forecasts at subseasonal-to-seasonal scales – considered more broadly useful to decision makers than information at the end-of-century timescale – and to identify the drivers of extreme events. To support climate-related research, survey respondents underscore the need to continually develop and maintain the observational network.

In analyzing these results, the paper offers guidance to researchers and to other members of the climate services community that may find these priorities useful in directing their own work to address the challenges posed by climate variability and change.

1. Introduction

Climate services involve the timely production, translation, and delivery of useful of climate data, information and knowledge for societal decision making (National Research Council, 2001). They are intended to facilitate both climate mitigation and adaptation to climate variability and change, widely recognized as important challenges to sustainable development in both the developed and developing world (Asrar et al., 2012; Wahlström, 2009). Interest in climate services has grown in recent years, particularly as attention to – and the quality of available information about – the climate system has increased (Giannini et al., 2016; Vaughan and Dessai, 2014; Visbeck, 2008).

The need for better coordinated and standardized climate services has both led and responded to the Global Framework for Climate Services (GFCS), a UN structure focused on improving the production, delivery, and application of climate information around the world, which was first implemented in 2011 (Hewitt et al., 2012). The GFCS is built on five "pillars," which represent the different stages of the value chain that support the production and application of climate services; these pillars are:

- A ***user interface platform***, which seeks to create and improve the ways in which climate service users and providers interact to identify needs and capacities;
- ***Climate services information systems*** to produce and distribute climate data, products and information according to the needs of users and to agreed standards;
- ***Observations and monitoring*** necessary to generate the data for climate services according to agreed standards;

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- ***Research, modeling and prediction*** to harness science capabilities and results and develop appropriate tools to meet the needs of climate services;
- ***Capacity development*** to support the systematic development of the institutions, infrastructure and human resources needed for effective climate services (WMO, 2014).

The GFCS Implementation Plan lists activities required to move forward under the five pillars. The Implementation Plan does not, however, identify priorities for research under each of the pillars – not even for the pillar that explicitly mentions climate research, modeling and prediction. Nor does the Implementation Plan attempt to qualify which of the pillars require more urgent attention (WMO, 2012, 2014). This leaves researchers without specific guidance regarding the sorts of topics that would be immediately useful to advancing the development, delivery, and use of those services in pursuit of increased resilience to climate variability and change.

Indeed, while the development of climate services generally occurs in the operational realm (Vaughan, Dessai, & Hewitt, in prep), research is needed to advance relevant climate and related science in ways that directly address the persistent challenges that limit use and utility. While a number of outlets allow members of specific research communities to communicate with each other, there are far fewer mechanisms that allow operational climate service providers and consumers to engage in two-way dialog on the questions they would like addressed by the research community. This two-way communication is essential given the overwhelming evidence that climate services are most useful when they are developed as part of an iterative process of "co-discovery," "co-development," and "co-evaluation" involving the producers and users of climate information (Dilling and Lemos, 2011; Steynor et al., 2016; Vaughan, 2010).

This paper addresses this lacuna by reporting and synthesizing the results of a survey that asked climate service professionals (described in more detail below) to report their own perceptions regarding priorities for research with respect to the GFCS five pillars. While the results of the survey cannot be seen as comprehensive, the paper highlights several areas of wide agreement, offering perspective on the state and evolution of research in key fields and geographic areas. The paper also offers recommendations on where resources may be expected to have the greatest impact in helping to develop, deliver, and exploit climate services for societal gain.

2. Methods

This paper reports the results of a survey issued by the Climate Services Partnership Working Group on Research Priorities, which was formed at the third International Conference on Climate Services, held in Montego Bay, Jamaica in 2013.

The working group received input from experts on their perception of research priorities in a number of geographic and sector areas (e.g., policy, agriculture, health, the Caribbean, Latin America, etc.). It also reviewed documents that addressed the concept of prioritizing research to advance climate services, including documents issued by the World Meteorological Organization (WMO, 2012), the World Climate Research Program (Busalacchi and Asrar, 2009; Ghassem and Hurrell, 2013), the Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (Rosenzweig and Horton, 2013), the European Joint Programming Initiative's Strategic Research and Innovation Agenda, the US National Weather Services (CFI Group, 2013) and the research priorities of a number of European projects (e.g., DRIAS, EUPORIAS, SPECS, NACLIM, CLIM-RUN, CORE-CLIMAX, ECLISE, etc.)

This led to the development of a 28-question survey, which was shared in a pilot phase with 25 individuals from 15 organizations involved in climate service development and delivery on 6 continents. Comments on this pilot survey were incorporated into a finalized version of the survey, distributed widely in November 2014. The survey asked respondents to report basic information about themselves and their work and to rank their priorities for research to advance climate services based on the GFCS pillars. The survey also asked respondents where investments were most needed and likely to make the biggest impact. The survey itself is found in the Appendix.

The survey reached distribution lists associated with the Climate Service Partnership; the European Climate Observations, Modeling, and Services (ECOMS) initiative; the US Regional Integrated Science Assessment (RISA) program; the Latin American Observatory for Extraordinary Events (OLE2); the Global Framework for Climate Services (GFCS); and the World Meteorological Organization (WMO) Commission for Climatology (CCI).

3. Results

The survey received 320 responses. The questions were divided into four sections covering (1) demographic information; (2) priorities within the GFCS five pillars; (3) most and least developed areas; and (4) impact. Results of each section are summarized below.

3.1. Demographic information

Organizations: Though respondents were not required to include information about themselves or the organization in which they work, more than 200 did so. Nearly 40% of these respondents indicated they were affiliated with meteorological and hydrological services, including in Africa (16), Asia (8), Australia & the Pacific (5), Europe (22), Latin America & the Caribbean (16), and North America (12). Universities (49), research institutes (24), and NGOs (18) were also well represented in the study. Thirteen respondents reported their affiliation to a government agency other than a meteorological or hydrological service; 12 identified an affiliation with a private company and four with intergovernmental organizations (e.g., WMO, WHO, and UNDP).

Organizational roles: All respondents were asked to identify the roles that their organizations play in developing or using climate services; 319 chose to do so, selecting more than one role where appropriate. The most commonly selected roles were applied research (197); climate service provider (167); and fundamental research (127). Ninety-three of 319 respondents identified themselves as climate service users.

On average, respondents chose 2.5 roles for their organizations. A majority (70% or more) of respondents who identified themselves as providers, users, or as engaged in fundamental research also identified themselves as involved in applied research. More than 50% of respondents from national government organizations or national NGOs also identified themselves as involved in applied research. More than a third of all respondents who identified as providers also identified as users; conversely, 63% of respondents who identified as users also identified as providers.

Respondents were given an opportunity to add textual responses to this question if they found the survey options limiting. Eight respondents used this option to describe the role of boundary organizations; seven respondents identified roles that had to do with education – including capacity building, training of graduate students, and knowledge management.

More on this is included in Table 1 below.

Table 1
Co-identification of organizational roles. Reading top to bottom, table shows the total number ("Total") of people who report their organizations playing any particular role, as well as the subset of those people who report their organizations playing any other role (e.g., 35% of the 167 respondents who identified themselves as "providers" also identified as "users").

	Provider	User	Fundamental research	Applied research	Sectoral research	Int'l NGO	National NGO	National gov	Municipal gov
Total	167	93	127	197	56	16	12	112	7
Subset of respondents that co-identified in other roles									
Provider		63%	65%	59%	50%	19%	42%	63%	43%
User	35%		32%	35%	41%	44%	58%	27%	29%
Fundamental research	50%	44%		48%	46%	19%	25%	38%	43%
Applied research	70%	74%	75%		77%	44%	58%	53%	43%
Sectoral research	17%	25%	20%	22%		13%	33%	11%	29%
Int'l NGO	2%	8%	2%	4%	4%		50%	5%	14%
National NGO	3%	8%	2%	4%	7%	38%		5%	14%
National gov	42%	32%	33%	30%	21%	38%	50%		57%
Municipal gov	2%	2%	2%	2%	4%	6%	8%	4%	

Table 2
Co-identification of individual roles. Reading top to bottom, table shows the total number of people who report being engaged in any particular activity, as well as the subset of those people that report being involved in any other activity (e.g., 48% of the 192 people who reported producing climate information also identified themselves as tailoring climate information).

	Producing climate info	Tailoring climate info	Comms of climate info	Climate-informed decisions	Policy development	Funding climate science	Funding application of climate info	Development of CS projects
Total	192	144	186	101	36	25	30	139
Subset of respondents that co-identified in other roles								
Producing climate info		65%	63%	48%	42%	52%	47%	63%
Tailoring climate info	48%		58%	60%	44%	44%	57%	65%
Communication of climate info	61%	75%		72%	69%	64%	67%	75%
Climate-informed decision making	30%	42%	39%		56%	52%	63%	41%
Policy development	8%	11%	13%	20%		40%	37%	15%
Funding climate science	7%	8%	9%	13%	28%		43%	11%
Funding application of climate info	7%	12%	11%	19%	31%	52%		16%
Development of CS projects	45%	63%	56%	56%	53%	60%	73%	

Individual responsibilities: Respondents were asked to identify their individual responsibilities; 319 respondents chose to do so, selecting more than one activity where appropriate. A majority of respondents reported being engaged in the production (192), communication (186), or tailoring (144), the development of climate service projects (139) and climate-informed decision-making (101).

On average, respondents identified themselves as engaged in 2.5 activities. While producing of climate information was slightly more common than communicating climate information, communication of climate information co-occurred with other activities most commonly. This is shown in Table 2, below.

Geographic focus: The geographic focus of respondents' work is relatively varied, with no one region claiming more than a quarter of responses (total responses = 319) (see Table 3).

Sectoral focus: The sectoral focus of respondent's work is also varied, with respondents choosing, on average, 3.5 responses (total responses = 295). A majority of the respondents associated themselves with the water, agriculture, and disaster sectors (see Table 4).

Specific issues: The survey asked respondents to describe the specific problems their work addresses. Textual responses were coded into six broad categories, including fundamental climate science, tailoring and transferring of climate information, assessing impacts, decision making, capacity development, and project development. More information is included in Table 5.

Table 3
Geographic focus of respondents' work.

Geographic focus	Number of responses
Europe	88
Africa	83
Global	72
South America	59
Asia	57
North America	54
Central America & the Caribbean	30
Australia & the Pacific Islands	20

Table 4
Sectoral focus of respondents' work.

Sector	Number of responses
Water	226
Agriculture	222
Disasters	170
Health	130
Energy	130
Infrastructure	93
Transport	81
Financial instruments	36

3.2. Five pillars

Respondents were asked to rank priorities within each of the five GFCS pillar areas; a binomial test was used to assess statistical significance ($p < 0.05$) of the difference in the most 'extreme' ranks (i.e., 1 and 5), compared to the middle one (i.e., 3). 263 responses were received for each of the five within-pillar rankings; 249 respondents ranked the priorities themselves. Results of the statistical tests are included in the Appendix.

Connecting information to decision making: Responses to this question were divided regarding the top priority in this pillar, with

Table 5
Summary of specific issues that respondents engage.

Topic	Frequency	Themes
Fundamental climate science	64	Data collection and quality control monitoring, forecasting, understanding extreme events
Tailoring and transferring of information	58	Making information more useable by communities, social science work to understand decision contexts, the development of decision support tools and early warning systems
Assessing impacts	31	Modeling of impacts, economic assessments, and vulnerability assessments
Decision making	16	Climate risk management, planning, and policy development
Capacity development	11	Training of personnel, building information systems, technical support to meteorological services, etc.
Project development	5	Articulating plans for national-level climate services

a third of respondents most interested in understanding effective communication of uncertain information and another third more interested in mapping climate information needs in particular locations.

Conversely, nearly two-thirds of respondents identified explicating the role of law in climate service provision and use as a lower priority than the other options offered. Since respondents were forced to rank the five items in each grouping, the results do not indicate that respondents consider those items given a low priority to be unimportant, simply that they do not consider them as important as higher-ranked items.

Respondents were able to offer their own thoughts regarding the research priorities for connecting climate information to decision makers. There were 47 responses to this question, with seven focusing on understanding users' needs, contexts, and capacities; six underscoring the need to improve communication; and four specifically mentioning the tailoring of information.

Observations and monitoring: Of the 263 responses to this question, 65% saw enhancing the observational network as the top priority and 46% viewed improving chemical observations of the climate as the lowest priority. Nearly half of the 90 respondents who took the opportunity to write additional comments regarding research priorities for climate services underscored a need to enhance and maintain the observational network. Other respondents addressed the need to integrate existing data into existing tools (8), to make better use of that existing data for the development of new tools (5), and to engage in data rescue (4).

Modeling and prediction: Responses to this question showed a clear preference for improving sub-seasonal to seasonal forecasts and understanding the drivers of extreme climate. Respondents were also clear that other options (downscaling, decadal prediction, non-linear impacts) were lower priorities. Seventy-one respondents supplemented their answers with textual information around three topics.

For instance, 17 respondents stressed that subseasonal-to-seasonal information was the most useful to society, with some pointing out that their timescale for long-term decision making was six months, or a few decades at most. Eight respondents pointed out that models could not be improved if the fundamental processes of the climate system were not better understood, and underscored the need to consider the physical processes at work. Finally, six respondents stressed the need to make better use of existing information, rather than increasing the amount of information available.

Climate information systems: Out of 263 responses, roughly one-third indicated that improving availability and access of climate information was a top priority, and another one-third prioritized the development of practical methods for integrating climate knowledge as most important. More than half saw the development of hardware for analyzing and interpreting model and observational information as the lowest priority. The textual comments underscore the community's focus on the first two priorities: 11 out of 55 responses emphasized the need for data sharing, while ten suggested that data management systems needed to be made accessible to a wide range of people.

Capacity building: Respondents had different opinions regarding priorities for capacity building, with the highest percentage of respondents suggesting that case studies to identify good practice were a top priority. Conducting country-specific capacity assessments and exploring the possibilities for e-learning were clearly identified as lower priorities. There were 41 textual responses associated with this question, though they did not converge around particular themes.

Prioritizing pillars: The survey asked respondents to rank the pillars themselves, indicating in which of the five they thought research was mostly likely to improve the efficacy of climate services in the near term. More than 40% of respondents ranked connecting climate information to decision making as the most important area for research; 30% prioritized observations and monitoring. The responses also clearly identified the systems by which information is archived, analyzed, exchanged and processed as a lower research priority.

3.3. Most developed areas and sectors

Respondents were asked about the sectors and geographic areas in which they believe climate services are most/least developed.

Geographic areas: The majority of respondents reported seeing climate services as most developed in Europe (75%) and North America (70%). More than 75% of all respondents reported perceiving climate services in Africa as least developed, while 35% indicated they believed climate services were least developed in Central America and the Caribbean.

Sector areas: There was somewhat less consensus regarding the development of climate services in different sector areas. In general, respondents saw agriculture (63%) and water (52%) as more developed than other areas; 55% of respondents indicated that they saw health as the least developed sector.

3.4. Prioritizing future investments

Respondents were asked where they believed investments in research were likely to make the biggest impact in the near term; the 253 responses to this question are varied, falling into three general categories.

Specific sectors: Seventy-eight respondents suggested that investments would make the biggest impact in targeting climate services to specific sectoral applications; 45 of these respondents mentioned agriculture. These 45 respondents include 28 people who described their own work as engaging the agricultural sector, though only 3 who engaged the agricultural sector exclusively. Respondents in this subset reported that their work engaged an average of 3.2 sectors.

Applications research: More generally, 34 respondents indicated that investments in "applications" research were likely to have the biggest impact, including the development of decision support systems, methods to integrate climate information into decision making, and work at the interface between how science is produced and how it is used, tailored, and communicated. Nine of these responses specifically focused on understanding users needs. Respondents who identified this priority were most likely to categorize the roles played by their organization as applied climate research (28); information predicted (25); or fundamental climate research (19). Twelve respondents in this group identified as climate information users.

Climate research: Thirty-nine respondents mentioned improved climate research, including issues related to forecasting, modeling, and prediction. Within this group of 39, respondents most commonly identified the roles of their organizations played as applied climate research (29); climate information provider (27); and fundamental climate fundamental climate research (18). Conversely, only 9 among this group of 39 identified their organizations as engaged in sectoral research; only 8 identified their organizations as user organizations.

4. Discussion

The survey was relatively successful in reaching a diverse range of international stakeholders that contribute to the climate service community, including people whose primary affiliations are national meteorological and hydrological services, research institutes and universities, private-sector actors, NGOs, government agencies, and intergovernmental organizations. Nearly a third of all respondents considered themselves climate information users. Though the results should not be seen as comprehensive, they do allow for several conclusions regarding the composition and perceived priorities of the climate service community.

4.1. Demographics

The survey results underscore the extent to which climate services represent a growing field. Indeed, the majority of respondents who identified themselves as either users or providers also reported being engaged in research – though in many cases, these research activities may not engage traditional academic settings. As a result, it is important for the climate service field to find ways to capture and widely share the results of research conducted in operational contexts, allowing the larger community to benefit from lessons learned in non-academic settings. Conferences and reports that highlight the work of the operational community may partially serve this role.

The survey results also highlight the extent to which people engaged in climate services play many roles; indeed, the results make it clear that a diverse range of actors see themselves as simultaneously involved in the receiving, tailoring, *and* distributing climate information. These results also seem to corroborate a growing sense within the climate services community that a strict separation between the "users" and "providers" of climate information is not (or is no longer) valid, particularly since as 63% of respondents who identify as users also identify as providers.

In the research literature, actors who play these different roles are often called "intermediaries" (May et al., 2013; Stigter, 2010) or, increasingly, "climate knowledge brokers" (Hammill et al., 2013; Meadow et al., 2015; Reinecke, 2015). Many of the survey respondents report playing roles described by (Michaels, 2009) as "knowledge-brokering strategies" – particularly since more than half report being involved in the communication of climate information. Indeed, there is no category of activity (producing, tailoring, funding of climate information, making policy, etc.), in which fewer than 60% of survey respondents co-identified as engaged in communication.

The centrality of communication to climate services, as indicated by the survey results, is matched by an increasingly diverse literature that engages climate-related communication. Much of this research draws on social and decision science, particularly where challenges posed by the communication of climate science are typical of challenges faced in other fields with technical content (Brulle et al., 2012; Corner et al., 2012; Pidgeon and Fischhoff, 2011). This work has resulted in the identification of several lessons regarding the way that mental models and social processing affect risk perception and the evaluation of response options, particularly with respect to long-term climate change (Marx et al., 2007; Morton et al., 2011; Weber, 2010).

Related research has explored models for the communication of uncertainties – both those associated with climate science, and those associated with adaptation and/or other response options (Moser, 2010a; Patt and Dessai, 2005; Patt and Weber, 2014; Taylor et al., 2015). This includes the exploration of best practice in the tailoring of climate information for specific audiences (Adams et al., 2015; Jones et al., 2015), particularly with respect to appropriate use of language (Fløttum and Dahl, 2012; Nerlich et al., 2010) and visualizations (Daron et al., 2015; Davis et al., 2015; Lorenz et al., 2015).

While this range of work has been valuable, the current survey shows it has not sated interest on the part of the climate services community to continue to explore issues around communication, particularly with respect to uncertainty. The survey may also reflect a disconnect between the research and operational fields: Even in cases in which research on the communication of climate information has been conducted, lessons on best practice may not quickly flow to the operational community. Efforts to take advantage of "boundary chains" (Kirchhoff et al., 2012; Lemos et al., 2014) and/or "knowledge networks" (Bidwell et al., 2013; Corlew et al., 2015; Feldman and Ingram, 2009) may help in this regard.

4.2. Five pillars: connecting to users

One of the most significant results of the study is respondents' prioritization among the five pillars, with 40% stressing the importance of connecting information to users. Though a growing body of research has focused on the "usability" of climate information (Dilling and Lemos, 2011; Ford et al., 2013; Kalafatis et al., 2015; Kirchhoff et al., 2013; Tang and Dessai, 2012; Wong-Parodi et al., 2014), this field is not as well developed as those around in climate modeling and prediction. Moreover, the "usability" of climate information continues to evolve along with advances in climate science.

Building the volume and sophistication of research focused on connecting information to users will require better engaging the social science community, including from disciplines including psychology, anthropology, sociology, decision science, and economics, etc.

Within this pillar, survey respondents also note a particular interest in the issue of mapping information needs. This includes the development and codification of methodologies that link climate-related information to particular capacity and vulnerability contexts, information decisions related to research and uptake (Thornton et al., 2006, 2014). The development of such methodologies requires the analysis not just of climate information, but also a range of social, economic, institutional, technological, ethical, organizational, ecological, and cultural issues related to how societies function.

Moser (2010b) points out that moving forward in this regard will require expanding vulnerability research both conceptually and geographically – including the development and monitoring of key vulnerability indicators and an improvement in our understanding of ripple effects and higher-order impacts, among other things. While many analyses have explored vulnerability at national or regional levels, or in a few key sectors, the community will also need to branch out to explore impacts, vulnerability, risk and adaptation in forgotten sectors and in places or at scales that are not much studied (Füssel, 2007; Moser, 2010b; Preston et al., 2011).

In addition to exploring vulnerability, the mapping of information needs requires work to characterize how and why decision makers are able to benefit from climate-related information – including studies that explore the fit, or lack thereof, between what decision makers think of as useful and what climate information providers can produce (Ingram and Stern, 2008; Porter et al., 2015; Rayner et al., 2005; Tribbia and Moser, 2008). This includes research into how communities currently use information (e.g., Bolson et al., 2013; Nordstrom, 2015), as well as their potential to use such information in the future (e.g., Ogallo and Oludhe, 2009; Scott and Lemieux, 2010).

Focusing on upstream issues, Weaver et al., 2013 have laid out an agenda to explore what they see as the severe underutilization of climate models as tools for supporting decision making. Improving the efficacy of these tools will require expanding our conception of climate models – not simply as prediction machines, but as scenario generators that provide insight into complex systems that allow for critical thinking within robust decision frameworks. More downstream, other researchers have explored the feasibility and effectiveness of different adaptation actions (Anwar et al., 2012; Biagini et al., 2014; Moser and Ekstrom, 2010; Moss et al., 2013). Moss, 2015 has also proposed research to evaluate decision support, shedding light on the kinds of tools that convey information in ways that are both useful and usable.

Given the diversity of work to understand and map climate information needs, it may be useful to create a repository of relevant information, allowing the community to share and compare the results of such studies even when they do not find their way into the peer-reviewed literature. An academic review of this material may also help direct operational actors to the knowledge most relevant to their work. This sort of activity will help the community to develop standards regarding the sorts of information, strategies, and methodologies that are useful in a variety of individual contexts, keeping in mind there is unlikely to be a single "best" way to develop specific services.

4.3. Five pillars: priorities in data collection, storage, and analysis

While prioritizing research that advances our ability to connect information to users, survey respondents identified priorities within the other four pillars, including a general agreement on the need to continually improve the climate observational network. Data scarcity is a major obstacle for creating and assessing the accuracy and precision of spatial interpolation of climatic fields, especially in climate-stressed developing countries (Bhowmik and Costa, 2014; Overpeck et al., 2011; Plummer et al., 2003; World Meteorological Organization, 2010).

While recent investments have targeted improving observations (Kaspar et al., 2015; United Nations Development Programme Climate Information for Resilient Development in Africa, n.d., World Bank Pilot Programme on Climate Resilience, n.d.), others have focused on rescuing and digitizing data that is locked in paper records (Brunet and Jones, 2011; Hawkins et al., 2013) or in developing merged satellite information products that allow for more accurate estimation of conditions in places, where data records are sparse (Dinku et al., 2016). Carrying forward on all of these fronts is clearly important to the climate services community.

Survey respondents also saw a need to increase the availability and accessibility of climate information systems. While interest in data sharing and accessibility is commendable, the best ways to organize and structure relevant information is still, in many cases, an open research question. For instance, recent reviews of climate information portals reveal a number of challenges posed by such websites; they also suggest that actors are confused and overwhelmed by the sheer number of information portals available (Climate Knowledge Brokers Knowledge Navigator, n.d.; European Environment Agency, 2015; Hammill et al., 2013; Hewitson and Waagsaether, 2016). Finding ways to improve and streamline delivery of actionable information will be important to the contribution to the climate service enterprise.

Within the pillar on modeling and prediction, respondents clearly identified a need to advance subseasonal-to-seasonal (S2S) prediction. Both the scientific and decision-making communities have shown broad interest in S2S prediction, which addresses the 20-to-90-day time range. A number of organizations are now involved in this research, with a particular focus on identifying sources of predictability, and on understanding and evaluating systematic errors, uncertainties, skill, and forecast methodologies in dynamical and statistical models. Although it is still too early to have actionable products for this timescale, promising results indicate the potential for skillful S2S forecasts that could be used in a range of sectoral applications (Robertson et al., 2015; World Meteorological Organization, 2015).

The community has also shown significant interest in understanding the drivers of climate extremes. This interest responds to two developments: First, the understanding that a warmer world will lead to changes in the occurrence and magnitude of extreme events, including droughts, heavy rainfall and floods, as well as shifting the geographic distribution of rain and snow (AghaKouchak et al., 2013) or reduced cyclone intensity (IPCC, 2012) and second, an awareness of various social processes, including poverty and uneven development, that have combined to make people and societies more vulnerable to extreme climate and weather events (Hellmuth et al., 2011).

In this regard, the IPCC's Special Issue on Extremes has helped to synthesize a range of issues (IPCC, 2012). More recently, progress in extremes-related research, along with a forward-looking research agenda, is articulated in a recent special issue of the journal *Weather and Climate Extremes* (Hay et al., 2015). Advancing this work is clearly a priority for the various stakeholders that are involved in the climate services community.

4.4. Five pillars: capacity building

There was much less agreement with respect to priorities in the pillar that engaged capacity building. While 30% of respondents prioritized case studies to establish good practice with respect to capacity building as a priority, responses in other categories fell closer to the expected value, indicating that there is no consensus regarding how to advance capacity building for climate services. This mix of response may also reflect different perspectives on what capacity building is, as well as the wide range of capacity building that is needed.

The GFCS itself identifies two very broad lines of work in this pillar area: (1) building the specific capacity required to deliver on the other four pillars; and (2) addressing the requirements (national policies/legislation, institutions, infrastructure and personnel) that would enable any GFCS related activities to occur (WMO, 2014). There is clearly a wide range of activities that fall under these headings, but much less research has been conducted on the sorts of efforts that are most needed, most effective, and/or those that should be prioritized in different contexts.

With respect to human capacity, work has focused on how to understand the determinants of success and to improve the ability of climate scientists and intermediaries working with users (Brugger et al., 2015; May et al., 2013). In the United States, McNie (2013) looked at efforts to build stakeholders capacity to absorb, understand and, utilize the information, finding that undemanded capacity building often laid the ground for future information demands by stakeholders, who often did not know what information they needed (McNie, 2013).

Other work has looked at the utility of games (Bachofen et al., 2012), deliberative processes (Hobson and Niemeyer, 2011), local knowledge (Jabeen et al., 2010), and art (Moser, 2014) to build capacity to understand and use climate information for decision making. Approaches that have received less attention include: internships, fellowships, and secondments (Ingram and Stern, 2008). Very little scholarship evaluates efforts to build capacity in terms of national policies/legislation, institutions, or infrastructure. Building this area of research will be important as the climate service field continues to develop. Separate studies may also be needed to map capacity building needs, and the efforts to meet them, in different contexts.

4.5. Most & least developed areas & impact

It is perhaps not surprising that respondents identified climate services as the most developed in Europe and North America; not only do resources likely play a part in this, the fact that more respondents hail from these locations provides a larger pool of respondents with first-hand knowledge of advances. Only 20 respondents (6%) reported working in Australia, for instance, in contrast to 88 (35%) for Europe and 54 (21%) for North America.

On the other hand, the majority of responses (77%) indicate that climate services are least developed in Africa, despite a relatively large number of respondents (26%) reporting work there. Similarly, more than half the respondents indicated that they perceived health as the least developed sector, though half the respondents also indicated their own work engaged health issues. Given the number of people working in this field, it may be reasonable to expect advances with respect to the climate services offered in these areas in the near future – though it may also be that certain characteristics of the sector have, and will continue to, slow progress.

It is telling that a great number of respondents see investments in climate services for agriculture as likely to make the biggest impact. Since many respondents (63%) see agriculture as the most developed sector, transferring and tailoring this expertise to other locations in Africa or Central America may result in big gains. Building out climate services in previously neglected areas will require significant research activities and should be prioritized by both research and funding organizations.

5. Conclusions

The survey results allow us to draw several broad conclusions about priorities within the climate services field.

First and foremost, the survey reveals an overarching interest in research that seeks to improve the connection between information and its intended users. Growing interest in this connection reflects a growing recognition on the part of the user community of the need to employ climate information to address challenges of variability and change. As evidenced in respondents' perspectives on their specific activities, it likely also reflects the fact that many in this field are regularly called upon to play many different roles (e.g., receiving, tailoring, and distributing climate information) and that most are engaged, in some way, in communicating climate information. In this context, building knowledge and skills needed to facilitate this connection has become a pressing concern for a wide range of actors.

Though it is unlikely to come as a surprise to many in the climate science community, the survey results underscore the need to continually invest in the observational network, and stress the need to maintain and build sustained, high-precision, and high-accuracy observational records that can facilitate improved understanding of the climate system, including the detection of subtle long-term trends. In many areas of the world, sufficient observational data is currently lacking, and without investments in basic observations, advances will be limited. Within the field of climate modeling and prediction, survey respondents prioritize advances in subseasonal-to-seasonal forecasting, which is seen as more immediately useful to decision makers focused on near-term resilience building than, say, increasingly advanced information about long-term trends.

The survey results have also called attention to several research areas that require more attention. These include strategies to communicate climate and related information, methodologies to understand and map climate information needs, and the evaluation and prioritization of human and institutional capacity building efforts. While research is underway in all of these fields, the survey results indicate that there is still a great deal of work to be done. This is particularly true of capacity building, which has received much less attention from the research community than both climate change communication and the mapping of information needs.

Researchers interested in climate services would do well to engage these topics, drawing on expertise in other relevant fields (education, institutional analysis, etc.) to help address specific issues where needed. Those with the ability to influence funding decisions should also take note of these results; though great advances have occurred in climate science in the last 30 years, building holistic services that can help societies to address the challenges of climate variability and change will require meeting research needs where they arise. Finally, climate information users and providers – and those who consider themselves intermediaries – should also make sure to share lessons they have learned around these topics, and to engage other researchers to help in their co-exploration.

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Appendix 1

Statistical significance of priorities regarding five pillars (1 = highest priority, 5 = lowest priority).

Answer Options	Rating Average	Response Count	Significant for 5	Significant for 1
Research priorities for CONNECTING INFORMATION TO DECISION MAKING				
Explicating the role of law in climate service provision and use	4.26	263	yes	no

(*continued on next page*)

(*continued*)

Answer Options	Rating Average	Response Count	Significant for 5	Significant for 1
Documenting how risk perception affects climate-informed behavior	2.83	263	no	no
Understanding effective communication of uncertainty	2.25	263	no	yes
Developing metrics to evaluate climate services	3.26	263	no	no
Mapping climate information needs in particular locations	2.40	263	no	yes
Research priorities for the advancement of OBSERVATIONS & MONITORING				
Enhanced observational networks for observational data	1.62	263	no	yes
Increased spatial and temporal resolution of satellite data	2.80	263	no	no
Improved chemical observations of the climate (carbon flux, ozone etc.)	4.08	263	yes	no
Soil and/or vegetation data	3.25	263	no	no
Crowdsourced weather & environmental data	3.25	263	no	no
Research priorities to advance MODELLING & PREDICTION				
Improved downscaled information about long-term climate change	3.30	263	yes	no
Improved seasonal to sub-seasonal forecasts	2.10	263	no	yes
Decadal prediction	3.49	263	yes	no
Understanding the drivers of extreme events	2.36	263	no	yes
Risks of non-linear impacts and tipping points	3.76	263	yes	no
Research priorities to advance SYSTEMS BY WHICH INFO IS ARCHIVED, ANALYZED, EXCHANGED, PROCESSED				
Availability & access to climate information in different regions & levels of society	2.22	263	no	yes
Development of hardware for analyzing & interpreting model & observational information	4.06	263	yes	no
Development of software for analyzing & interpreting model & observational information	3.14	263	no	no
Development of practical methods for integrating climate knowledge into decision making	2.25	263	no	yes
Interoperability of data sets	3.33	263	no	no
Research priorities regarding CAPACITY DEVELOPMENT				
Conducting country-specific capacity analyses	3.24	263	yes	no
Exploring long-distance capacity building through e-learning	3.53	263	yes	no
Developing case studies & identifying good practice	2.43	263	no	yes
Integration of social science methods into capacity building	2.94	263	no	no
Exploring how users build confidence and skills to understand probability	2.87	263	no	no
Research priorities ACROSS THE FIVE PILLARS				
Climate observations & monitoring	2.63	249	no	yes
Modeling & prediction of climate	3.20	249	no	no
Systems by which info is archived, analyzed, exchanged, processed	3.48	249	yes	no
Connecting climate information to decision making	2.55	249	no	yes
Capacity building	3.14	249	no	no

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