The use of climate information in humanitarian relief efforts: a literature review

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Abstract

Purpose – This paper aims to provide a systematic literature review of the state-of-the-art applications of climate information in humanitarian relief efforts, to further the knowledge of how climate science can be better integrated into the decision-making process of humanitarian supply chains.

Design/methodology/approach – A systematic literature review was conducted using a combination of key search terms developed from both climate science and humanitarian logistics literature. Articles from four major databases were retrieved, reduced and analyzed.

Findings – The study illustrates the status of application of climate information in humanitarian work, and identifies usability, collaboration and coordination as three key themes.

Originality/value – By delivering an overview of the current applications and challenges of climate information, this literature review proposes a three-phase conceptual framework.

Keywords Supply chain management in disaster relief, Humanitarian logistics, Climate change, Natural hazards, Disaster relief operations, Interorganizational coordination

Paper type Literature review

1. Introduction

Over the past 50 years, climate change and extreme weather events have caused a surge in natural disasters, impacting underdeveloped countries in a disproportionate way. According to a report by the WMO and UNDRR, between 1970 and 2019, more than 11,000 disasters were related to either weather, climate or water. These disasters account for 62% of total disasters, 80% of total deaths, and 99% of total losses of US$3.65 trillion (WMO, 2021). In addition to its impacts on commercial supply chains (Papadopoulos *et al.*, 2017), climate change also affects humanitarian supply chains (HSCs) as HSCs respond to and work in disasters (Halldórsson and Kovács, 2010; Kovács and Spens, 2009). To adapt to the increasing climate risks (Kovács and Spens, 2011), HSCs need to increase "efficiency and cost effectiveness through investment in key technologies and human resources" (Majewski *et al.*, 2010, p. 15). Climate science represents an important aspect of the "key technologies" (Braman *et al.*, 2010). One example is considering climate factors in decision support systems in warehouse location selection (Charles *et al.*, 2016). However, despite the increasing attention and amount of research on climate-related issues, the use of climate science in HSCs is far from its full potential.

A review study on sustainable HSCs has acknowledged that climate change adaptation should be integrated into sustainable HSCs (Dubey and Gunasekaran, 2016). Nevertheless, the research gaps identified in the past years have received little attention, and the number of contributions to sustainable HSCs remains relatively limited considering its importance (Dubey and Gunasekaran, 2016). To have a comprehensive overview of the application of climate science in HSCs, a state-of-the-art review is yet to be conducted.

Climate information refers to all kinds of information related to climate in a broad sense and can provide decision-makers with valuable insights. This study intends to understand how climate information is used in humanitarian relief efforts and HSCs. The study also explores the challenges encountered by the current applications, and the potential solutions to these challenges. To achieve the research goal, a systematic literature review (SLR) was conducted to prevent the loss of knowledge and keep valuable insights of relevant articles (Tranfield *et al.*, 2003). The study follows the paradigm of SLR in supply chain management (SCM) proposed by Durach *et al.* (2017). In total, 77 articles were analyzed to provide an overview of the applications of climate information in humanitarian relief efforts. As the logistics aspect is a key component in humanitarian operation, the study also draws link between logistics and humanitarian relief efforts.

The systematic literature culminates in a theoretical framework. In this framework, the process of applying climate information is divided into three phases: development, adoption and operation. For each of the phases, one key theme

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is identified and discussed. In the development phase, usability, a matter of "how science is produced and how it is needed in different decision contexts" (Dilling and Lemos, 2011), plays a key role. In the adoption phase, collaboration, "the ability to work across organizational boundaries to build and manage unique value-added processes to better meet customer needs" (Fawcett *et al.*, 2008a, p. 93), plays a key role. In the operation phase, coordination, "dependencies between activities" (Malone and Crowston, 1994), plays a key role. How they are linked to and differentiated from each other will be discussed in detail in Section 4.

This paper is structured as follows. First, the methodology section describes how the research was designed and how data was collected. Second, the main findings and challenges found are presented. Finally, the recurring themes identified in the literature review are discussed.

2. Methodology

Originally used in medical science as an evidence-based approach to improve the quality of literature review (Tranfield *et al.*, 2003), SLR has been widely applied to other fields because of its transparent and inclusive principles. SLR enables a more comprehensive inclusion of literature selected in a relatively objective and replicable manner (Denyer and Tranfield, 2009). Over the past years, SLR has been extensively used and developed in management studies (Denyer and Tranfield, 2009; Mulrow, 1987; Tranfield *et al.*, 2003). This paper is based on the paradigm for SLR developed by Durach *et al.* (2017) for SCM research.

The paradigm consists of six steps that are commonly found in an SLR and illustrates how SCM researchers can adapt them into a SCM study (Durach *et al.*, 2017). In Step 1, in addition to stating research question and justifying the relevance and timeliness of the paper (Denyer and Tranfield, 2009; Mulrow, 1987; Tranfield *et al.*, 2003), SCM researchers should also develop an initial theoretical framework, which the SLR intends to refine based on the findings (Durach *et al.*, 2017). In Step 2, when designing the inclusion and exclusion criteria, SCM researchers should select literature based on their potential contribution to the initial theoretical framework proposed in Step 1 (Durach *et al.*, 2017). In Step 3, when gathering the literature sample, researchers should carefully consider terminologies because different terms can be used to describe an identical phenomenon. In other cases, the same terminology refers to different phenomena (Durach *et al.*, 2017). In Step 4, the inclusion and exclusion criteria are applied, in the principle that the selected literature must contribute to the refinement of the proposed theoretical framework. This can lead to a smaller yet stronger sample and ensure that irrelevant literature that can distract or distort the research findings can be excluded (Durach *et al.*, 2017). In Step 5, when the literature is synthesized and analyzed, it is recommended that SCM researchers should not target for general cause–effect conclusion, but instead contingent causalities that can contribute to the development of the theoretical framework (Durach *et al.*, 2017). Finally, in Step 6, when reporting the research results, researchers should focus on how the theoretical framework has been refined and improved based on the SLR findings.

The study started with defining research questions and justifying the relevance and timeliness of the paper (Denyer and Tranfield, 2009; Mulrow, 1987; Tranfield *et al.*, 2003). The research questions for the study are as follows:

RQ1. How is climate information being used in humanitarian relief efforts and HSCs?

RQ2. What are the challenges encountered by the current applications and the potential solutions to these challenges?

By addressing these questions, the study intends to lay out the status of the field and provide a research agenda for further studies.

We modified Step 1 due to the lack of an available initial theoretical framework. According to Durach *et al.* (2017), the inclusion and exclusion criteria of literature should be defined based on potential contribution to the initial theoretical framework proposed in Step 1. Even though there is abundant published research about either HSC or climate information, the number of academic articles directly related to both topics is limited. We also identified no initial theoretical framework that can serve as a basis for the SLR. Therefore, instead of refining an existing theoretical framework, our contribution in this SLR is to develop a new theoretical framework based on the findings. Consequently, inclusion and exclusion criteria of literature are defined based on the potential contribution to the development of a new theoretical framework.

This study focuses on empirical peer-reviewed academic articles in English, published between 2000 and 2020 on hydrological or meteorological natural hazards topics related to climate. This inclusion criteria ensure quality, relevance and impact of the studied material. Articles focusing on other types of natural hazards such as volcanic eruptions or manmade disasters are excluded. Articles without substantive and empirical relevance are also excluded as their contribution to the development of the theoretical framework can be slim.

Initial literature sample was then defined. According to Durach *et al.* (2017), the keywords should follow SCM terminology. We carefully consider the possibility that different terms are used to describe an identical phenomenon, or the same terminology is used to refer to different phenomena. The set of search terms for this research was developed based on desktop research, recommendations from experts in the field and the authors' prior knowledge. Two sets of strings were created and combined to ensure a large baseline sample and avoid neglecting articles that might add to the research findings. Set A includes "climate information," "climate science," "climate forecast," "climate prediction," "climate service," "seasonal forecast" and "weather forecast." Set B includes "humanitarian," "disaster relief," "supply chain" and "logistics." Each of the strings in Set A was combined with each of those in Set B, using the Boolean "AND" (e.g. "climate information" AND "humanitarian"), resulting in 28 search terms in total. Such a combination ensures that the resulting sample includes both climate information and HSCs. The databases used for the search are Emerald Insight, Springer Link, Science Direct and Wiley, four databases that are transdisciplinary and where both SCM/operations management and climate science journals are found. The 28 search terms returned a total of 1,438 items, of which at least one of the search terms is present in either the title or the abstract. In total, 191 of the articles were duplicates and were removed. However, many articles only contain the other search term in the reference section. In other cases, the other search term may only appear once or twice in the article as side topics. Therefore, even though the initial sample seems large, many articles are only related to one of the search terms.

The inclusion and exclusion criteria were applied to the sample of 1,247 unique articles to focus on those contributing to the development of the theoretical framework. We consider an article to be of potential contribution if:

- It informs about a practice of using climate information in the humanitarian context; and
- It informs about a practice of using climate information in logistics commercial context that can serve as a lesson for the humanitarian sector.

This leads to a smaller but stronger sample of 77 articles and ensures that irrelevant literature that can distract or distort the research findings can be excluded (Durach *et al.*, 2017). Inclusion and exclusion criteria were applied to title, abstract and keywords to assess the relevance of each article. A complete list of selected literature is attached in the Appendix.

As shown in Figure 1, even though with some spikes, the field in general has attracted more attention over the past decade.

The selected literature was synthesized and analyzed. The goal of this step is not to target general cause–effect conclusions, but instead look for contingent causalities that can contribute to the development of the theoretical framework (Durach *et al.*, 2017).

Finally, research results focusing on how a theoretical framework can be proposed based on the SLR findings.

The research design, including the development of search terms and selection of databases, was conducted prior to the review to ensure the research's inclusiveness (Tranfield *et al.*, 2003). The broadness of the source of literature was achieved by covering articles from both supply chain focus and climate science focus. The development of the selection criteria is aligned with the research goal. The application of the criteria has been consistent, and data quality has been carefully ensured (Seuring and Gold, 2012).

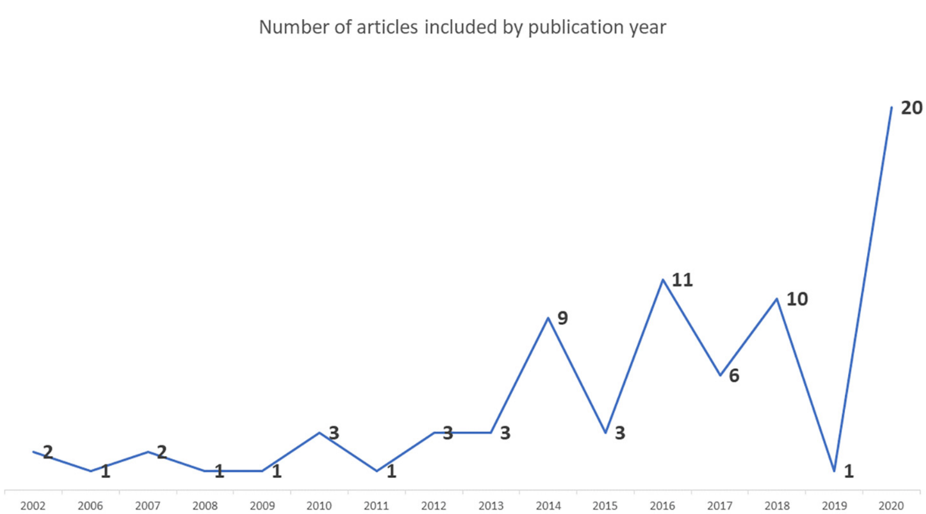
3. Findings

3.1 Current applications of climate information

The results show that there is no unified definition of climate information. The term is used in a broad sense to refer to all kinds of climate-related information such as precipitation and air temperature. In practice, climate data are collected, processed and disseminated by organizations at different levels: national, regional, research institute and private sector providers (Vaughan and Dessai, 2014). The potentials and challenges of climate information in disaster risk management were already discussed in the early 2000s (Wernstedt and Hersh, 2002). Currently, climate information is applied in humanitarian relief efforts usually in the form of forecasts to support planning in different stages, from early warning to recovery of the disaster (Alfieri *et al.*, 2018; Goddard *et al.*, 2014; Fall *et al.*, 2007). In addition to forecast models, the development of geospatial technologies based on climate information enables the monitoring of the development of natural hazards such as drought (Vicente-Serrano *et al.*, 2012) and flood risks in real time (Koriche and Rientjes, 2016).

Climate information is applied across spatial contexts. Even though most research focuses on development of models in developing countries, such as in Central and West Africa (Braman *et al.*, 2012; Cornforth, 2012; Djibo *et al.*, 2015; Dunning *et al.*, 2016; MacLeod *et al.*, 2020; Siegmund *et al.*, 2015; Tanessong *et al.*, 2020) and South Asia (Dinnissen *et al.*, 2020; Nissan *et al.*, 2020), there are also efforts to develop models for Europe (Sirdas *et al.*, 2006). In a smaller scale, most literature focuses on rural context. Though, climate information-based decision support systems to mitigate disaster risks are also developed for urban contexts (Baklanov *et al.*, 2018). As technology advances, weather and climate information is also applied using big data and crowdsourcing techniques (Ali *et al.*, 2016; Guntha *et al.*, 2020).

Figure 1 Number of articles included by publication year



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Climate information is used in humanitarian operations in response to different types of natural disasters (Altay and Narayanan, 2020), including drought (Boult *et al.*, 2020; Brown *et al.*, 2007; Brown, 2009; Krishnamurthy *et al.*, 2020; Vicente-Serrano *et al.*, 2012), flooding (Braman *et al.*, 2012; Cornforth, 2012; Djibo *et al.*, 2015; Koriche and Rientjes, 2016; Siegmund *et al.*, 2015; Tanessong *et al.*, 2020; Wu *et al.*, 2020; Yossef *et al.*, 2013), storms (Cuaton and Su, 2020; Emerton *et al.*, 2020; Kuleshov *et al.*, 2020; Robertson *et al.*, 2020) and heat waves (Dinnissen *et al.*, 2020; Nissan *et al.*, 2020).

Climate information also provides insights for decision-making in inventory management and warehouse location (Davis *et al.*, 2013; Morrice *et al.*, 2016; Pedraza-Martinez and Van Wassenhove, 2016; Taskin and Lodree, 2011) in the context of hurricane and storm threats.

Furthermore, climate information is applied both at macro and micro levels. On a macro, long-term scale, climate information is used to identify disaster-prone areas. Therefore, vulnerable regions susceptible to climate threats receive more attention (de Sherbinin, 2014; Schwerdtle *et al.*, 2020). On a micro, short-term scale, climate information is used to help public health systems address weather-related emergencies (Runkle *et al.*, 2018). Climate information is communicated to the public on social media to mitigate the damage of natural disasters (Mesmar *et al.*, 2016).

Finally, climate information has been integrated into the operations of humanitarian organizations. A forecast-based financing scheme based on climate forecast was developed to distribute funding to humanitarian organizations in advance to disasters in an automated manner. This scheme enables humanitarian organizations to adopt anticipatory actions (de Perez *et al.*, 2015; Hagen *et al.*, 2020; Lopez *et al.*, 2020; Schwerdtle *et al.*, 2020). The scheme of forecast-based financing is further developed by Lopez *et al.* (2020) by introducing a valuation approach, which helps various types of users to determine what thresholds should be used as the triggers for early actions.

3.2 Challenges and potential solutions

Despite the benefits of applying climate information in humanitarian relief efforts (Tall, 2010), many factors can hinder the use of climate information and prevent it from being applied. Some of these challenges are technical and pertinent to the skills of climate forecast and availability of data. Other challenges are managerial and related to the perception and attitude of decision-makers (Shareef *et al.*, 2019; Vicente-Serrano *et al.*, 2012).

The reliability and availability of climate forecast are highly important to gain trust from the users (Krishnamurthy *et al.*, 2020; Tart *et al.*, 2020). However, depending on the local conditions, the reliability and availability vary heavily from context to context (Gitonga *et al.*, 2020; Tart *et al.*, 2020).

3.2.1 Accuracy and relevance

One challenge regarding climate information is the accuracy of climate forecasts, as these are not always correct and can significantly vary from one context to another. Across regions, stakeholders have different experiences concerning the effectiveness of early warning systems based on climate information (Lumbroso *et al.*, 2016). The effectiveness of systems based on climate information should be further evaluated in different regions to obtain a better idea of what can be improved. The evaluation is also key to building trust between providers and end-users, which will further facilitate the use of climate information-based products (Alfieri *et al.*, 2018). Some techniques are still in development and not very mature. For example, downscaling seasonal forecast, used to provide forecast at a higher solution for local uses, is found to be sensitive to region and data set. However, it is not as reliable as the coarser resolution forecast in place (Nikulin *et al.*, 2018). In locations where the conditions do not support decent forecast, decision-makers should be cautious before making decisions based on climate information (de la Poterie *et al.*, 2018). It is therefore recommended that decision-makers should clearly identify local needs and determine if climate information should be applied, and to what extent they should rely on climate information.

3.2.2 Discrepancy

A major problem is how to bridge the gap between scientific research and practical applications (Vaughan and Dessai, 2014; Wall *et al.*, 2017; Wu *et al.*, 2020; Zaval and Cornwell, 2017) because poorly communicated climate information proved to be unhelpful to the users (Hewitson *et al.*, 2017; Oloruntoba *et al.*, 2017).

A commonly found factor that hinders the use of climate information is the discrepancy in perception. As end-users, humanitarian organizations do not share the same view of climate information-based products as climate scientists, the developer and provider of these products (de Perez and Mason, 2014). This may be due to their different perception of climate risks. People who lack awareness or accessibility to such information and people have received false information in the past tend to be indifferent to weather forecast (Hossain and Paul, 2018; Tart *et al.*, 2020). In addition, the same risk is perceived in different ways by different people. Local communities may value short-term over long-term solutions (Staub *et al.*, 2020). Therefore, it is suggested that other than the climate forecast, the context and setting in which the natural hazard occurs are also crucial factors (Ramírez and Briones, 2017). The discrepancy may result in a lack of "interoperability" among government bodies and NGOs working to relieve disasters (Shareef *et al.*, 2019). The political context would also influence how people make decisions when facing a natural hazard. For example, in places where the issue of climate change is politicized, it is less likely that decision-makers would perceive climate risks in an objective way (Oloruntoba, 2013).

To tackle the discrepancy of perception, potential solutions include helping end-user organizations better understand the usefulness of climate products (de Perez and Mason, 2014; Tall, 2010; Njau, 2010), providing information in an understandable way for practitioners (de Perez and Mason, 2014; Tall, 2010; van Aalst *et al.*, 2008) and facilitating partnership between science workers and humanitarian organizations (de Perez and Mason, 2014; Hansen *et al.*, 2014; Tall, 2010). A promising example is the development of a serious game to help humanitarian workers better understand the value of climate information (Parker *et al.*, 2016). Nonetheless, communication is not only between science workers and local organizations, but also between climate information providing scientists and scientists from local communities at risk (Lyon *et al.*, 2014).

Discrepancy also exists between what end-users want and what the scientific community can offer (Giannini *et al.*, 2016), between what is provided and what is needed (de la Poterie *et al.*, 2018; Carr and Onzere, 2018) or between how climate risks is perceived and how local communities respond to the perceived risks. These mismatches are due to the communication gaps between science workers and the local communities (Baudoin and Wolde-Georgis, 2015; Parker *et al.*, 2016). Even though climate risks have been recognized by certain communities, very few plans exist to integrate newly developed climate information into their hazard mitigation plans (Stults, 2017). The primary reason is that climate information is not understandable or usable (Tschakert *et al.*, 2010). However, the understanding and trust of the local communities are key in humanitarian relief work. If climate information fails to convince the local communities of its benefits, it will not be adopted. Furthermore, it can even be dangerous when end-users misunderstand the climate information and make decisions based on the misinterpretation (de la Poterie *et al.*, 2018).

Therefore, it is essential to provide training for end-users (Vicente-Serrano *et al.*, 2012). The mode of training provided by climate scientists to practitioners also switches to user driven. End-users of climate information are involved in the early stage of the training to ensure that the training design meets local needs (Mantilla *et al.*, 2014). This mode of early engagement of user communities has been confirmed to be important by the stakeholders (Giannini *et al.*, 2016).

To better address this problem, scientists also call for a different approach for knowledge production, climate product development and climate product design. A bottom-up approach is suggested to facilitate community-based risk reduction (van Aalst *et al.*, 2008). Co-production of knowledge is encouraged. For example, local traditional climate knowledge should be incorporated to tailor the climate information products for local conditions (Egeru, 2016; Kniveton *et al.*, 2014; Wall *et al.*, 2017). Groups such as disability and women that may be marginalized in some communities should also be involved (Webb, 2020).

Hazard information is found to be most useful if combined with local information (Alfieri *et al.*, 2018). A study identifies the main challenges as the scattered information flow within organizations, and between the humanitarian sector and the scientific community (DeCrappeo *et al.*, 2018). A deeper mutual understanding is yet to be found between the local communities and scientific workers. It is crucial to understand how vulnerable groups respond to disasters (Tschakert *et al.*, 2010). Peer pressure may also hinder application of climate information, who are more conservative to embrace new ways of practice. Understanding how to alleviate this pressure is critical to achieve usable design of products based on climate information (Carr and Onzere, 2018).

3.2.3 Accessibility

Accessibility is another challenge for climate information applications (Gitonga *et al.*, 2020; Tart *et al.*, 2020). The availability of climate information is absent in some parts of the world, especially the rural communities. Therefore, a decentralization of climate information dissemination is needed (Njau, 2010). Digital platforms on which climate information is made available and accessible for non-climate specialists are developed to aid humanitarian works (Blumenthal *et al.*, 2014). Some scholars also advocate a real-time release of climate information (Vuillaume *et al.*, 2018). However, channels to disseminate climate information should adapt to local conditions. For example, community meetings are a better channel to disseminate climate information than radio in some communities (Egeru, 2016).

3.2.4 User definition

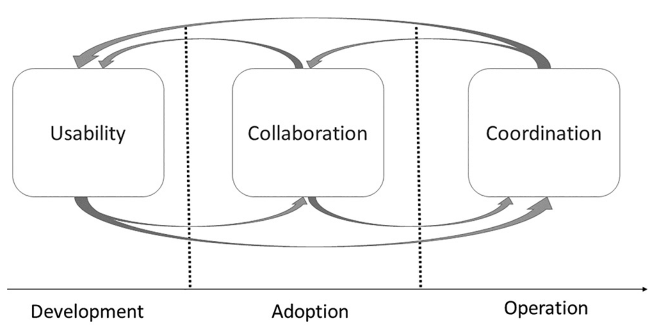
It is difficult to develop a tool without knowing what purpose and which users the tool is developed for. The definition of the "end user" of climate information varies. In some studies, the end-user of climate information refers to humanitarian organizations (de Perez and Mason, 2014). While in some other studies, the end-user of climate information refers to local communities (Baudoin and Wolde-Georgis, 2015). Another study identifies three types of end-users, namely, the local communities, decision-makers from humanitarian organizations and humanitarian workers that implement the operation (Djenontin and Meadow, 2018). The different positioning of end-users may affect the design approach, prioritization of interest, how the decision support systems should be designed considering the capabilities and needs of different users (Moss, 2016).

4. Discussion

From the literature review, a wide range of challenges have been identified. These challenges are also found to be interconnected. To better map the process of the use of climate information, we introduce a three-phase division: development, adoption and operation. By dividing the process into three phases, it is easier to identify the most important challenges and factors in each phase. In each phase, a key theme plays the most important, as illustrated by Figure 2. The key themes, namely, usability, collaboration, and coordination, are also interconnected and affect each other. To better illustrate their roles in each phase and interdependencies, we developed a framework to synthesize the recurring patterns from findings.

In the following sections, the key themes are defined and differentiated from each other. Their importance in each phase of climate information application and their interdependencies are explored. A more detailed discussion on each of the themes and their role in each of the phases will be explored in the following subsections.

Figure 2 A three-phase framework of the use of climate information



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4.1 Phase 1: development

The application of climate information in humanitarian relief efforts starts from the process of development. In Phase 1, climate scientists develop climate information by converting raw climate data into informed knowledge. Then, informed knowledge is turned into decision-oriented knowledge (Lemos *et al.*, 2012). This process is described by Lemos *et al.* (2012) as "value adding," because the process transforms raw data into more useful knowledge for decision-makers.

However, not all information developed is usable for a specific user group or a specific purpose. A persistent gap exists between the production of knowledge and the application of knowledge. There are two drivers that play a significant role in the use of climate information, including the internal factor of attitude toward knowledge and the external factor of decision-making environment (Kirchhoff *et al.*, 2013). Climate information, when used in a real-world decision-making context, is subject to misuse and misinterpretation (Lemos *et al.*, 2002). It may not match with user need or contribute to solving problems. In addition, how the information is presented also determines if its target users can use it effectively.

Therefore, in this phase, usability plays the most important role. Usability is a matter of "how science is produced and how it is needed in different decision contexts" (Dilling and Lemos, 2011). Usability measures to what extent the information produced for the intended users matches user need. If scientists cater to the needs of target users and deliver climate information in a comprehensible and ready-to-use form, the climate information is of good usability.

Most of the challenges in Phase 1 arise due to a mismatch between the supply and the demand side of the climate information. Such a usability gap can be narrowed by better collaboration and coordination.

By collaboration, we refer to "the ability to work across organizational boundaries to build and manage unique value-added processes to better meet customer needs" (Fawcett *et al.*, 2008a, p. 93). Collaboration is not only important because of the collaborative nature of application of climate tools, but also because collaboration is conducive to decision-making (Allred *et al.*, 2011). Collaboration helps reduce costs and achieve a high level of customer satisfaction (Fawcett *et al.*, 2010). However, most organizations struggle to achieve effective collaboration (Fawcett *et al.*, 2008a).

On the other hand, by coordination, we refer to the management of "dependencies between activities" (Malone and Crowston, 1994). Coordination enables the involved actors to rapidly respond to changes (Kanda *et al.*, 2008; Simatupang *et al.*, 2002), and reduces costs, inventory, and lead time as well as resolve conflicts (Kanda *et al.*, 2008). Coordination is crucial in this context as the production, adoption and operation of climate information presents an intricate network of activities that are interdependent on each other. Such dependencies result from shared limited resource, producer–consumer relationships, simultaneity constraints and task and subtask dependencies (Malone and Crowston, 1994).

It is to be noted that in some literature, the terms coordination and collaboration are used interchangeably (Bealt *et al.*, 2016; Jahre and Jensen, 2021; Jensen, 2012). However, in this article, we adopt the differentiation proposed by Wankmüller and Reiner (2020) that coordination is limited to the process of "organizing, aligning and differentiating" to "reach a shared goal in the context of disasters." On the other hand, collaboration, in this study, focuses more on "establishing a close and intensive relationship between NGOs for jointly solving problems" (Wankmüller and Reiner, 2020). In short, coordination focuses on the realm of organization of activities while collaboration on the realm of relationship management across organizational boundaries.

To close the usability gap, sufficient communication among partners is indispensable. Such a level of communication often requires that good trust be achieved (Kirchhoff *et al.*, 2013). Good collaboration ensures that target users could effectively communicate their needs (Lemos, 2012). Local communities can also contribute to the development of climate information by sharing their valuable local knowledge (Alfieri *et al.*, 2018). Such process enables scientists to develop climate information based on the input from its target users and avoid false assumptions. Therefore, the outcome is a collaborative product that all involved parties have contributed to, ensuring good usability.

One way to achieve good collaboration in Phase 1 is to create boundary organizations, which facilitate the interaction between knowledge producer and knowledge user (Kirchhoff *et al.*, 2013) and bridge the knowledge gap between them (Lemos *et al.*, 2014). Such organizations are also known as boundary spanners (Salem *et al.*, 2018). Boundary organizations usually consist of people with knowledge of two distinct fields and can work across cultural norms. International Research Institute for Climate and Society based in Columbia University is a good example of a boundary organization, whose researchers work closely with humanitarian organizations such as IFRC and strive to link science with policy (Agrawala *et al.*, 2001; Braman *et al.*, 2010; Buizer *et al.*, 2016; de Perez and Mason, 2014).

While good collaboration provides a platform available for idea exchange, good coordination guides how to have a conversation that leads to outcome of good usability. A well-coordinated conversation should clarify and differentiate the goals and responsibilities. Unclear goals and confusing division of roles may lead to unsatisfactory usability.

When it comes to climate information application in humanitarian relief efforts, usable climate information requires customization because of the great diversity of the capacity, resource, purpose, working context of the target users. Therefore, in Phase 1, the target users should clarify their needs before the scientists start working on climate information. Scientists should keep in mind that their goal is to fulfill the needs of target users, and refrain from assuming what climate information can do before consulting the target users. Otherwise, scientists may produce climate information that may not be what the target users want (de la Poterie *et al.*, 2018; Carr and Onzere, 2018).

Another role of the target users is to provide scientists with feedback so that scientists can discover the shortcomings of the current design, and "redevelop" the tool to achieve better usability.

4.2 Phase 2: adoption

In Phase 2, developed climate information awaits the adoption of relevant humanitarian actors. We argue that adoption is rather a prolonged process than an instant action. In this process, the usability of the developed climate information is scrutinized by the intended users, who would decide whether to adopt it in their organization.

Government bodies, NGOs and scientific partners all have vastly different organizational structure and culture. These differences can lead to misunderstanding and difficulties in Phase 2. Therefore, the capability to manage relationships is decisive in whether usable climate information can be adopted.

Barriers that hinder collaboration include entrenched organizational structure and culture (Allred *et al.*, 2011; Fawcett *et al.*, 2008b, 2010, 2015), interorganizational conflicts, lack of clear guidelines, lack of willingness to share information (Fawcett *et al.*, 2008b, 2015), lack of shared risks and rewards (Fawcett *et al.*, 2008b). While these barriers are identified in the application of climate information in humanitarian work, collaboration can also happen on a selective basis and unevenly distribute benefits and burdens to the collaborating actors (Fawcett *et al.*, 2008b). In collaborative effort, selective collaboration can jeopardize the result. These barriers are the resisting force, either internal or external to the organizations (Fawcett *et al.*, 2008a), that prevents effective collaboration.

Interorganizational conflicts occur without aligned goals and risk perception. Organizations refuse to apply climate information in decision-making due to a lack of trust in it (Oloruntoba, 2013). Some organizations are reluctant to take the risks, given limited resources and concerns over responsibility. In most cases, climate information is delivered in the form of forecast-based contingency plans, which are subject to uncertainty. The lack of clear guidelines is even more detrimental in this context because actors must make decisions based on the information provided by other parties (Fawcett *et al.*, 2008b).

Therefore, collaboration plays the most critical role in Phase 2. Good relationship management and trust building increase the likelihood of convincing relevant parties to take the risks of an innovative approach. Good usability and coordination contribute to the adoption decision.

On the one hand, an easy-to-understand product makes it easier to convince stakeholders. Good usability of developed climate information helps to boost the trust between scientists and humanitarian organizations, facilitating future collaboration. On the contrary, poorly designed climate information that does not meet the target users' expectations sows doubt and mistrust, making any future attempt at collaboration more difficult.

On the other hand, success resulting from good coordination in Phase 3 would reversely reinforce trust and facilitate further collaboration. Such success can make it easier to convince the user to expand the usage of climate information. The good reputation of the approach will also spread to other potential users who have not yet adopted climate information.

4.3 Phase 3: operation

In Phase 3, climate information is operationalized by the humanitarian actors as contingency plans and put into practice when natural hazards hit.

Even though contingency plans vary case by case, they are similar in that they involve multiple parties to take actions depending on the outcome of a preceding event, especially in cases where multiple humanitarian organizations work toward the same goal.

The outcome of an operation depends on how well the parties involved coordinate the planned activities, usually with the assistance of local governments and communities.

Usability of climate information determines the quality of the contingency plan. A poorly planned action increases the difficulty to effectively coordinate the operation and will heavily affect the outcome. Good collaboration boosts information sharing during operation.

Of course, after an unsatisfactory operation, it should be reflected in which phase things went wrong. Is it that the contingency plan was designed beyond the capability of the users in Phase 1, or unnecessary mistakes were made in Phase 3, or both? Such an evaluation would again require that the parties involved have achieved good collaboration to guarantee an objective conclusion.

As illustrated in Figure 2, the three themes are interconnected and form three loops. To turn them into positive feedback loops can facilitate the use of climate information in humanitarian relief efforts. However, if any of them is poorly managed, a negative feedback loop will be quickly formed. Poor usability prevents humanitarian workers from using climate information and provides infeasible recommendations that makes it difficult to effectively organize, align and differentiate their actions. Consequently, the disappointing outcomes make it harder for involved parties to achieve mutual trust and work together in the future.

5. Conclusion

Even though with many challenges ahead, climate information is being applied in various ways in humanitarian relief efforts. However, research focused on applications of climate information in HSCs in particular is still limited. There are very few examples found to be directly related to both climate information and humanitarian logistics.

In this article, the themes of usability, collaboration and coordination were found to be recurring during the literature review and account for most of the success or failure of application of climate information in humanitarian relief efforts. Therefore, we propose a three-phase framework to divide the process of using climate information in humanitarian relief efforts into development phase, adoption phase and operation phase. Usability, collaboration and coordination each play an important role in the process. These three themes are also interconnected and form three loops.

We recommend that more research that connects HSCs with climate science to be conducted. For example, mapping out the complex network of the involved parties, their interactions and their behavioral patterns can help further develop the proposed framework.

This framework provides researchers with a basis which future development of climate information applications can build upon and refer to. It helps researchers, especially those involved in the development of climate information applications, to stay focused on the key aspects of development and ensure that the outcomes are valuable to the users.

This framework also provides practitioners with a tool to reflect on their application of climate information. It helps practitioners to identify the technical and relational aspects that need further improvement and in what way the improvement can be achieved.

Limited by the subjectivity of choosing a limited number of search terms, the article may not represent an exhaustive review of the field. By including more search terms to widen the literature, the review results may be different. Further research is needed to draw a conclusion that reflects a more comprehensive perspective of the field.

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Appendix

Table A1 Articles by journal

Journal	#	Articles
Annals of Operations Research	1	Shareef *et al.* (2019)
Applied Geography	1	Vicente-Serrano *et al.* (2012)
Atmospheric Science	1	MacLeod *et al.* (2020)
Big Data Analytics	1	Ali *et al.* (2016)
Climate Risk Management	4	Carr and Onzere (2018), Egeru (2016), Nissan *et al.* (2020), Stults (2017)
Climate Services	3	Dinnissen *et al.* (2020), Nikulin *et al.* (2018), Tart *et al.* (2020)
Climatic Change	4	de Sherbinin (2014), Lemos *et al.* (2002), Moss (2016), Tschakert *et al.* (2010)
Current Environmental Health Reports	1	Runkle *et al.* (2018)
Disasters	3	Braman *et al.* (2012) Kniveton *et al.* (2014), Oloruntoba *et al.* (2017)
Earth Perspectives	7	Blumenthal *et al.* (2014), de Perez and Mason (2014), Hansen *et al.* (2014), Giannini *et al.* (2016), Goddard *et al.* (2014), Lyon *et al.* (2014), Mantilla *et al.* (2014)
Earth Systems and Environment	1	Hossain and Paul (2018)
Environmental Management	2	DeCrappeo *et al.* (2018), Djenontin and Meadow (2018)
Environmental Science and Policy	1	Alfieri *et al.* (2018)
Eos, Transactions American Geophysical Union	1	Brown *et al.* (2007)
European Journal of Education	1	Zaval and Cornwell (2017)
Frontiers in Ecology and the Environment	1	Wall *et al.* (2017)
Geography Compass	1	Brown (2009)
Global Environmental Change	1	van Aalst *et al.* (2008)
Global Food Security	1	Krishnamurthy *et al.* (2020)
Globalization and Health	1	Schwerdtle *et al.* (2020)
International Journal of Disaster Risk Reduction	3	Cuaton and Su (2020), de la Poterie *et al.* (2018), Emerton *et al.* (2020)
International Journal of Disaster Risk Science	3	Baudoin and Wolde-Georgis (2015), Parker *et al.* (2016), Ramírez and Briones (2017)
International Journal of Forecasting	1	Altay and Narayanan (2020)
International Journal of Production Economics	1	Davis *et al.* (2013)
Journal of Geophysical Research: Atmospheres	3	Dunning *et al.* (2016), Robertson *et al.* (2020), Siegmund *et al.* (2015)
Journal of Hydrology: Regional Studies	1	Djibo *et al.* (2015)
Journal of Operations Management	2	Morrice *et al.* (2016), Pedraza-Martinez and Van Wassenhove (2016)
Journal of Public Health Policy	1	Mesmar *et al.* (2016)
Journal of the American Water Resource Association	1	Wernstedt and Hersh (2002)
Journal of the Operational Research Society	1	Taskin and Lodree (2011)
Meteorological Applications	1	Boult *et al.* (2020)
Natural Hazards	4	Fall *et al.* (2007), Kuleshov *et al.* (2020), Lumbroso *et al.* (2016), Vuillaume *et al.* (2018)
Physics and Chemistry of the Earth, Parts A/B/C	1	Koriche and Rientjes (2016)
Population and Environment	1	Staub *et al.* (2020)
Procedia Computer Science	1	Guntha *et al.* (2020)
Procedia Environmental Sciences	2	Njau (2010), Tall (2010)
Progress in Disaster Science	1	Hagen *et al.* (2020)
Regional Environmental Change	1	Webb (2020)
Technological Forecasting and Social Change	1	Oloruntoba (2013)
Tellus A: Dynamic Meteorology and Oceanography	1	Sirdas *et al.* (2006)
Theoretical and Applied Climatology	1	Tanessong *et al.* (2020)
Urban Climate	1	Baklanov *et al.* (2018)
Water Resources Research	1	Yossef *et al.* (2013)
Weather	1	Cornforth (2012)
Weather and Climate Extremes	1	Lopez *et al.* (2020)
Wiley Interdisciplinary Reviews: Climate Change	2	Hewitson *et al.* (2017), Vaughan and Dessai (2014)
Wiley Interdisciplinary Reviews: Water	1	Wu *et al.* (2020)
World Development Perspectives	1	Gitonga *et al.* (2020)

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