

OPINION

Challenges to the sustainability of climate services in Europe

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Abstract

Climate services have emerged as a research and operational field in recent years. This development has been underpinned and supported by significant research, funding and agenda-setting efforts such as the Global Framework for Climate Services internationally and the Roadmap for Climate Services and the Copernicus Climate Change Service in Europe. The fast pace at which this field is developing raises a number of key challenges that need to be critically examined and addressed to ensure the future development and sustainability of climate services in Europe. This opinion piece highlights a number of challenges currently threatening the viability of climate services including the complexity of the concept of climate services; the complex landscape of complementary research and development areas relevant to climate services; existing rights to freely access and use climate services; current limitations to funding structures and mechanisms and how that impacts on the development of climate services; the emphasis on co-production as a precondition to climate services development; and the limited role of the social sciences in the research and operational field of climate services. Effectively addressing these challenges will require a commitment from the scientific and practitioner communities to engage in critical and reflective debates around the future conceptualization and operationalization of climate services in Europe. This paper aims to provide critical input to stimulate a necessary and overdue debate around the sustainability and future of climate services in Europe.

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KEYWORDS

challenges for climate services in Europe, concept of climate services, co-production, governing rights, social sciences

1 | INTRODUCTION

Despite the development of climate science for more than a century (Vaughan & Dessai, 2014), climate services as a research and operational field has only emerged in recent years (Brasseur & Gallardo, 2016; Hewitt, Mason, & Walland, 2012). The notion of climate services was only fully operationalized as a result of the World Climate Conference in 2009, which led to

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TABLE 1 Examples of climate services definitions

A climate service is considered here to be the provision of climate information in such a way as to assist decision-making by individuals and organizations. The service component involves appropriate engagement, an effective access mechanism and responsiveness to user-needs (GFCS, 2014).

Climate services aim to make knowledge about climate accessible to a wide range of decision makers. In doing so they have to consider information supply, competing sources of knowledge, and user demand (Field et al., 2014).

The transformation of climate-related data—together with other relevant information—into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counseling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large. As such, these services include data, information and knowledge that support adaptation, mitigation and disaster risk management (European Commission, 2015a).

Climate services involve the production, translation, transfer, and use of climate knowledge and information in climate-informed decision making and climate-smart policy and planning. (...) Easily accessible, timely, and decision-relevant scientific information can help society to cope with current climate variability and limit the economic and social damage caused by climate-related disaster. (Climate Services Partnership, undated).

the establishment of the Global Framework for Climate Services (Hewitt et al., 2012; Vaughan & Dessai, 2014). The rapid development of climate services over the last years has been underpinned and supported by significant transnational research and funding efforts such as the Global Framework for Climate Services at the international level (Hewitt et al., 2012; WMO, 2017) and the Roadmap for Climate Services and the Copernicus Climate Change Service in Europe (European Commission, 2015a; Street, 2016). However, the rate and magnitude at which the field of climate services is expanding raises key challenges that should be critically problematized, examined, reflected and addressed in order to help further understand and support the development of effective climate services efforts. This opinion piece aims to highlight some of those key challenges that, in our view, pose significant threats to the long-term viability and sustainability of this field and raise a number of lines of enquiry that hopefully will help to stimulate a critical debate about the future development and legacy of climate services in Europe.

2 | THE MULTIPLE (POTENTIAL) MEANINGS OF CLIMATE SERVICES

Since its appearance as an operational concept in 2009 (Vaughan & Dessai, 2014) the concept of climate services has since expanded into an array of definitions which now permeate the literature (see, e.g., Table 1).

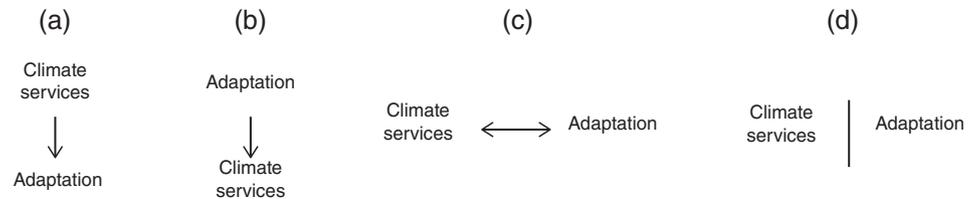
Central aspects common to these definitions are the *provision of climate information/data/tools that supports user needs through engagement with the users of the services*. However, despite such commonalities, all of these concepts—climate information, users, needs, provision, engagement—can be interpreted differently depending on the context (Bruno Soares, Alexander, & Dessai, 2018; Vaughan & Dessai, 2014). In addition, the concept of climate services is also often associated with other ideas and assumptions such as production, use, knowledge, impact, accessibility, customisation, added value, adaptation, etc.

As a result, this is an intricate and complex concept which can easily lead to different (and even conflicting) interpretations of what we mean and what we can expect when talking about climate services. It is therefore imperative to disentangle this notion in ways that are useful and meaningful to the range of actors involved in the production, translation and use of climate services.

For example, in weather services it is common to differentiate between public weather services and specialized weather services where the former corresponds to those provided (normally by National Hydrological and Meteorological Services) to benefit society at large; whilst the latter is associated with complementary services developed to meet the needs of specific users (Zillman, 2005). This type of distinction could also be linked to the idea of climate services as a “public good” (and freely available) as opposed to as a “private good” (with a cost attached) which is commonly used in the literature around ecosystem services (Fisher, Turner, & Morling, 2009). Such approach could also be adapted in order to correspond to different levels of accessibility, impacts and benefits to those accessing and using these two types of services although there are more practical implications of doing so in the context of climate services (see section below on governing rights in climate services).

Another possibility could be to distinguish between climate service as the process of development (of, e.g., a decision-support tool) versus the climate service as the implementation of the tool developed (cf. O'Brien, Eriksen, Schjolden, & Nygaard, 2004). This approach would be somewhat akin to the literature on public policy where the stages of policy

FIGURE 1 Tentative conceptual and/or operational linkages between climate services and adaptation



formulation/development and implementation/outcomes are differentiated to facilitate the analysis of how policy is developed, organized and operated as well as its impacts on society (Hill & Varone, 2014).

So how can we effectively address this challenge as a community? How can we define meaningful and useful ways of differentiating the disparate (potential) meanings of climate services to avoid conflicting interpretations and help us better manage expectations? And what are the best approaches for distilling this complex concept into useful, manageable and practical interpretations?

3 | A CROWDED LANDSCAPE

As previously mentioned, critical elements associated with the notion of climate services are the *provision of climate information in ways that supports decision-making through engagement with the users of that information*. However, the idea of using climate information to support and better inform decisions is not new. Scholarship on climate change vulnerability, impacts and adaptation and disaster risk reduction and management, all make use of climate information and tend to engage with the users as a precondition to pursuing activities aimed at adapting to current and future climate variability and change and/or best prepare for extreme weather events and related hazards (Field et al., 2014).

The majority of climate services definitions (see Box 1) identify these as processes for “(...) bridging science and decision making (...) in the communication, transfer and development of climate-related knowledge, including translation, engagement, and knowledge exchange” (Field et al., 2014, p. 26). In such conceptual and operational contexts, climate services can be perceived as an area able to encapsulate and provide support for other areas such as adaptation in the sense that, in some cases, the development of the services aims to address and respond to a specific adaptation issue (or disaster risk management). In this context, the potential linkage between climate services and adaptation could be schematically represented as in Figure 1a.

Other authors, such as Goosen et al. (2014) perceive climate services as focusing on the provision of climate information and potential impacts in order to support adaptation without providing the level of detail necessary to inform policy and reach those who need it the most. In their conceptualization, climate adaptation services encompass the process of generating relevant climate information that fits adaptation and decision-making (as illustrated in Figure 1b; e.g., GFCS, 2016). Another situation could be one where climate information obtained from public climate services (e.g., through a National Meteorological and Hydrological Services—NMHS—website) could be used to support the development of a specific adaptation assessment and/or strategy (Figure 1c). In addition, there is also the potential for climate services to fall outside the remit of adaptation studies and the two areas not interacting (Figure 1d). For example, when adaptation efforts do not depend on a direct input from climate services particularly in situations where the climate information required to inform the adaptation process already exists or where there is a lack of accessibility to more refined and tailored climate services (Figure 1d).

A range of practical expressions of these different conceptual combinations on the relation between climate services and adaptation as well as others fields (e.g., disaster risk reduction and management) are exemplified in Nicklin, Cornwell, Witthaus, Rowlands, and Griffiths (2012).

So, what exactly is new about the concept of climate services and how does it differentiate from similar operational and research areas? How do we conceptualize these different but interlinked areas? And how can we effectively pursue complementarity between these closely related fields?

4 | GOVERNING RIGHTS IN CLIMATE SERVICES

Another critical challenge to the long-term sustainability of climate services is the existing tensions between a climate service as a public good versus a climate service as a business opportunity. Whilst in the former, the services provided are freely available but generally less tailored to specific users' needs (given the wider scope of the service) in the latter, the provision is

tailored specifically to the requirements of one or a few users although the service is often provided at a cost directly covered by its users via a fee.

However, in climate services, a distinction between public and private provision is not linear (or particularly useful) as different business models can be pursued within the same organization (Vaughan & Dessai, 2014). For example, whilst the majority of NMHS provide (to different extents) publicly accessible climate information as part of their mission (WMO, n.d.) many of them also pursue commercial opportunities in the provision of climate services as a way of offsetting an, often decreasing, level of public funding. The challenge therefore is not to differentiate between public and private provision per se but rather to understand the complexity within and across organizations with regard to issues of intellectual property rights (IPR), licensing agreements and accessibility under which climate services, and the underpinning data, is distributed and made accessible to individuals (e.g., Hubbard, 2014). In other words, the challenge is not about who generates or “owns” the data but rather the conditions under which a specific dataset or software can be shared and/or linked to proprietary IT solutions. In that sense, opening up the possibility for data and tools to be used commercially, as it has somehow already happened in the Coordinated Regional Climate Downscaling Experiment (CORDEX¹) and is happening in the Copernicus Climate Change Service (C3S²), has the potential to significantly change the landscape of downstream climate services applications by allowing “intermediate” users to develop value added solutions whilst at the same time maintaining an open and free environment. Furthermore, it is fundamental to create the necessary conditions by which the climate data can be easily combined with other types of data (and/or sources) in order to support the development of effective climate services, that is, achieving interoperability and using common standards to facilitate data accessibility and use (Giuliani, Nativi, Obregon, Beniston, & Lehmann, 2017).

As a result, and particularly given the current emphasis and push for the creation of a climate services market in Europe underpinned by a logic of economic growth (European Commission, 2015a, 2015b; Street, 2016), the accessibility to climate information, data and tools generated (particularly by those seeking commercial opportunities) needs to be critically examined to help better understand not only the complexity of IPR in climate services but also how that reflects in terms of licensing agreements and accessibility to the services developed.

A particularly important related aspect is the need to understand not only this complex landscape of rights and duties but also how to effectively regulate and manage accessibility to climate services in relation to wider issues of justice and equity and the protection of those most vulnerable in dealing with the risks of climate change (cf. Keele, 2019; Webber & Donner, 2017). The challenge of governing the rights in climate services (i.e., the data, tools and products generated through these processes) in inclusive ways raises a number of other pertinent questions that also need to be discussed and addressed. For example, how can we assure a level of quality, standards and legitimacy in a context of open data and tools? How can we ensure the necessary level of guidance and training to those who have the right to access the data, tools and information but require support to be able to effectively use those services?

5 | LIMITATIONS OF FUNDING STRUCTURES AND MECHANISMS

Much of the ongoing efforts on climate services in Europe is being pursued through research with European funding programs (e.g., Framework Program 6 and 7 and currently the Horizon 2020 funding program) or initiatives such as the Joint Programming Initiative for Climate “Connecting Climate Knowledge for Europe” (JPI Climate) which support a variety of projects within this field (see, for example, CORDIS, 2018; ERA4CS, 2016). Although these funding frameworks can help secure a level of adequacy in relation to the European research agenda as well as structural consistency across the various projects, it can also limit the development of research as the availability of such funding is dependent upon a set of pre-established structures regarding the scope of the research to be developed, the way in which the research should be structured and organized and, in some instances, which countries and organizations are allowed to apply for such funding (e.g., JPI Climate).

Furthermore, current research funding largely focuses on the development of climate services applications and the mainstreaming of such services (European Commission, 2017). Whilst this is a positive direction towards the potential operationalization of such services on the ground, there is the need to ensure sufficient funding to support the underpinning science particularly in emerging and expanding scientific areas such as decadal predictions (e.g., Menary & Hermanson, 2018; Suarez-Gutierrez, Li, Müller, & Marotzke, 2018).

In the development and operational side of climate services, initiatives such as the C3S³ and Climate-KIC largely fund the development of applications and operational services. However, such initiatives are also dependent on funding mechanisms. For example, the C3S platform which aims to provide open access “information for monitoring and predicting climate change and help to support adaptation and mitigation strategies.” and whose funding is currently only guaranteed up to 2020⁴ (European Commission, 2015b, 2016; Thépaut, Dee, Engelen, & Pinty, 2018). In their study, Georgeson, Maslin, and

TABLE 2 Levels of citizen participation and level of user engagement in climate services

| Levels of citizen participation (based on Arnstein, 1969) | | Levels of user engagement in climate services | |
|---|--|---|--|
| <i>Citizen power</i> | Individuals have agency and different degrees of power and decision-making over the process at hand. | <i>Co-production</i> | Individuals (users) have a degree of power in regard to the process of co-producing climate services. |
| <i>Tokenistic approaches</i> | Individuals are given a “voice” but no agency or power to decide on the course of action. | <i>Active engagement</i> | Individuals can be involved in the development process to different extents and via a range of mechanisms depending on the objectives at hand. |
| <i>No participation</i> | Individuals are not involved in the process but such processes are used to educate them. | <i>Passive engagement</i> | The users are not involved in the development of the services but rather informed of what is available and accessible to them. |

Poessinouw (2017) analyzed the commercial supply of weather and climate services globally and highlighted the impact that open-access data available at the C3S can have not only in Europe but also in less developed countries seeking access to freely available information. In this case, it is critical to understand the potential impacts of C3S ceasing to exist due to lack of funds with regard to the development and research of climate services in Europe and beyond.

In addition, whilst stimulating a climate services market by targeting innovation calls and seeding grants to promote SME activities can be a positive step towards supporting actions these tools are only likely to succeed if enough resources are devoted to the maintenance of the underpinning technical infrastructure. In that sense, climate services in Europe can only become sustainable if sufficient resources are made available for the maintenance of the observational network (ground-based and satellite), for the data infrastructure that make the production (Partnership for Advanced Computing in Europe⁵), the distribution (Earth System Grid Federation⁶) and the post-processing of the data (Climate Data Store toolbox⁷) so that everything can be as much as possible free at the point of use.

Existing funding mechanisms - for both research and development of climate services - pose a number of questions including how to create funding structures that allow the development of user-led research proposals? How to support the ongoing development and operationalization of climate services, innovation and user interface? And how to ensure that the underpinning science is adequately funded?

6 | A (MIS) EMPHASIS ON CO-PRODUCTION

The concept of co-production (interchangeably used with notions of co-design and co-development) has become somewhat of a pre-condition in climate services projects and initiatives (see, e.g., Hewitt et al., 2012; Vaughan & Dessai, 2014). Underpinning this need to co-produce climate services with the users are wider theoretical discussions including an awareness of the need to counteract the conventional loading-dock model of science production in order to increase the usability of the climate science in decision-making as well as the need to justify expenditure on research and show value for money (Cash, Borck, & Patt, 2006; McNie, 2007; Feldman & Ingram, 2009).

Although as a theoretical concept co-production can be linked to an array of definitions (see, e.g., Bremer & Meisch, 2017), co-production is often used as a “(...) normative framework for engaging non-scientists as active partners in the funding, making and use of such knowledge” (Lövbrand, 2011, p. 227). However, from a practical implementation point of view point of view, there are significant disparities by what is meant by co-production and how it is applied methodologically in this emerging and complex landscape of climate services (cf. Hinkel & Bisaro, 2016). In this context, the limited and fairly fragmented input from the social sciences in a space largely influenced by the climate sciences perpetuates ongoing issues regarding the quality, adequacy and effectiveness of both the methodological approaches implemented as well as the empirical outcomes of such co-production processes (Vaughan, Dessai, & Hewitt, 2018). Adding to this emphasis on co-production in climate services is also the lack of debate and differentiation regarding the different typologies for engaging with users and bringing them into such collaborative processes (Hewitt, Stone, & Tait, 2017; Meadow et al., 2015).

As Arnstein so rightly stated back in the late 1960s “There is a critical difference between going through the empty ritual of participation and having the real power needed to affect the outcome of the process.” (Arnstein, 1969, p. 216). Her seminal work, whilst focusing on the different types of citizen participation, is helpful to illustrate the disparate agency and roles that users can have (or are allowed to have) in the co-production of climate services (Table 2).

Processes of co-production whereby the user—as the “client”—have a degree of power and an active voice and agency over the process of climate services production can be expected more in the private provision of services; whilst a more passive engagement from the (potential) users of the climate services are expected in the context of a services' provision that aims to reach out a wide range of users (e.g., through a website). This highlights the somewhat negative correlation between effective processes of co-production and the number of users involved in such processes and vice-versa. In this context, it is critical to reflect upon the implications and compromises that need to be considered when deciding the type of climate service to be developed since, in some cases, it can be more productive and effective to positively assume that co-production (as defined in Table 2) it is not required (or feasible) given the aim and purpose of the service at hand (e.g., general products available through a NMHS website). In addition, the label of “co-production” in climate services initiatives often helps to feed the perception of being a user led service when, in practice, the input is largely provider led based on the assumptions that climate model outputs will be useful for decision making (linking back to the conventional loading-dock approach; cf. Cash et al., 2006).

In a context where the need for co-production is often misinterpreted conceptually as well as misapplied methodologically (e.g., in ways that lack a critical appreciation of power dynamics) thus impacting on the outcomes of such “co-production” processes a number of key questions arise including: how can we implement effective and meaningful processes of co-production in climate services in order to avoid pursuing “empty rituals”? How can we critically open up this debate in order to clarify and de-construct what exactly is meant by the concept of co-production and how it is currently implemented? And how can we implement appropriate, legitimate and feasible forms of co-production into the design of climate services targeting very different stakeholders and needs?

7 | CONFINED ROLE OF THE SOCIAL SCIENCES

Last but (definitely) not least in the list of challenges for the future sustainability of climate services in Europe is the key role of the social sciences (including the humanities and behavioral sciences). Despite recent efforts to include more social sciences in climate services research this area is still “fragmented and needs to be consolidated, connected and implemented.” (Desmond, West, Bruno Soares, Manderscheid, & Malnaca, 2018a, 2018b, p. 12). Although the current landscape shows a higher contribution from researchers with social sciences backgrounds, in our experience, the onus of the work lies on merely engaging with the users or focusing on communication aspects. This per se is not a problem in itself. The point here is the array of themes and areas of expertise that the social sciences could significantly contribute to and that could help address many of the challenges that climate Services currently face (as described above). Areas such as the governance of climate services, modes of co-production, justice and equity, innovation in climate services, accessibility and rights to use the services produced, and the value and benefits of climate services are just a few examples of research areas where the social sciences could significantly contribute beyond the current research focus which primarily aims to develop climate services prototypes (and/or aspects of the underpinning science). The European Roadmap for Climate Services for example, goes as far as suggesting disciplines within the social sciences which can play a significant role in climate services including sociology, anthropology, geography, political sciences, history, psychology, cognition, and communication sciences. However, despite the call for further integration of the social sciences in climate services over the past few years (European Commission, 2015a; Vaughan, Buja, Kruczkiewicz, & Goddard, 2016) in our experience, current research streams and available funding is still largely oriented to the natural sciences and their scientific interests. It is therefore critical to create forums that allow this (still fragmented) group of social scientists working on climate services to come together as a community of practice in order to contribute to and influence the research agenda at European (and national) level (e.g., the new JPI action group on “Enabling societal transformations in the face of climate change⁸”; Desmond et al., 2018a, 2018b). In addition, there is also a fundamental need to allow the social sciences to pursue areas of research that are critical to help us adequately address the challenges described above (e.g., different meanings of climate services as a concept, crowded landscape, governance rights, funding mechanism, and the problematization of co-production) and ensure the long-term sustainability of climate services in Europe.

In this particular context it is therefore critical to understand how can we promote and facilitate the integration of communities of practice focusing on the social sciences of climate services in Europe? How can we support the social sciences to have a more prominent role in informing the European research agenda? How to create and/or give access to funding streams that focus on critical aspects of climate services in relation to the social sciences? And how can the social sciences have a more prominent presence in such debates and climate services efforts?

8 | CONCLUSIONS

This opinion article aims to highlight some of the key challenges that, in our view, can hinder the long-term sustainability of the research and development of climate services in Europe.

Whilst proposing solutions to tackle these complex and interlinked challenges is out of the scope of this paper, we believe that any effective response to addressing these will require joint efforts from actors involved in the development and implementation of climate services through open processes that allow critical and reflective debates regarding the future of climate services.

This will require bringing together the different communities engaged in climate services in order to engage in reflective dialogues around (a) the conceptualization and operationalization of climate services in general and in relation to areas of complementary research and development; (b) the ethical, governance and legal implications of open versus restricted access and rights to use climate services; and (c) how to engage social science expertise in order to promote critical perspectives on climate services design and development and knowledge co-production processes that can enhance the quality and effectiveness of climate services efforts going forward. An open, critical, and reflective debate around these conceptual and operational challenges should, in our view, provide the basis for a necessary and overdue discussion around the sustainability and future of climate services efforts in Europe.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

ENDNOTES

¹ See, for example: <https://github.com/ESGF/esg-orp/blob/master/web/licenses/CordexCommercialLicense.xml>.

² See, for example: <http://apps.ecmwf.int/datasets/licences/copernicus/>.

³ C3S stands for Copernicus Climate Change Service.

⁴ However, there is a strong signal from the European Commission that the C3S will continue being financed in the future. See, for example: <http://earsc.org/news/the-new-eu-space-programme-regulation-proposal-and-the-future-of-the-ec-downstream-services-sector> and http://www.europarl.europa.eu/doceo/document/A-8-2018-0405_EN.html#title2.

⁵ For more see: <http://www.prace-ri.eu/>.

⁶ For more see: <https://esgf.llnl.gov/>.

⁷ For more see: <https://cds.climate.copernicus.eu>.

⁸ This new JPI Climate Action Group aims to promote the Social Sciences and Humanities as key disciplines in the sustainable societal transformation in the context of climate change (including climate services) (Desmond et al., 2018a, 2018b).

FURTHER READING

Adams, P., Eitland, E., Hewitson, B., Vaughan, C., Wilby, R., & Zebiak, S. (2015). Toward an ethical framework for climate services: A white paper of the climate services partnership working group on climate services ethics. *Climate Services Partnership*. Retrieved from <http://www.climate-services.org/wp-content/uploads/2015/09/CS-Ethics-White-Paper-Oct-2015.pdf>

Kirchhoff, C. J., Lemos, M. C., & Dessai, S. (2013). Actionable knowledge for environmental decision-making: Broadening the usability of climate science. *Annual Review Environmental Resources*, 38(1), 393–414.

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Climate Change*, 2(11), 789–794.

Morss, R. E., & Hooke, W. H. (2005). The outlook for US meteorological research in a commercializing world: Fair early, but clouds moving in? *Bulletin of the American Meteorological Society*, 86(7), 921–936.

- Pettifer, R. E. W. (2015). The development of the commercial weather services market in Europe: 1970–2012. *Meteorological Applications*, 22(3), 419–424.
- Swart, R., Biesbroek, R., & Lourenço, T. C. (2014). Science of adaptation to climate change and science for adaptation. *Frontiers in Environmental Science*, 2, 29.
- World Meteorological Organization. (2014). *Implementation plan of the global framework for climate services*. World Meteorological Organization. Retrieved from https://library.wmo.int/doc_num.php?explnum_id=3580

REFERENCES

- Arnstein, S. R. (1969). A ladder of citizen participation. *Journal of the American Institute of Planners*, 35(4), 216–224. <https://doi.org/10.1080/01944366908977225>
- Brasseur, G. P., & Gallardo, L. (2016). Climate services: Lessons learned and future prospects. *Earth's Future*, 4(3), 79–89.
- Bremer, S., & Meisch, S. (2017). Co-production in climate change research: Reviewing different perspectives. *WIREs Climate Change*, 8(6), e482.
- Bruno Soares, M., Alexander, M., & Dessai, S. (2018). Sectoral use of climate information in Europe: A synoptic overview. *Climate Services*, 9, 5–20.
- Cash, D. W., Borck, J. C., & Patt, A. G. (2006). Countering the loading-dock approach to linking science and decision making: Comparative analysis of El Niño/Southern Oscillation (ENSO) forecasting systems. *Science, Technology, & Human Values*, 31(4), 465–494.
- Community Research and Development Information Service (CORDIS). (2018). *Results for European projects on climate services*. Retrieved from https://cordis.europa.eu/projects/result_en?q=%27climate%20services%27%20AND%20result/reasons/categories/resultCategory/code%3D%27report%27
- Desmond, M., West, J. J., Bruno Soares, M., Manderscheid, P., & Malnaca, M. (2018a). *Expert workshop on social sciences and humanities in climate services research*. Venice, Italy: Report on JPI Climate Workshop. Retrieved from <http://www.jpi-climate.eu/media/default.aspx/emma/org/10895260/AG+EST+Report.pdf>
- Desmond, M., West, J., Bruno Soares, M., Manderscheid, P., & Malnaca, M. (2018b). *Report on JPI climate workshop expert workshop on social sciences and humanities in climate services research*. Venice, Italy: Isola di S. Giorgio Maggiore. Retrieved from <http://www.jpi-climate.eu/media/default.aspx/emma/org/10895260/AG+EST+Report.pdf>
- European Commission. (2015a). *A european research and innovation roadmap for climate services*. Luxembourg: European Commission.
- European Commission. (2015b). Annex 1 to the commission implementing decision concerning the adoption of a financing decision for 2015 in the framework of the copernicus programme. Brussels, 17.2.2015 C(2015) 767 final.
- European Commission. (2016). Climate change service. Retrieved from http://copernicus.eu/sites/default/files/documents/Copernicus_Factsheets/Copernicus_ClimateMonitoring_Feb2017.pdf
- European Commission. (2017). Work programme 2018-2020. 12. Climate action, environment, resource efficiency and raw materials. Retrieved from http://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-climate_en.pdf
- European Research Area for Climate Services (ERA4CS). (2016). The booklet of funded projects. Retrieved from http://www.jpi-climate.eu/media/default.aspx/emma/org/10882216/ERA4CS_joint_call_abstracts_funded_projects_30Mar2017.pdf
- Feldman, D. L., & Ingram, H. M. (2009). Making science useful to decision makers: Climate forecasts, water management, and knowledge networks. *Weather, Climate, and Society*, 1(1), 9–21.
- Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., ... White, L. L. (2014). Intergovernmental panel for climate change. In *Climate change 2014: Impacts, adaptation, and vulnerability. Summaries, frequently asked questions, and cross-chapter boxes. A contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change* (p. 190). Geneva, Switzerland: World Meteorological Organization.
- Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, 68(3), 643–653.
- Georgeson, L., Maslin, M., & Poessinouw, M. (2017). Global disparity in the supply of commercial weather and climate information services. *Science Advances*, 3(5), e1602632.
- Giuliani, G., Nativi, S., Obregon, A., Beniston, M., & Lehmann, A. (2017). Spatially enabling the global framework for climate services: Reviewing geospatial solutions to efficiently share and integrate climate data & information. *Climate Services*, 8, 44–58.
- Global Framework for Climate Services (GFCS). (2014). *Implementation plan of the global framework for climate services (GFCS)*. World Meteorological Organization. Retrieved from http://www.wmo.int/gfcs/sites/default/files/implementation-plan/GFCS-IMPLEMENTATION-PLAN-FINAL-14211_en.pdf
- Global Framework for Climate Services (GFCS). (2016). *Climate services for supporting climate change adaptation: Supplement to the technical guidelines for the national adaptation plan process*. World Meteorological Organization. Retrieved from https://library.wmo.int/pmb_ged/wmo_1170_en.pdf
- Goosen, H., de Groot-Reichwein, M. A. M., Masselink, L., Koekoek, A., Swart, R., Bessembinder, J., ... Immerzeel, W. (2014). Climate adaptation services for The Netherlands: An operational approach to support spatial adaptation planning. *Regional Environmental Change*, 14, 1035. <https://doi.org/10.1007/s10113-013-0513-8>
- Hewitt, C., Mason, S., & Walland, D. (2012). The global framework for climate services. *Nature Climate Change*, 2(12), 831–832.
- Hewitt, C. D., Stone, R. C., & Tait, A. B. (2017). Improving the use of climate information in decision-making. *Nature Climate Change*, 7(9), 614–616.

- Hill, M., & Varone, F. (2014). *The public policy process*. Abingdon, England and New York, NY: Routledge.
- Hinkel, J., & Bisaro, A. (2016). Methodological choices in solution-oriented adaptation research: A diagnostic framework. *Regional Environmental Change*, 16(1), 7–20.
- Hubbard, C. (2014). Open data policy. Met office. Retrieved from https://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/3/5/opendatapolicy_metoffice_v1.0.pdf
- Keele, S. (2019). Consultants and the business of climate services: Implications of shifting from public to private science. *Climatic Change*, 1–18. <https://doi.org/10.1007/s10584-019-02385-x>
- Lövbrand, E. (2011). Co-producing European climate science and policy: A cautionary note on the making of useful knowledge. *Science & Public Policy*, 38(3), 225–236.
- McNie, E. C. (2007). Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. *Environmental Science & Policy*, 10(1), 17–38.
- Meadow, A. M., Ferguson, D. B., Guido, Z., Horangic, A., Owen, G., & Wall, T. (2015). Moving toward the deliberate coproduction of climate science knowledge. *Weather, Climate, and Society*, 7(2), 179–191.
- Menary, M. B., & Hermanson, L. (2018). Limits on determining the skill of North Atlantic Ocean decadal predictions. *Nature Communications*, 9, 1694.
- Nicklin, S., Cornwell, B., Witthaus, M., Rowlands, C., & Griffiths, J. (2012). *Climate exchange*. Geneva: Tudor Rose Publications and World Meteorological Organization. Retrieved from https://library.wmo.int/pmb_ged/climate_exchange.pdf
- O'Brien, K., Eriksen, S. E., Schjolden, A., & Nygaard, L. P. (2004). What's in a word? conflicting interpretations of vulnerability in climate change research. *CICERO Working Paper*.
- Street, R. B. (2016). Towards a leading role on climate services in Europe: A research and innovation roadmap. *Climate Services*, 1, 2–5.
- Suarez-Gutierrez, L., Li, C., Müller, W. A., & Marotzke, J. (2018). Internal variability in European summer temperatures at 1.5° C and 2° C of global warming. *Environmental Research Letters*, 13(6), 064026.
- Thépaut, J., Dee, D., Engelen, R., & Pinty, B. (2018). The Copernicus Programme and its Climate Change Service (C3S): A European response to climate change. *COSPAR Scientific Assembly*, 42 A0.4-15-18. Retrieved from <http://adsabs.harvard.edu/abs/2018cosp...42E3368T>
- Vaughan, C., Buja, L., Kruczkiewicz, A., & Goddard, L. (2016). Identifying research priorities to advance climate services. *Climate Services*, 4, 65–74.
- Vaughan, C., & Dessai, S. (2014). Climate services for society: Origins, institutional arrangements, and design elements for an evaluation framework. *WIREs Climate Change*, 5(5), 587–603.
- Vaughan, C., Dessai, S., & Hewitt, C. (2018). Surveying climate services: What can we learn from a Bird's-eye view? *Weather, Climate, and Society*, 10(2), 373–395.
- Webber, S., & Donner, S. D. (2017). Climate service warnings: Cautions about commercializing climate science for adaptation in the developing world. *WIREs Climate Change*, 8(1), e424.
- World Meteorological Organization. (2017). *Priority needs for the operationalization of the global framework for climate services (2016–2018)*. Geneva, Switzerland: World Meteorological Organization.
- World Meteorological Organization (n.d.). Role and operation of National Meteorological and hydrological services. A statement by the world meteorological organization for directors of NMHSs. Retrieved from https://library.wmo.int/pmb_ged/2015_role-operation-nmhs_en.pdf
- Zillman, J. W. (2005). *The role of national meteorological services in the provision of public weather services*. World Meteorological Organization. Retrieved from <http://www.wmo.int/pages/prog/amp/pwsp/downloads/cbs/conference%20presentations/Zillman1.pdf>

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