AGU PUBLICATIONS

Earth's Future

COMMENTARY

10.1002/2015EF000338

Key Points:

- The success of climate services has been hampered by the inadequate business model adopted so far
- To be effective, climate service providers should host under the same roof a diversity of specialists as well as stakeholders representing the corporate world and public services as well as social managers, engineers, and communication specialists
- International collaboration is key for strengthening the local and regional capacities in developing and emerging countries

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Citation:
Brasseur, G. P., and L. Gallardo (2016), Climate services: Lessons learned and future prospects, *Earth's Future*, *4*, 79–89, doi:10.1002/2015EF000338.

Received 10 NOV 2015
Accepted 11 FEB 2016
Accepted article online 15 FEB 2016
Published online 30 MAR 2016

Climate services: Lessons learned and future prospects

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Abstract This perspective paper reviews progress made in the last decades to enhance the communication and use of climate information relevant to the political and economic decision process. It focuses, specifically, on the creation and development of climate services, and highlights a number of difficulties that have limited the success of these services. Among them are the insufficient awareness by societal actors of their vulnerability to climate change, the lack of relevant products and services offered by the scientific community, the inappropriate format in which the information is provided, and the inadequate business model adopted by climate services. The authors suggest that, to be effective, centers should host within the same center a diversity of staff including experts in climate science, specialists in impact, adaptation, and vulnerability, representatives of the corporate world, agents of the public service as well as social managers and communication specialists. The role and importance of environmental engineering is emphasized.

1. Introduction

In a report published in 2001, the US National Academy of Sciences [*National Research Council (NRC)*, 2001] highlighted that "climate is becoming an increasingly important element of the public and private decision-making process" and that "the timely delivery of useful products through direct and accessible user interface" could limit national risks. Historically, climatology had focused to a large extent on the statistical analysis of weather records, but, as noted by the authors of the report, new advances in our understanding of the climate system have provided the opportunity to perform experimental predictions of seasonal-to-interannual climate patterns, and more reliable climate projections on the decade-to-century timescales. The same Academy report provided a definition of what could become operational climate services: *The timely production and delivery of useful climate data, information, and knowledge to decision makers*. The report identified five conditions for climate services to be successful: (1) the activities and elements of a climate service should be user-centric; (2) the climate service function should be supported by active research; (3) advanced information (including predictions) on a variety of space and time scales is required to serve national needs; (4) the climate services knowledge base requires active stewardship; and (5) climate services require active and well-defined participation by government, business, organized civil society, and academia. Table 1 provides other and slightly different definitions of climate services.

At the World Climate Conference-3 organized in 2009 by the World Meteorological Organization (WMO) (https://www.wmo.int), a Global Framework for Climate Services (GFCS) [*Hewitt et al*., 2012] was established "to guide the development and application of science-based climate information and services in support of decision-making." The vision expressed at this conference was "to enable society to better manage the risks and opportunities arising from climate variability and change, especially for those who are most vulnerable to such risks." The initial sectors retained for priority action were agriculture and food security, water, health, and disaster risk reduction. The framework focuses on the delivery of information and capacity building, specifically in developing countries, and where hydrometeorological services can provide capacity and infrastructure. Many developing countries are particularly vulnerable to extreme meteorological and hydrological events, and climate services should be designed to help minimize climate-related risks in these regions.

Different national or regional initiatives followed the vision expressed by the World Climate Conference-3: In different countries, meteorological services started to extend their activities from the traditional

Table 1. Different Definitions Adopted for Climate Service

Source	Definition
National Research Council [2001]	The timely production and delivery of useful climate data and knowledge to decision makers.
Global Framework of Climate Services (GFCS)	Climate information provided in a way that assists decision making by individuals and organizations. Requires appropriate engagement along with an effective access mechanism and must respond to user needs.
Climate Services Partnership (CSP)	Production, translation, transfer, and use of climate knowledge and information in climate-informed decision making and climate-smart policy and planning.
Joint Programme Initiative (JPI-Climate)	User-driven development and provision of knowledge for understanding the climate, climate change and its impacts, as well as guidance in its use to researchers and decision makers in policy and business.
European Commission [2015]	Transformation of climate-related data—together with other relevant information—into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessments), counseling on best practices, development and evaluation of solution, and other services in relation to climate that may be of use for society at large. Includes data, information, and knowledge that support adaptation, mitigation, and disaster risk management.

weather forecast activities to the provision of climate information and data [*Miles et al*., 2006]. Interdisciplinary projects in universities and research centers were initiated with the purpose of assessing society's vulnerability and proposing science-based approaches in support of adaptation policies.

After several years of activities, it is important to assess to what extent the original vision has translated into successful initiatives. Have the existing climate services responded to the needs of different actors in society? And more fundamentally, do the needs of potential stakeholders that have been identified more than 10 years ago really exist? Is there a market for climate services and has the information provided by the scientific community already influenced corporate decisions or policies by public authorities? Perhaps the real level of success of climate services is best measured by evaluating the rate and quality of changes implemented by their customers in their attempt to mitigate climate change or to adapt to expected climate impacts.

The purpose of this paper is to provide some personal views on the role and achievements of recently established climate services, and to propose ways to make them more effective in providing usable information. The paper provides an overview of the developments of climate services, discusses the role of providers and users, describes some limitations of climate services, and proposes some possible ways to overcome these limitations.

There has been considerable discussion among economists about how to drive innovation and bridge knowledge across the "Valley of Death" between research, development, market orientation, and commercial exploitation of technological products [*Marczewski*, 1997; *Wessner*, 2005; *Barr et al*., 2009]. Some of these approaches have been discussed in the context of environmental problems, and specifically to narrow the gaps between providers and users of climate knowledge [*Lemos et al.*, 2012]. These studies have introduced the concepts of sustainability, resilience, vulnerability, and climate adaptation [*Weaver et al*., 2014], which are useful to analyze the response of society to climate change and to manage climate-related risks. The need for scientists and practitioners to codesign and coproduce applied research has been highlighted as the central approach adopted by international programs such as Future Earth (http://www.futureearth.org) to develop a more effective participating process (bottom-up approach). The challenge is to evolve from the concept of *useful* information to the concept of *usable* information [*Lemos et al*., 2012], and to provide the intellectual support required to accelerate different society's transformation toward sustainability. These studies have provided the theoretical framework under which climate services centers operate. Practical implementation of the proposed concepts has revealed some serious challenges that will be highlighted in the next Sections. The paper is not a comprehensive review or an objective study that intends to measure how well climate services have successfully turned knowledge into action. Rather, it presents a few remarks, perhaps somewhat provocative, based on personal experience and in some cases on anecdotal observations. The paper presents a few ideas that could improve the credibility, effectiveness, and performance of climate services. It concludes with a few suggestions on a desirable model for climate services and the new role of service providers following the conclusion of the COP21 agreement in Paris.

2. International Initiatives

A pioneering event that led to the recognition of the societal importance of environmental issues has been the United Nations (UN) Conference on the Human Environment that took place in Stockholm, Sweden, in 1972 [*United Nations*, 1972]. This landmark event, a predecessor of the Rio conferences of 1992 and 2012, highlighted the importance of global environmental problems, and recognized the role of science and technology, research and education as well global cooperation as essential for protecting the Earth's environment in the future. The United Nations Environment Programme (UNEP) (http://www.unep.org) was created in 1972 soon after the Stockholm conference. Two international research programs were established in the following years: the World Climate Research Programme (WCRP) (http://wcrp-climate.org), whose stated objective at that time was to assess climate predictability and project the response of the climate system to human activities, and the International Geosphere Biosphere Programme (IGBP) (http://www.igbp.net/) with the objective of investigating the links between the Earth's biological, chemical, and physical processes and their interactions with human systems. Both programs mobilized a large interdisciplinary community of scientists in different parts of the world, and developed an active portfolio that became the intellectual basis for providing authoritative science-based information to policymakers.

The Intergovernmental Panel for Climate Change (IPCC) (http://www.ipcc.ch) established in 1988 under the auspices of the WMO and the United Nation Environment Programme (UNEP) was a major attempt to disseminate information on the outcome of climate research and particularly in support of the United Nations Framework Convention on Climate Change (UNFCC) (http://unfccc.int/2860.php). The Panel does not carry its own research, but has produced and published every 6–8 years detailed assessments of the scientific literature that includes quality-checked scientific information of relevance for policymakers.

The IPCC process has been directly useful to international negotiators who have been involved in the Conference of Parties (COP) of UNFCCC. It constitutes the scientific basis for international discussions and serves as a reference because it presents a consensus view from the scientific community in spite of the organized voices from some "climate deniers" who questions the entire IPCC process and some of its conclusions. Increasingly, IPCC reports have taken a broad and global perspective dealing not only with the physical climate system, but also with issues related to impacts, vulnerability, mitigation, and adaptation. In spite of this broadening of the approaches, the information found in the IPCC reports does not necessarily address concrete climate-related questions posed by individual economic sectors, corporations, and public services. Users are increasingly asking for relevant and specific solutions to be implemented as part of their business. Such requests go beyond the mission of IPCC, which is to provide policy relevant, but not policy prescriptive information. As a result, regional impact assessments nowadays included in the IPCC fall short of addressing the needs of subregional policy and decision makers, particularly in developing countries where national capacities are insufficient to satisfy those needs. Easily accessible, timely and authoritative information about climate is required to help individuals, corporations, and government agencies to make informed decisions in support of their business and of their community.

3. The Establishment of National Climate Services

Following the 2009 decision made at the World Climate Conference-3 by Heads of States, Ministers, and Heads of delegation to launch the GFCS, different meteorological services decided to establish climate services. The United States of America, for example, recognized that up to one third of its gross domestic product depends on accurate weather and climate information [*Dutton*, 2002] and that a reorganization of National Oceanic and Atmospheric Administration's (NOAA's) dispersed climate capabilities under a single line office would more efficiently respond to America's increasing demand for scientific data and for climate information [*NOAA, Vision and Strategic Framework*, 2010]. The attempt by the US to create a national climate service failed, however, because Congress did not provide the budget requested to develop such a service. "Our hesitation," said Rep. Andy Harris (R-Md.) at a hearing in June 2011, "is that the climate services could become little propaganda sources instead of a science source." [*United States House of Representatives*, 2011]

In Europe, the UK's Meteorological Office realized that its expertise in weather forecasting and services could be used to assess climate risks, and, as part of its commercial objectives, has organized itself to advice public and private sectors on climate-related issues (http://www.metoffice.gov.uk). With the support of a substantial marketing effort and the creation of a new team of applied scientists and consultants, the Office developed an end-to-end delivery chain extending from core climate research to model prediction, information translation, service development, and customer delivery. Two key areas of the UK effort have been the development and production of seamless operational forecasts for periods ranging from weeks to decades ahead, and the translation and application of these forecasts to add value for the users and decision makers. In Germany, the *Deutsche Klima Dienstleistung* (DKD or German Climate Service), a national network of agencies and offices provides long-term climate information, and the German Institute for Climate Services (GERICS) of the Helmholtz Association, provides regional climate projections and advise on climate adaptation. Other initiatives, often with the support of weather services, were taken in France, the Netherlands, Norway, and other European countries. The European Commission took a very different stand than the US Congress. Beside an ambitious research program within the Horizon-2020 program, it launched in 2015 a preoperational "Copernicus Climate Change Service (C3S)" to be operated by the European Centre for Middle Range Weather Forecast (ECMWF) in Reading, UK. This initiative complemented the implementation of atmosphere, marine, and land monitoring services, now under the EU Copernicus Program as well as major investments in research and development projects.

Contrary to the "top-down" approach taken, for example, by meteorological services, several university departments and research centers adopted a more "bottom-up" approach, and focused on questions related to climate impacts, social vulnerability, and adaptation to climate change. The Potsdam Institute for Climate Impact, the International Research Institute for Climate and Society at Columbia University, and the International Institute for Applied System Analysis in Laxenbourg, Austria, for example, have developed pioneering programs on the governance of the social–ecological systems and on the transformation needed to deal with societal change. National initiatives developed around this philosophy include the UK Climate Impact Programme (UKCIP) at Oxford University in collaboration with the UK Met Service, which provides practice-based advises to help organizations, sectors, and governments adapt to climate change. Here, the academic communities involved are very different from those involved in the traditional climate research; they include specialists in economics, social science, political science, governance, communication, etc.

In developing and emerging countries, the establishment of climate services has been slower than in the developed world due to the lack of strong national institutions, particularly weather services. Although weather services have a mandate from WMO to develop such capacities, one often finds incomplete observational records, lack of trained personnel, and computer power to run climate simulations. In some countries, and in some regions, interinstitutional alliances involving academia and central governments are showing incipient results.

4. The Stakeholders

In several cases, climate services have been established with the assumption that an active market of users and stakeholders is in place to rapidly benefit from science-based information. Unfortunately, the market has only been partially established and the relation between climate services and potential stakeholders remains weak or ad-hoc in many cases. The explanations for the lack of connection involve several factors [*Vaughan and Dessai*, 2014]: (1) the insufficient awareness by some societal actors of their vulnerability to future climate change, (2) the lack of relevant and timely products and services offered by the scientific community, (3) the inappropriate format in which the information is provided, and (4) the inadequate business model adopted by the climate services. The challenge for climate services is therefore to analyze their potential market and to narrow the gap between information providers and prospective users.

To address the first of these four different issues, it is important to recognize the diversity of stakeholders. Some of them, such as small business, city administrations, or local professional organizations should be regarded as end users with generally limited access to climate information and little in-house expertise.

Such users, which often operate at the local scale, may not realize the importance and the risks for their business of future climate disturbances. And if they appear to be convinced of the importance of climate change, they may not know precisely the type of problems they will be facing and what measures they will have to take as a response to these problems. Other users, to be considered as intermediate users, are often engaged in activities related to climate variability and change; they may be consultant offices, engineering firms, nongovernmental organizations, or large corporations that use climate data to produce and disseminate customized information to a spectrum of end users. In both cases, climate services have to work closely with these users and identify their real needs as well as the professional culture under which they operate. This requires that a clear collaborative process be established and accepted by all partners. Topics of common interest must be identified early in the process (codesign of research), and joint projects can be delineated to address the questions of mutual interest (coproduction of knowledge). Although this approach, which must be accompanied by an iterative dialogue between partners [*Lemos and Morehouse*, 2005; *Weaver et al*., 2014; *Addor et al*., 2015], has provided successful results when conducted by climate services with policymakers in public services, it has been much more difficult to implement with representatives of the corporate world, who do not always perceive the immediate benefit of such joint activity.

The second issue is the inadequacy between the products offered by the scientific community and the needs of many potential users. Here again, the diversity of potential users and of their specific requirements must be recognized. Processes and products must be adapted to the needs and the culture of the users. Climate science in the last decades has emphasized long-term climate trends resulting from increasing emissions of greenhouse gases. This question is certainly of relevance for institutions in charge of long-term investments, including governments, investment banks, infrastructure developers, etc., but is of little or no relevance for many corporations, which limit their “long-term” planning horizon to 5–10 years or less. At the same time, prediction of decadal variability, of high societal relevance, including the occurrence of extreme weather events, remains a challenging problem [*Meehl et al*., 2009, *Hurrell et al*., 2010]. Two specific examples of societal relevant questions illustrate differences between long-term and short-term concerns of specific decision makers. A city in the Andes may be concerned by the likelihood that water resources produced by glaciers will not address the needs of its growing population in several *decades.* At the same time, the authorities of major European or North American airports may want to know the likelihood that ground operations may be disturbed in the next few *months* by major weather disturbances such as snowstorms. These two questions require completely different scientific approaches; the science may be mature to provide long-term projections with statistical information, but is currently unable to successfully predict weather variability at seasonal to interannual timescales. Although many questions posed by stakeholders (in the area of agriculture, tourism, energy, water, etc.) cover situations that range from a season to a few years, the predictability of climate variability on such timescales remains a debated question, and the provision of reliable predictions remains a scientific challenge [see e.g., *Meehl et al*., 2009; *Keenlyside and Ba*, 2010]. In any case, the mismatch between of time horizon of interest to stakeholders and the time scales considered in most climate studies constitute a major difficulty for the communication between the climate community and many stakeholders.

The third issue is to tailor the information to the users' needs. Users interested in risk management often ask for reliable predictions, while scientists insist on the uncertainties associated with their predictions or projections. In some cases, however, risk managers deal with probabilities and uncertainties, and have learned how to integrate uncertain climate information in their decision process. As stated by *Street* [2014], “the task of climate services is to transform climate-related data into customized products, to advise on best practices, and to develop and evaluate solutions that may be of use for society.” Uncertainties in climate projections/predictions and therefore in climate information result from uncertainties due to (1) future greenhouse gas emissions, (2) the climate response to radiative forcing (model spread), (3) natural variability in the climate system, and (4) initial conditions used to initialize climate predictions [*Kirtman et al*., 2013; *Bowyer et al*., 2014]. The importance of the different sources of uncertainties varies with the timescale under consideration and the variable to be examined. The first uncertainty, which is dominant for multidecadal projections, is directly associated with unknown factors related to future economic development and policy actions, so that different forcing scenarios must be considered. To address uncertainties linked to the spread in model projections for specified scenarios, a limitation that is particularly relevant for projected climate information related to the next few decades, the scientific community is conducting multimodel ensemble simulations, and derives the mean and spread (variance) of model projections. The third source of uncertainty, which limits the reliability of climate information primarily on monthly, seasonal, and interannual timescales, is directly associated with the lack of predictability of the chaotic variations in climate variables and the insufficient accuracy of model initialization. As a consequence, the skill in seasonal forecasting has been limited, except perhaps in regions directly affected by slowly varying oceanic conditions and in the tropics under the influence of multiyear variations (e.g., El Niño). Regional model projections at relatively high resolution have been produced (http://www.cordex.org/) and made available to provide spatially detailed information to interested users. Regional models, however, inherit uncertainties in the atmospheric circulation provided by global models [*Xie et al*., 2015] and may not be more reliable than the coarser resolution simulations provided by global models. Probabilistic distributions of regional climate change require large ensemble simulations.

Furthermore, it is clear that end users will not be served by information provided only in terms of climate data or model projections. There is an expectation that climate services will advise the users on how to use model-based data and projections, how to deal with uncertainties, and how to respond to the challenges they are facing. The first step is therefore to establish a relationship with users or clients based on mutual confidence. One should not underestimate the time and effort required to establish such a relationship. Users expect climate services to provide authoritative and objective information rather than being guided by ideological motivations. Since for users, specifically for corporation and public administration, climate change represents additional financial, economic, or social risks that need to be integrated in their planning process, the information content must be broad and include advises regarding potential physical and social impacts, vulnerability of operations and people, as well as avenues to adapt to expected changes. The task must involve not only climate scientists, but also a broad group of experts that focus on engineering, economy, social management, and communication.

Finally, the fourth issue is the business model adopted by climate services, which is not always adapted to the culture of the users. Specifically, users from the corporate world request specific information on short notice and against immediate financial retribution to the providers. This approach is not always compatible with the legal rules that govern the functioning of most research institutions or of publicly funded climate services, and is inconsistent with the business model that they have adopted. In most cases, these institutions work and receive their funding from external sources under prenegotiated contractual agreements (e.g., structured research projects). As a result, corporations often favor collaborative work with private consulting firms, whose operational modes and response time are more in line with their way of doing business. Willis-Re (http://www.willisre.com), for example, helps reinsurance companies to anticipate how their market will evolve in response to climate change, and specifically provides risk modeling expertise, capital market solutions, actuarial services, and reinsurance design.

The business model of climate services must also recognize that users in the private sectors are subject to commercial competition. As a result, they prefer some direct bilateral interactions and do not operate in large groups that include competitors nor participate in large open conferences, such as those often organized by the academic community.

These four challenges highlight the fact that the market for climate services is not yet fully developed, especially regarding adaptation to climate change; the initial assumption that the income of climate services would soon be generated by the products delivered to users has appeared to be incorrect. Climate services should serve public good and be therefore funded in large part by the taxpayer. Their products should be freely accessible (no charge) to any citizen. Only specific requests for the exclusive use of clients should be provided against retribution.

Finally, we should emphasize that an important group of providers and users, located in the developing and emerging world, may have specific requirements and limited infrastructure and capability. Interesting projects have been initiated, very often in partnership with European or North American funding agencies or nongovernmental organizations. For example, the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), developed jointly by the governments of Germany and 10 western African countries, is a research-focused Climate Service Center designed to enhance the resilience of human and environmental systems to climate change. The funding provided by Germany is dedicated to the strengthening of the climate-related research infrastructure and capacity in West Africa. In another part of Africa, the Climate Services Centre established by the Southern African Development Community (SADC) with 15 African member states, and funded by different national agencies (NOAA, UNDP) and international organizations (United Nations Development Programme, World Meteorological Organization, World Bank), provides operational services for monitoring and predicting extremes in climate condition. Its objective is to better manage climate-related risks in the region. For such initiatives, the development of partnerships and the transfer of knowledge and technologies are fundamental, but funding is often insufficient to secure long-term activities. Approaches to capacity building will have to evolve from ad-hoc and top-down training activities to more sustained (multiyear) commitments to mentoring relationships with the financial support of research institutions and agencies. In a recent paper, *Hewitson* [2015] highlights several conditions required to break from a long history of attempts that is littered with repeated failures. New skills must not just be learned; they must be used. Climate services that develop capacity building programs for emerging intellectual leaders must therefore provide on-hand opportunities in an enabling environment and create the conditions that allow young talents to use their capacity, to grow independently, and to deliver long-lasting value to their country.

5. Products, Services, and Processes

The portfolio of existing climate services remains often limited to past climate indicators (e.g., temperature, precipitation) deduced from observations and data analyses, to global and regional climate projections including, for example, those conducted by a large ensemble of models in support of the IPCC process, and in certain cases to seasonal-to-decadal climate predictions. NOAA, for example, as part of its climate information services, provides a dashboard with past observations and, in some cases, future estimates of atmospheric CO_2 concentration, temperature, precipitation, Arctic sea ice extent, El Niño indices, etc. Many meteorological services also provide educational web pages including climate guides that include introductions to climate science and related approaches. For many users, however, services are expected to support decision and policymaking with an analysis of uncertainties in the context of decision making. Several institutions have therefore chosen to focus on current and future vulnerability of regions and sectors, on international, national, or sub-national adaptation strategies, and to develop tools for supporting adaptation planning. The European Environment Agency in Copenhagen (http://www.eea.europa.eu), for example, has established a Climate Adaptation Platform that provides a wealth of information on the adaptation strategies adopted by different European countries; it also presents several adaptation case studies with potential adaptation options. Climate adaptation has become a central theme also for the Framework Programme for Research and Innovation Horizon 2020 of the European Commission (https://ec.europa.eu/programmes/horizon2020), for the Joint Programming Initiative JPI-Climate (www.jpi-climate.eu), and for several hydro-meteorological services. A large number of websites provide additional information produced by groups focusing on impact, adaptation, and vulnerability.

Users often indicate that, in spite of the creation of climate services, the provision of climate information remains very inhomogeneous, with a lot of unnecessary repetitions between providers, a lack of clarity and usable information, and occasionally an inconsistent message. At other instances, they complain about the fact that they do n't know from which institution they can rapidly receive relevant information for the specific needs of their business. Clearly, an international effort needs to be undertaken to clarify the provision of information and to facilitate access to a broad spectrum of users with different requirements. Such effort is being undertaken by the Climate Service Partnership (CSP) (http://www.climate-services.org), and needs to be amplified in the future by the GFCS operated by the WMO. GFCS has been established in 2009 by an extraordinary session of the World Meteorological Congress as a worldwide mechanism to enhance the quality, quantity, and application of climate services. The project is overseen by an intergovernmental board, and is currently undertaking pilot projects. It needs to better appreciate how scientific research could improve the quality of services and their communication to users.

In many emerging countries, day-to-day needs related to extreme weather and other natural disasters tend to overtake the resources and the focus of institutions with a lack of long-term planning for the development of mitigation and adaptation policies. Policymakers increasingly provide a coherent discourse about the consequences of climate change and the need for the world to take action. Budgets and policy priorities, however, do not reflect this discourse. Furthermore, decisions are based on the experience acquired in developed countries, while vulnerability assessments are performed through short-term consultancies. As more positive attitudes toward action are emerging in countries with strong economies, many emerging countries are starting to identify the need for more accurate and relevant climate information. The recently published "Intended Nationally Determined Contributions (INDCs)," in which countries publicly declare their intended actions under a climate agreement, reflect in part the emergence of a market for climate services, specifically in emerging countries. Climate services will have to monitor the efficacy and relevance of these INDCs. International collaboration is therefore key for strengthening the local and regional capacities in developing countries, and specifically for building resilience and catalyzing adaptation to social and environmental change of marginalized populations.

6. Outreach and Dissemination

Information to be provided to stakeholders must be *credible* (of high technical quality), *legitimate* (fair and impartial, with the interests of users in mind), and *salient* (relevant to users and capturing their attention) [*NRC*, 2007]. The dissemination of information requires therefore that the climate services establish a communication strategy that addresses these requirements. Research institutions have traditionally communicated through the scientific literature with little impact on societal actors. Even in their attempts to inform stakeholders, the approach has been very "top-down" with the assumption that knowledge, seen as the privilege of scientists, should be distilled toward those who lack knowledge and understanding. Today, it is recognized that communication will not change people's behavior substantially if it is based solely on scientific evidence or media reports, but the strategy to be defined will have to recognize the role of social norms (political and economic systems, social constructs) and of individual beliefs (personality structure, political affiliations, religious and family systems, etc.) (J. Kiehl, personal communication). There have been suggestions, originating in particular from the social science community, to replace the traditional top-down dissemination of information by the cogeneration and coproduction of knowledge involving scientists and users (i.e., engagement of researchers and policymakers in the joint development of evidence-influenced policy). The international Future Earth program (http://www.futureearth.org/) has adopted this concept for providing knowledge and support to accelerate society's transformations to a more sustainable world. Even though this new approach appears attractive, it still has to prove its efficiency and in particular demonstrate that stakeholders, who need to successfully operate their own business, will invest time and finances in this kind of joint venture. It is clear that issues around outreach and dissemination faced by climate services require more attention and research. Effective communication will result from a close and transparent collaboration between climate services and users, and help stakeholders identify vulnerabilities, and manage key climate risks [*Jones and Mearns*, 2005].

7. Future Prospects

Several initiatives to develop climate services have been taken during the last 5 years in different countries of the world. Have these initiatives led to discernible changes in the way stakeholders operate and conduct their business? Despite the great enthusiasm that have prevailed with the development of the first climate services, the success today is clearly limited. Some of the reasons have been highlighted above. The most striking of them is that, even though there is an established need by many stakeholders for weather-related information and predictions, the market for longer term climate information remains marginal and often undefined. This is probably why the European Union, which highlights that "climate services have the potential to become the intelligence behind the transition to a climate-resilient and low carbon society" has decided to support the development of "a market in which public and private services operators develop a variety of customized high added-value services." For the European Union, the development of such a market requires sustained research and innovation, and calls for a demonstration of the benefits that climate services can generate through an engagement of stakeholders.

The engagement of stakeholders will be limited by the relevance of the information for their business. As mentioned by Milton Friedman, "the business of business is business," which reminds us that the central objective of most corporations is to increase their profits, not to address climate change. Private companies, however, start to see the benefit to integrate a "climate dimension" in their planning process. Their stated goal is not to become Good Samaritans, but to limit the potential disruptive effects of climate change on their business. The solution to their potential problems will not be provided only from climate scientists or even from social scientists. It will have to involve experts who understand the business culture in the private

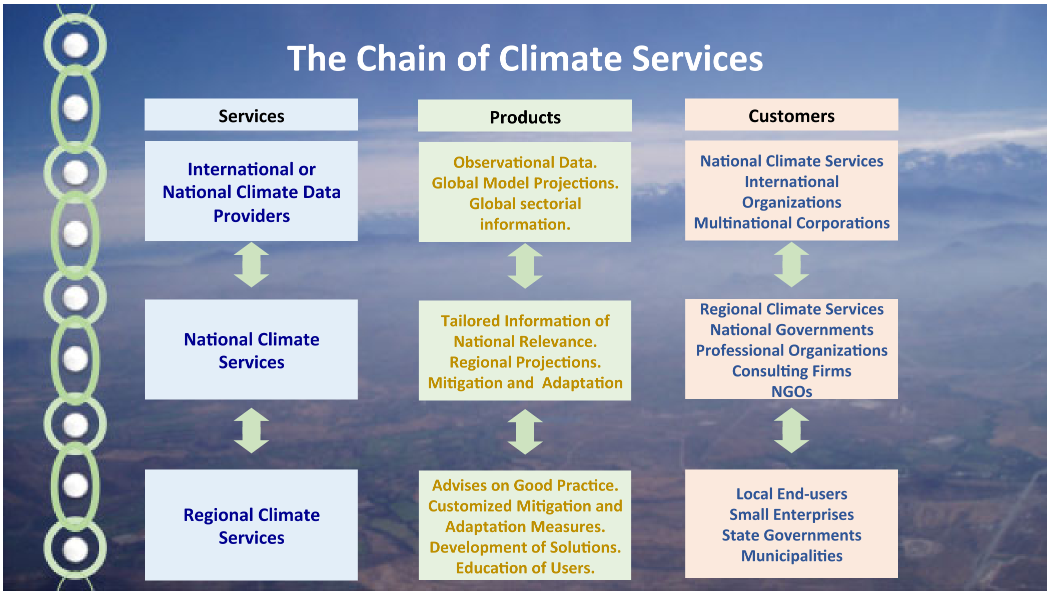

Figure 1. Chain of responsibilities, products, and users for climate services. Each level of service [international (e.g., European), national, and regional (subnational)] should address the needs of different customers and provide different types of services. At each level, partnerships with supporting research or development organizations and with intermediate and end users should be established in an effort to develop an iterative collaborative process.

sector or who are familiar with the political and administrative processes in the public sector. Many climate services in place today are populated with scientists who have limited experience with the operational constraints of stakeholders.

Perhaps, a new architecture should be developed around a chain of activities (Figure 1) along which information is geographically downscaled, while at the same time enriched by regional or sectorial information.

The top of the chain, in this model, would include data providers who would collect and make accessible available observations and model projections. The Copernicus Climate Change Service provides an example of such activity; it includes a large climate data store, a sectorial information system providing tailored indicators for primary users and commercial applications and a quality control process. The clients for the products distributed by this level of the chain would be primarily downstream national climate services and perhaps international organizations such as the European Commission or large multinational companies.

The role of the *national* climate services, including those operated by national meteorological services, would be to transform this data into customized products with added information specific to regions and sectors. Climate Services in Scandinavia, for example, could be the primary institutions to provide detailed climate information specific to the Arctic and sub-Arctic, while equivalent centers in southern Europe would specialize in issues related to climate change in the Mediterranean region. At this level of the chain, the customers would be federal governments, national policymakers and professional organizations, consulting firms, nongovernmental organizations, and regional climate services.

Regional (subnational) climate services would disseminate and customized information to regional governments, city managers, and other local end users (small companies and decentralized administrations). An educational component would have to be implemented together with targeted mechanisms to advise on best practices and to recommend methods to develop concrete solutions to the questions of the end users. In this area, climate services should be working with educational institutions that have developed innovative frameworks to foster an iterative dialogue between climate scientists and decision makers [*Gornish et al*., 2013; *Addor et al*., 2015].

Specifically within national and regional climate services, an interesting institutional model would be to host within the same center a diversity of staff representing different disciplines and sensitivities: (1) experts in climate science able to perform, analyze, and synthesize model simulations and representing the culture of the climate science community; (2) specialists in impact, adaptation, and vulnerability, specifically economists, representing not only the academic culture but also the approaches adopted by consulting firms; (3) representatives of the corporate world with good knowledge of the culture of business in the private world; (4) representatives of public services, understanding the culture of the political world and public administration, specifically urban planners, and finally (5) social managers and communication specialists with a strategic vision and a good understanding of the specificity of the different communities involved. This model would provide a unique opportunity for developing truly transdisciplinary approaches with the participation of stakeholders and customers with emphasis on bottom-up approaches. The detailed structure of such climate service centers would have to be adapted to the specificities of the target markets and the requirements for their governance. Because users increasingly seek the development and evaluation of concrete solutions, the role of environmental engineers including specialists in surface hydrology, urban planning, air quality, etc. needs to be emphasized. Most existing climate services have not yet recognized this dimension for their operation, which often remains dominated by scientists with an academic background.

The suggestion of developing climate services around a team of diverse talents and complementary disciplines operating "under the same roof" does not call for a hierarchical or "command and control" type of leadership that lacks in flexibility and undermine collegiality. Rather, the proposed institutional arrangement provides opportunities for a distributed type of leadership [*Davison et al*., 2014] that facilitates vision, innovation, and collaboration, and is based on strong interpersonal relationships and mutual support of the interacting staff members. The interdisciplinary role of climate services is achieved by the development of sustained relations with colleagues representing different disciplines in the distributed academic world and by an internal effort to synthesize knowledge and to turn it into practical implementation. The need of a central institution is justified by the fact that climate services are primarily operational rather than research organizations that must provide articulated responses to the requests from their customers within a strict and generally short time frame.

In developing and emerging countries, in particular, there is a need of strengthening the local institutions to be able to quantify vulnerabilities, and produce nationally and locally relevant policies, which in turn will be served by climate services. In addition to political will from these countries, a decisive role from international well-established climate service institutions is badly needed. In fact, if the world is to avoid the 2 °C limit, it is a key to put in place adequate mitigation policies in the part of the world that is expecting economic growth, and where vulnerabilities are usually amplified by inequity.

Finally and perhaps most importantly, the concept of climate services will have to rapidly evolve in response to the agreements reached in Paris during COP21. New investments by both the private sector and public administrations will have to be developed to fundamentally modify our worldwide system of energy consumption, and specifically to decarbonize our industrial, transport, and domestic activities. New financing mechanisms will have to be rapidly established, new projects initiated, and some deep restructuring of our industrial tissue and our agricultural practices implemented. A major challenge will be to restructure urban areas, which are currently the source of a large fraction of CO_2 emissions and of other climate agents. Climate services will have to consider a fairly new dimension for their role and their activities that goes far behind their original efforts of providing climate information and model projections. They will have to help to prioritize climate-smart investments and, by working in concert with financial and engineering specialists, review the design and relevance of proposed projects. Such new type of service will necessarily have to be conceived by a public (neutral) authority at the international level to ensure that choices for financing projects preserve a fair competition between proposing corporations and other organizations and encourage ethical behavior and full financial transparency.

Acknowledgment
The data used in the paper are listed in the references.

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