Connecting Climate Information Producers and Users: Boundary Organization, Knowledge Networks, and Information Brokers at Caribbean Climate Outlook Forums

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ABSTRACT

Boundary organizations, knowledge networks, and information brokers have been suggested as mechanisms that help integrate information into decision-making and enhance interactions between the producers and users of climate information. While these mechanisms have been discussed in many studies in disparate fields of research, there has been little empirical research describing how they relate and support each other within studies on climate services. In this paper, two Caribbean Regional Climate Outlook Forums (CariCOFs) convened in 2014 are studied. CariCOFs facilitate the production of regional seasonal climate information and the dissemination of it to a diverse climate and socioeconomic region. Network analysis, key informant interviews, and small group discussions were used to answer two questions: 1) what are the barriers to using seasonal climate forecasts (SCFs) by CariCOF participants and 2) what are the iterative processes of information exchange that address these barriers? The barriers to using SCF include difficulty in demonstrating the value of the forecast to potential users, difficulty in interpreting and explaining the forecast to others, and challenges associated with the scientific language used in the information. To address these constraints, the convener of the CariCOF acts as a boundary organization by enabling interactions between participants representing diverse sectoral and geographic settings. This develops a network that helps build shared scientific understanding and knowledge about how different sectors experience climate risk. These interactions guide information brokering activities that help individuals communicate and translate climate information to facilitate understanding at local levels.

1. Introduction

Climate variability affects many aspects of society. Drought affects livelihoods by reducing the availability of water and affecting agriculture productivity (e.g., Farrell et al. 2010), frequent and intense precipitation can cause damaging floods (e.g., Cayan et al. 1999), and active hurricane seasons can increase the risk for land-falling storms (e.g., Coughlin et al. 2009; Landsea et al. 1999). Climate services, which involve the provision of climate-related knowledge and information to specific decision-makers often in the form of tools, products, websites, or bulletins (Vaughan and Dessai 2014), offer the potential to help society cope with and adapt to these and other impacts by facilitating the incorporation of

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science-based information and prediction into policy and practice (WMO 2009, p. 162).

There is wide recognition that climate conditions—most notably anomalies associated with the El Niño–Southern Oscillation (ENSO)—shift precipitation and temperature probabilities in certain regions and during specific seasons (Goddard et al. 2001; Zebiak et al. 2014). This has contributed to skillful seasonal precipitation and temperature forecasts. Consequently, scientists have realized the potential benefit of seasonal climate information, and attempts have been made to connect it to resource management and policy. One mechanism is through regional climate outlook forums (RCOFs), which facilitate the production and dissemination of seasonal climate information, including seasonal climate forecasts (SCFs), and discussions on the implications of probable climate outcomes with users from climate-sensitive sectors. RCOFs represent a major international climate service effort that began in the late 1990s and that helps support early warning systems for, among others, drought conditions and malaria outbreaks. Currently, the World Meteorological Organization (WMO) supports 15 RCOFs around the globe.

While there is some evidence that RCOFs have helped decision-makers use SCFs (e.g., Braman et al. 2013; Ogallo et al. 2008), in many cases barriers have prevented SCF use or resulted in their suboptimal use (Dilling and Lemos 2011; Feldman and Ingram 2009). Some of the barriers relate to unequal access to information (Broad et al. 2002; Roncoli et al. 2001), insufficient delivery systems (Ziervogel and Downing 2004), misunderstandings of the forecasts (Ogallo et al. 2008) and technical language (Stern and Easterling 1999), and converting a generalized regional forecast to more local conditions (Orlove and Tosteson 1999; Lemos et al. 2002; Luseno et al. 2003).

The identification of barriers and successes has generated recommendations on how SCF and climate information can more effectively inform climate-related decisions. Stern and Easterling (1999) state that enhancing the utility of SCFs requires customized dissemination and distribution channels, including developing institutional structures, trust in information sources, and modes of delivery. Lemos and Morehouse (2005) discuss the importance of producing knowledge and information that match, or "fit," a defined problem. They suggest that interactions between end users and producers of information can coproduce knowledge and information with a higher degree of fit. McNie (2007) similarly states that contextualizing climate information within broader decision-making contexts can help overcome barriers.

Dilling and Lemos (2011) reviewed published studies on the application of SCF and found that many barriers originate because information is produced without an awareness of the decision-making environments. They note that cases of successful integration of SCF information into decision-making often accompanied closer interactions between the producers and users of SCFs. Within this context, they suggest several mechanisms that can enhance interaction, including information brokers, knowledge networks, and boundary organizations. These concepts have been discussed in many disparate fields of research (i.e., information brokers have been discussed in public health, science policy, organizational studies, etc., and boundary organizations can trace their roots to the social studies of science). However, within the domain of climate services, there is little empirical research that describes if and how these mechanisms are put into practice and how they relate to each other.

To address this gap, we present results from the study of and participation in two Caribbean Climate Outlook Forums (CariCOFs). The CariCOFs bring together a diverse audience of national and regional meteorologists and climatologists who develop the SCFs and decision-makers from many different sectors who, in theory, could use the information to inform their decisions. Our research questions are 1) what are the barriers to using SCF in the Caribbean and 2) what are the iterative processes of information exchange at the CariCOF that address these barriers? We used network analysis, small group discussions, and key informant interviews with participants attending two CariCOFs convened in 2014. We show the CariCOF is fostering engagement activities that have been linked to enhanced use of climate information elsewhere, and we provide empirical evidence of activities that help participants translate and mediate SCFs for decision-making.

2. Regional context

a. Caribbean diversity

The Caribbean spans a large geographic area that causes the timing and exposure to climate risks to vary. Generally, the onset and duration of the wet season occurs between May and October (Karmalkar et al. 2013), but there is large regional variability. There is also a pronounced dry period within the wet season that displays considerable variation in its timing and duration (Karmalkar et al. 2013). Alterations in the character of the climate contribute to, among other impacts, droughts, water supply shortages, and an increased number of bush fires (Farrell et al. 2010). In 2014, for example, drought

TABLE 1. Select national information for CIMH member states. Participants at the CariCOFs are not exclusively from these countries. GDP is based on purchasing power parity. The annual average loss is the percentage loss caused by the disasters. The exposure index evaluates the current risk of a region being impacted by extreme climate-related events (drought, wildfires, tropical cyclones and storms, storm surge, severe local storms, precipitation induced landslides, flooding, and sea level rise) but also incorporates risk posed by the projected changes in baseline climate parameters.

Country	Population[a] (thousands)	Area[a] (km^2)	Per capita GDP[a] (Int$)	No. of disasters[b] (1980–2013)	Annual avg. loss[b] (% GDP)	Exposure index category[b]
Anguilla	16.4	91	12 200	—	—	—
Antigua and Barbuda	92.4	442	23 700	9	2.870	High
Barbados	290.6	430	16 700	7	0.194	Low
Belize	347.4	22 806	8600	10	1.907	High
British Virgin Islands	33.5	151	42 300	—	—	—
Cayman Islands	56.1	264	43 800	—	—	—
Dominica	73.6	751	11 600	9	2.943	Extreme
Grenada	110.7	344	13 000	6	5.704	Low
Guyana	735.2	196 849	7200	7	1.124	Low
Jamaica	2950.2	10 831	8800	24	1.111	Extreme
Montserrat	5.2	102	8500	—	—	—
St. Kitts and Nevis	51.9	261	22 800	6	5.567	Extreme
St. Lucia	163.9	606	12 000	13	7.378	Low
St. Vincent and the Grenadines	102.6	389	11 000	9	0.597	Low
Trinidad and Tobago	1222.4	5128	32 800	7	0.000	Medium
Turks and Caicos	50.3	948	29 100	—	—	—

[a] Central Intelligence Agency (2015).
[b] CAF (2014).

and fires in Jamaica led to losses in agriculture productivity (Jamaica Information Services 2014). Hurricanes also routinely incur costs to the region in excess of $1 billion (U.S. dollars; Pielke et al. 2003), with greater impacts in certain countries. Climate-related disasters each year in St. Lucia, St. Kitts and Nevis, and Grenada generate economic losses greater than 5% of their respective gross domestic products (GDPs), whereas in Trinidad and Tobago, losses generally amount to a negligible portion of GDP (Table 1; CAF 2014).

Socioeconomic conditions in the region also vary because of island size, population, and per capita income (Table 1). National meteorological departments, who provide weather and climate information, are equipped with varying levels of capacity. For example, smaller islands often have fewer staff and less technical ability to monitor, develop, translate, and disseminate information than the departments of larger islands.

This diversity produces a complex geography of climate vulnerability across the region (e.g., Adger 2006). Climate vulnerability studies have documented this in the relationship among hurricane hazards, socioeconomic status, and infrastructure (Lam et al. 2014); the relationship between water security and poverty (Cashman 2014); the relationship between temperatures and public health (Akpinar-Elci and Sealy 2014); and in comprehensive assessments of climate vulnerability (CAF 2014).

b. *CIMH and the CariCOF*

The mission of the Caribbean Institute for Meteorology and Hydrology (CIMH) is to assist in the development and improvement of meteorological, climatological, and hydrological services in 16 member nations (see Table 1 for a list of the nations). CIMH achieves these objectives through training, research, investigations, and the provision of related specialized services and advice. CIMH plays a critical supporting role to the meteorology departments of its member nations in their efforts to provide climate and weather services; for the smaller states, CIMH is the primary provider of climate services at the regional scale.

CIMH is a WMO Regional Climate Centre (currently in demonstration phase). One of its roles in this capacity is to provide climate early warning information to the Caribbean region. To help achieve this, CIMH organizes, provides some funds for attendance, and leads the CariCOF sessions, including pre-CariCOF training of meteorologists and climatologists.

The CariCOF was first convened in response to the 1997/98 El Niño, but it has only recently become a routine event. Since 2012, forums in the Caribbean have been convened in a different country at least once each year prior to the onset of the wet/hurricane season. In early December 2014, CIMH convened the first dry season CariCOF in Antigua and Barbuda. The expectation is to have two CariCOFs per year moving forward as long as funding permits.

CariCOFs bring together meteorologists and decision-makers from many sectors, including agriculture, water management, and disaster management. Between 60 and 80 people participate; about half of these are meteorologists or climatologists. The CariCOF is usually preceded by a training event for meteorologists and climatologists, and the forum itself includes broader participation from decision-makers and academics. CIMH and climate scientists from the International Research Institute for Climate and Society (IRI) co-lead the training to build the regional forecasting capacity and to produce the forecasts that are subsequently shared at the forum. The forum includes presentations, group discussions, and interactive sessions. Climate products presented and discussed at the CariCOF include 3-month precipitation and temperature forecasts at 0- and 3-month lead times (which display the chances that precipitation and temperature will fall in each tercile category); drought forecasts based on the 6- and 12-month standardized precipitation index (SPI); and, beginning in 2015, shifts in the seasonal frequency of extreme rainfall events.

c. *Proposed mechanisms to enhance the use of climate information*

Through the CariCOF, CIMH is attempting to avoid what Cash et al. (2006) identified as the ''loading-dock approach,'' which occurs when climate information is assumed to be useful and its production and distribution occurs without knowledge of its end use. Contrary to this approach, evaluations of the successful use of climate information in decision-making point to the need for sustained, iterative interactions between the producers and users of climate forecasts (Lemos and Morehouse 2005; Pagano et al. 2002; Cash et al. 2006). Dilling and Lemos (2011) identified five such mechanisms: information brokers, collaborative group processes, embedded capacity, boundary organizations, and knowledge networks. We focus on the three we observed at the CariCOF: knowledge networks created by the CariCOF, information brokering that helps create useful connections in the network, and the boundary organization role of CIMH that enables and supports knowledge networks and information brokering.

1) Knowledge networks

Knowledge networks are informal groups of policy-makers, scientists, government agencies, and nongovernmental organizations that are in continual contact as they share and disseminate climate information (Feldman and Ingram 2009; Dilling and Lemos 2011). They provide decision support and information mediation in order to make climate knowledge usable across a wide spectrum of users and can help link different groups that otherwise would not be connected. These networks operate at a variety of scales and are able to mediate mismatches (i.e., in spatial or temporal scales) in the development of usable climate information by increasing the fit between regional information and the localized decision context (Kalafatis et al. 2015).

2) Information brokers

Information brokers are often individual actors. They have been discussed in numerous disciplines, including public health (Ward et al. 2009), organizational studies (Currie and White 2012), and science policy (Bielak et al. 2008) as individuals who foster knowledge exchange and help facilitate action. The activities of brokers are numerous. They include synthesizing, translating, and disseminating information (e.g., Guido et al. 2013). Brokers can share information without modifying it, or they can alter it in response to user preferences (Buizer et al. 2010; Lemos et al. 2012). Brokers are integral parts of knowledge networks because they create the links via the sharing of information.

3) Boundary organizations

Boundary organizations have a broad definition in the literature. Their core functions can span the entire end-to-end process, ranging from basic science research to product development and enhancing end-user experience (e.g., Agrawala et al. 2001). A key aspect of boundary organizations is their ability to facilitate interaction, often between people or groups operating within different institutional and professional cultures (Cash 2001; Cash et al. 2002; Guston 2001; Gieryn 1999; Feldman and Ingram 2009). In so doing, boundary organizations create and enhance opportunities in which different perspectives are brought to bear on an issue. This includes convening a meeting, structuring an event, translating information, collaborating on a project, and/or mediating the collaboration (Cash et al. 2006). Within these activities, boundary objects are often used to focus interaction in order to build consensus, facilitate mutual learning, and negotiate differences between parties (Jacob 2005; Lynch et al. 2008; Creswell and Clark 2011). Boundary objects can be workshops, reports, forecasts, and even iconic events.

These three mechanisms all attempt to enhance understanding and facilitate action. The efforts undertaken by boundary organizations, knowledge networks, and brokers therefore serve all parties. They help information producers understand the context in which information is used. In addition, they help the information users understand the technical aspects of the information and the state of the science. Finally, they help the intermediary actors build relationships and trust.

3. Research methods

We employed a multimethod analysis of two sequential CariCOFs. The first was held in Kingston, Jamaica, on 28 May 2014 and was attended by 67 people from 26 countries (all 16 CIMH member nations participated). The second forum was convened on 1–2 December 2014 in St. Johns, Antigua, and was attended by 66 people from 24 countries (15 CIMH member nations participated). At both forums, participants represented diverse sectors, with a slight majority of attendees identifying their work within meteorological and climate services. A total of 27 people attended both CariCOFs. Hereafter, we separate the participants into two groups: meteorologists, which includes individuals working in meteorology and climate services, and decision-makers, which includes people working in the sectors of water, disaster, agriculture, health, research, and others (see Fig. 1 for a list of sectors).

Our methods produced complimentary information. At the Kingston CariCOF, we conducted a participatory network mapping exercise with 40 participants, small group discussions, and 12 key informant interviews. At the Antigua CariCOF, we repeated part of a network exercise and facilitated group discussions. Network mapping helped quantify the CariCOF knowledge network and brokering activities. The interviews and discussions revealed barriers to using climate information and shed light on how these mechanisms helped addressed those barriers. For interviews and discussions, we coded responses into key themes and have presented both exemplary responses and descriptive statistics. For the network, we transposed participant responses from the network activity into UCINET to generate maps; since the CariCOF network represents only a snapshot in time, we opted to use the maps heuristically.

a. Participatory network mapping

At the Kingston CariCOF, we adapted the participatory network method described by Schiffer and Hauck (2010). For this exercise, 40 participants organized into groups of 4–8. A facilitator/rapporteur guided each group through two progressive sections. First, participants individually identified from whom they typically receive the SCF and with what individual or organization they will share the SCF presented at the CariCOF. Participants then noted the information they will add to the SCF when sharing it with each organization or individual. In the second part, participants collectively mapped on a poster board the organizations with whom they will share the forecasts. The facilitator/rapporteur encouraged the participants to discuss why they shared the information and how they shared it. This participatory exercise had the advantage of enabling the visualization of the connections among the participants at the table, which helped stimulate conversations. However, because we did not divide groups intentionally, some tables produced unconnected networks that did little for encouraging conversation. Additionally, we sought information about future activities—how participants intend to share the information—because some participants were receiving the climate information for the first time. We recognize that people do not always follow their intentions. For the purposes here, however, aspirational questions provided an adequate means to describe the network.

At the Antigua CariCOF, 23 people completed the first part of the exercise used in Kingston. They also reported the mechanisms in which they shared the forecasts (i.e., in person, e-mail, etc.). A full group discussion was facilitated after to discuss with whom and how people share SCF information.

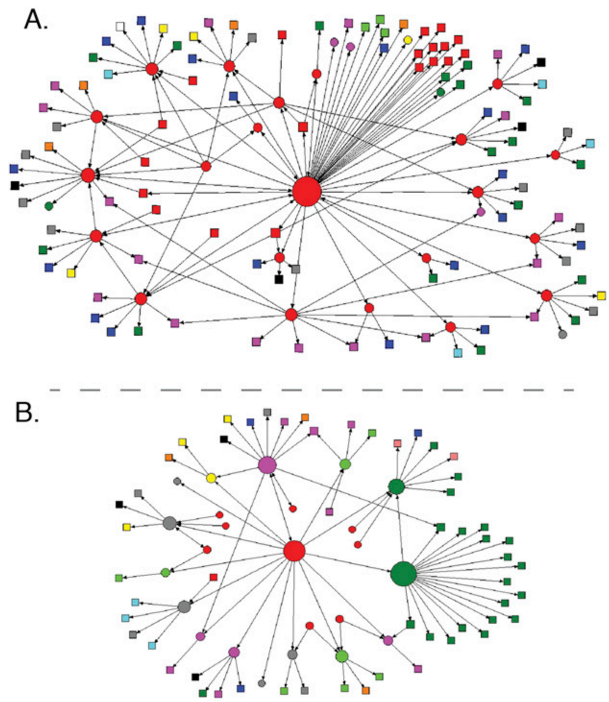

FIG. 1. Seasonal climate forecast communication network depicting sector connections (i.e., the node colors correspond to different sectors) for (a) meteorologists and (b) decision-makers. Circles represent people/organizations who were present at the CariCOF; squares represent people/organizations who were not present. Arrows denote the direction of the communication. Size of the node is proportional to the number of connections.

TABLE 2. Examples of commonly cited barriers to using SCFs cited by participants at the Kingston and Antigua CariCOFs.

Barrier	Summary of participant responses
Lack of capacity or resources	• Some organizations/individuals feel that communicating the forecast is not part of their jobs • Time limitations because of other job responsibilities • Lack of mechanisms within organizations to distribute and/or communicate the forecast
Demonstrating value and benefit of forecast	• The public does not understand the impacts and therefore would likely not act on the forecast • More information specific to each sectors is desired in order to communicate the impacts more effectively • ''What does this mean for us? Unless I can answer this question it's pointless.'' (decision-maker, research sector)
Interpreting and explaining the forecast	• Difficulty communicating uncertainty and probability associated with the forecast • ''I was confused about the circles and the colors [on the maps]. . .and would have liked more training so I can communicate it more effectively.'' (decision-maker, disaster management sector) • Media members do not understand the forecast or other climate products and therefore do not communicate effectively to the public
Lack of trust in forecast	• Those who share the information must trust it because they associate their credibility with the information they disseminate; the information must also be trusted by recipients in order to use the information • Forecast communicators and recipients may not understand the reliability of the forecast
Scientific language barriers	• Language barriers associated with translating the science and working with people unfamiliar with scientific jargon

b. *Key informant interviews*

In Kingston, four members of the research team conducted 12 semistructured key informant interviews using a preestablished guide. The research team interviewed individuals who had extensive knowledge of the CariCOF—those who were involved in developing the CariCOFs or knowledgeable about its history—and/or who were considered important users of climate information. These interviewees represented a variety of institutions, including national meteorological services, regional and national public health agencies, regional agricultural organizations, the CIMH, the IRI, and the National Oceanic and Atmospheric Administration (NOAA). CIMH helped identify the informants and facilitated the interviews. All interviews were recorded. One member of the research team subsequently listened to all interviews and coded the responses based on the interview guide and emergent themes.

c. *Small group discussions on barriers*

At the Kingston CariCOF, participants divided into small groups to discuss questions related to barriers. At the Antigua CariCOF, we first summarized the barriers identified at the Kingston CariCOF and other barriers described in the peer-review and gray literatures. Then, each participant noted one barrier they perceived to be the easiest to overcome and one barrier they perceived to be the most challenging to overcome. Participants presented their responses and a brief discussion followed.

4. Results

a. *Barriers to SCF communication in the Caribbean*

The barriers to using seasonal climate information noted by participants include a lack of capacity or resources, difficulty in demonstrating the value of the forecast to potential forecast users, difficulty with interpreting and explaining the forecast to others (which includes challenges with understanding technical scientific language), a lack of trust in the SCF, and challenges associated with the scientific language (Table 2). Related to a lack of capacity, one meteorologist stated, ''Met services in many countries can barely keep up with the weather and there is great difficulty in adding seasonal forecasting to their duties.'' Insufficient capacity in meteorological service offices was also perceived as limiting the advancement of forecast skill. According to another meteorologist, ''Many countries do not have real time data. That is a major weakness and that is affecting the accuracy of the models.'' Related to communicating the forecast, several respondents noted difficulty communicating and understanding the tercile forecast format. One meteorologist stated, ''It is not obvious what to do with a tercile forecast, especially when there isn't a strong signal.'' Another decision-maker working in the public health sector stated, ''I know for sure that certain people that we have worked with, at certain levels, particularly if you are talking with a minister, they look at the forecast and shut off. . . .People look at it and can't really understand it.'' For these decision-makers, the confusion generated by the terciles undermined the ability to use the information.

Many interviewees recognized the need for translation and mediation of the forecast for it to be usable at the local scale and for different decision-makers. One decision-maker working in the agricultural sector shared this view: ''It is not easy to understand, so simplification of any news is helpful. I recognize that there is a level of science and information to help the planning. There needs to be an intermediary where somebody, like extension, is trained to take this scientific information and share with the user.'' Another meteorologist suggested the need for a communications specialist at the CariCOF to assist participants in reaching decision-makers, stating ''What we might want to say to the people in health you may not use the same language for the people in water, and we need that kind of communication, risk communication, component to the forecast.'' That the SCF needs to be translated, adapted, and mediated for different users was underscored by other participants as well.

Although SCFs present formidable communication challenges, participants at the Antigua CariCOF identified communication as the easiest barrier to overcome in 32 of the 50 responses (64%). These included statements about communicating probability, explaining the tercile forecast, and knowing the best type of communication. Conversely, barriers related to decision-making were cited as the *most challenging* to overcome. These included flexibility of government or organizational policy and lack of resources or capacity and accounted for 28 of 49 (57%) of the responses.

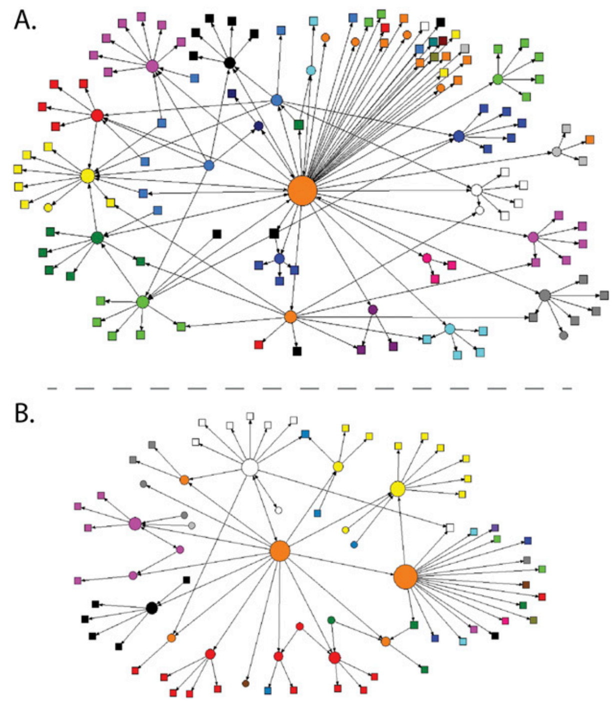

FIG. 2. As in Fig. 1, but depicting country connections.

b. *Knowledge networks at CariCOF*

The mapping exercise created a one-time snapshot of a continuously evolving network that is linked through the CariCOF (Figs. 1, 2). There are several important features of the network. First, CIMH is the main source from which participants receive the SCF information. This was expected because CIMH convenes the CariCOF and leads the monthly production of the forecasts and their distribution via e-mail and the web. This makes the network relatively centralized, although, on average, many participants received the forecast from one other source in addition to CIMH. Some national meteorology and hydrology services, for example, prepare their own forecasts and are possible sources of forecast information for people and organizations within those countries.

Second, participants at the Kingston CariCOF reported anticipating sharing the forecasts and related information across 11 sectors (Fig. 1) and 26 countries (Fig. 2) for a total number of 265 unique connections. The total number of connections from meteorologists and decision-makers tallied 169 and 96, respectively. The CariCOF therefore helped enable interactions that draw upon the diverse sectoral and geographic settings in which the participants work. It is also evident that the meteorologists and decision-makers generally communicated about the forecast with several sectors (Fig. 1). Therefore, both groups cast a relatively wide net, and this presents challenges to tailoring communication to the numerous interests and needs of different sectors. On the other hand, communicating with diverse actors can develop a more detailed understanding of the ways climate information is used by different groups.

Third, with the exception of a few participants who represented organizations acting at a regional scale, decision-makers and meteorologists mostly anticipated communicating within their country (Fig. 2). Meteorologists reported anticipating sharing the forecasts with about six organizations or individuals, while decision-makers reported sharing the information with about four organizations or individuals. Participants anticipated sharing the forecasts with many more people or organizations not attending the CariCOF than with those who were in attendance. This suggests that individuals that participate in the CariCOF return to their respective countries and engage within their own communication networks.

While the number and pattern of connections represent the structure of a network, the vehicles that are used to communicate represent another important characteristic. At the Antigua CariCOF, participants anticipated sharing the information in an interactive mode about 29% of the time, which included encounters in person, Skype/virtual meetings, or over the phone (Table 3). In this case, an interactive mode is considered one in which an assessment of information receipt and comprehension can be made in real time. Sharing information in a one-way manner, such as via e-mail and

TABLE 3. The frequency with which different modes of communication are used by participants at the December 2014 CariCOF in Antigua and Barbuda when sharing the SCF within their network. The total number of respondents was 36. In total, participants anticipated sharing the information a combined 129 times across different methods.

Method of sharing	Number (%) of times reported	Number (%) of people who reported
One-way communication		
E-mail	61 (47)	33 (92)
Website	14 (12)	4 (11)
Newsletter	5 (4)	2 (6)
Radio	4 (3)	3 (8)
Bulletins	2 (2)	1 (3)
Report	2 (2)	2 (6)
Fax	1 (1)	1 (3)
Pamphlets	1 (1)	1 (3)
Social media	1 (1)	1 (3)
TV	1 (1)	1 (3)
Total	92 (71)	
Two-way communication		
In person	17 (13)	13 (36)
Phone	17 (13)	9 (25)
Skype/virtual meetings	3 (2)	2 (6)
Total	37 (29)	

web bulletins, occurred about 71% of the time. We note that e-mails and social media can be interactive. However, they are often considered one-way communications because it is often unknown if the messages are read or understood and feedback is limited.

c. *Information brokering activities*

Participants at the Kingston and Antigua CariCOFs engage in numerous brokering activities when communicating the forecasts (Table 4). About 61% of the connections in the network involved at least one activity in addition to sharing the information.

The brokering activities differed between meteorologist and decision-maker groups. Meteorologists tended to include additional data that connects the forecast to more local-specific information. One meteorologist stated that he/she includes the ‘‘upper and lower amounts expected.’’ Another meteorologist noted he/she adds the ‘‘total amount of rainfall that is expected during the season; [provide] example of the amount that would receive from normal, above- and below-normal [forecasts].’’ Decision-makers tended to provide information related to the potential impacts of the forecasts. For example, decision-makers often included information about potential impacts to crops, environmental quality, and public health. One decision-maker working in disaster management wrote: ‘‘Add info on proposed actions to be taken (cooperative/collaborative actions between the 2 sister isles) for preparedness and mitigation planning.’’ Both groups also provided some recommendations on how to prepare for potential climate hazards, which included how to mobilize resources, mitigate impacts, and collaborate within and among communities.

5. Discussion

a. *CIMH as a boundary organization*

CIMH’s explicit mission involves improving and developing the meteorological, climatological, and hydrological services in its member states and building awareness of the benefits of these services. Therefore, they simultaneously enhance the production of and demand for information. Viewed through the lens of boundary organizations, CIMH uses the CariCOF to create an opportunity for diverse actors to advance their skills and understanding of climate risks as well as learn how others in different sectors interact with climate risk.

In convening the CariCOF, experts help CIMH staff advance the forecast skills of national meteorologists during the training event that precedes the forum. For some of these meteorologists, the training introduces new methodologies and makes clearer the uncertainties and interpretations. In the training, the SCFs for that month are created and subsequently presented at the forum (along with other information). In this respect, the training develops boundary objects that focus discussions with decision-makers. Through these discussions, both meteorologists and decision-makers learn from each other. Meteorologists listen to how decision-makers use seasonal climate information, the challenges to using the forecasts, the impacts of the forecast on different sectors, and other desired information. This information, theoretically, helps the meteorologists better understand ways to effectively communicate the information as well as to identify where new information may be needed. For example, a decision-maker at the

TABLE 4. Examples of brokering activities performed by meteorologists (mets) and decision-makers (DMs) at the May 2014 CariCOF in Kingston, Jamaica, and December 2014 CariCOF in Antigua. A total of 27 and 21 mets and DMs, respectively, performed at least one brokering activity.

Brokering activity	Examples	Total number
Explain science jargon	• Explanations of acronyms and legend • Explain what terms mean, such as "tercile" and normal, above normal, and below normal	3 mets 4 DMs
Interpret forecast	• Provide adequate headlines and take away messages to media • Simplify the forecast and explain trends and extremes • Add a summary of predictions in simpler form	7 mets 4 DMs
Add local climate information	• Data specific to the country such as rainfall and temperature • Review of past rainfall for different areas in the country • Previous forecast outcomes and local field conditions	16 mets 5 DMs
Explain potential impacts to sectors	• Likely impacts based on sectors • Crop impacts • Implications for mosquito breeding potential	3 mets 9 DMs
Recommend how to prepare	• Advice for farmers based on outlook to aid in decision-making • Proposed actions to be taken (cooperative and collaborative actions between isles) for prepositioning of resources and mitigation planning	6 mets 6 DMs
Provide additional and complimentary resources	• How to access the data online • Latest hurricane forecast if applicable • Inform of additional tools like the Drought Outlook and seasonal forecast	4 mets 2 DMs
Open lines of communication	• Who to contact for more information	0 mets 1 DMs

CariCOF in Antigua stated at the end of the CariCOF: "I don't understand what a tercile means." This suggests a need to convey the probabilistic information in different formats that are more accessible to some users and/or the need to develop decision-maker training opportunities. This process also helps CIMH experiment with new products such as seasonal drought forecasts and extreme rainfall forecasts, which have recently been introduced in the CariCOFs. On the other hand, the decision-makers learn from meteorologists about how the forecasts are produced and their technical interpretation and limitations, which in turn can help them communicate more accurately within their networks.

CIMH and its partners designed the CariCOF to develop a regional network. Each CariCOF is convened in a different county, drawing people from the host country who would not be otherwise be able to attend. This can help increase the size of and number of connections within the CariCOF network through time. It also can lead to the benefits of two-way learning described above.

b. *The role of networks and brokers in mitigating barriers to SCF use*

Participants cited a variety of barriers to communicating and using SCFs at both CariCOFs (Table 2). These barriers are similar to those reported elsewhere (see Dilling and Lemos 2011).

One aspect of the network that appears to help address barriers related to demonstrating the value and benefit of SCFs is the fact that many attendees take the regional information produced and discussed at the CariCOF and communicate it within their own country. This suggests the importance of filtering regional information through individuals who have a greater awareness of sectors and management practices at the local level and are able to add local and sector-specific information (e.g., Pagano et al. 2002). This is particularly important in diverse areas like the Caribbean where information is initially presented at a regional scale and therefore lacks more national and local contexts.

Similarly, the knowledge network and brokering at the CariCOF can help with mitigating barriers related to understanding and interpreting the forecast. One participant (noted previously) stated that intermediaries help translate the information. This is evident in the network maps, which show attendees sharing the regional information within their respective country (Fig. 2) and demonstrated by the variety of brokering activities that provide local context (Table 4). Participants at the CariCOFs, for example, added precipitation and temperature values that correspond to above-, below-, or near-normal categories on the forecasts and noted the possible impacts associated with the forecast. Studies elsewhere have documented the desire of decision-makers to receive information at more local levels (Braman et al. 2013; Lemos et al. 2002; Marshall et al. 2011; Orlove and Toteson 1999).

Brokering also helps users understand the probabilistic format so interpretations are not misconstrued. This is particularly important because tercile forecasts have a long production history and continue to be disseminated despite studies highlighting the challenges that probabilistic formats present to end users (e.g., Stern and Easterling 1999; Dilling and Lemos 2011). In the absence of different forecast formats, brokering can help mediate understanding. An aspect of improving understanding also relates to avoiding technical scientific language, which was noted as a barrier by CariCOF participants. Brokering also seems important to help users understand the implications of the forecast. This is one possible explanation for why many respondents added impacts and recommendations on how to prepare.

Participants also noted barriers related to capacity and resources limitations. The CariCOF, and the knowledge network it is helping to steward, helps address these barriers via training and building connections. Whether the connections actually led to the leveraging of resources and changes in decision-making based on the climate information was not explicitly documented here. We note, however, that the CariCOF in Kingston, Jamaica, spawned a climate service project between participants there and a research team to which the authors contribute.

Moreover, during interviews several participants pointed to the importance of the networks at the CariCOF. One meteorologist explained that he came to the CariCOF "to become more familiar with the state of climate, but also to network. A lot of the work we do requires some interface with the decision-makers and the people that are working in the same area." The approach to engage new individuals at each CariCOF may, on the surface, delay some of these benefits. With limited resources and space for participants, building a robust network takes time. When asked how the CariCOF could be improved, many participants pointed out the need to have greater participation from underrepresented sectors such as health and tourism. This presents a trade-off. Expanding the decision-maker network comes at the cost of enabling repeated participation necessary for capacity to be adequately developed and strong connections to be fostered. This is particularly the case for decision-makers because meteorologists attend the CariCOF more routinely as a result of the training sessions.

Although brokering and knowledge networks can help overcome some barriers, the mode of communication and the character of the network can help influence the efficacy of the information. At the Antigua CariCOF, 29% of the participants reported that they often share information in a two-way mode that has direct interaction (i.e., in person), while the majority of participants shared information in a more unidirectional, one-way mode (e.g., e-mails, web outlets). It has been noted that two-way communication tends to enable learning and active engagement more than less-interactive forms (e.g., Moser 2010) and to be more influential on personal behavior (Dunwoody 2007; Lee et al. 2002; Moser 2010). Also, one-way communication can prevent opportunities to clarify the information, discuss its meaning, and provide feedback that could improve the presentation and delivery of the information. Ziervogel and Downing (2004), for example, found that farmers in Lesotho, Africa, preferred interactive dissemination methods, which gave them opportunities to ask questions and decide if they wanted to use the information. When information is received that is not understood or does not meet information requirements, and there is no opportunity to clarify and discuss the information, that information may not be passed on. We note that e-mail interactions can be interactive and lead to enhanced understanding. However, there is some evidence that written forms are less effective at informing decisions than more conversational forms (Lee et al. 2002); also, written forms tend to enable learning and active engagement less effectively than more interactive communication modes (Moser 2010). Given that one-way communication via social media and web services will continue to play a large role in disseminating information, brokering activities, building mutual understanding through events like forums, and expanding knowledge networks can all aid in the use of the information.

We note that participants at the CariCOF provided additional information when sharing the SCF about 60% of the time, while the remaining 40% involved the sharing of only the SCF. In cases where participants are not adding information, there are numerous explanations. First, many of the participants do not fully understand the information themselves and are therefore ill equipped to be brokers. In fact, many participants stated that the SCF information is difficult to understand. Second, participants may feel that there is no basis for adding additional information: the recipient may understand the information completely or the sender may not understand how to tailor the information for the people with whom they communicate. Finally, participants may not feel it is part of their job, which was also mentioned, and brokering requires additional work that may be challenging or impossible to complete because of resource limitations. Many participants at both CariCOFs highlighted resource and capacity limitations as a main barrier to using the SCF.

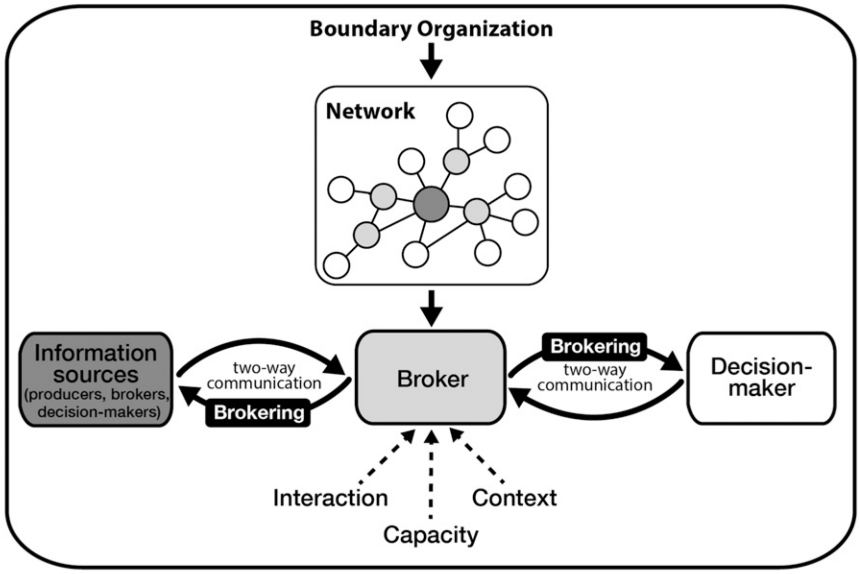

FIG. 3. Conceptual model for the relations and functions of boundary organization, network, and brokers. The network inset conveys that the brokering interactions presented in this figure are a subset of a more expansive network. Interaction, context, and capacity represent characteristics we posit to be important for enhancing the impact of brokering. The dark gray, light gray, and white colors denote information producer, broker, and decision-maker, respectively. In practice, an information producer can be all of the individuals.

c. *Conceptualizing the relations of boundary organizations, networks, and brokers*

Results from the present study highlight the presence of three interacting mechanisms that connect users and producers of information at the CariCOF: a boundary organization, network, and information brokers. Figure 3 conceptualizes the relations and functions of these mechanisms. The boundary organization supports and develops a network by convening, creating space for mutual learning, and training decision-makers and meteorologists. While boundary organizations are just one means for supporting a network, their advantage generally lies with their more permanent institutional presence and higher resource endowment than individuals or project-based activities (Dilling and Lemos 2011). Within the network, key individuals emerge who help connect information from upstream sources—from information producers and from other brokers and decision-makers—to downstream users through brokering activities. While each of these individuals can be an information producer, we use "producer" to refer to the production of technical information (i.e., seasonal forecasts). The brokers share and transform information, which can help overcome barriers that lead to more effective information use on the one hand and the development of more tailored information on the other.

Across diverse research and practice traditions, brokers have been critical for translating information into action (Bielak et al. 2008; Currie and White 2012; Ward et al. 2009). While this ought to hold true in climate services, little is known about who climate service brokers are, what makes them effective, and whether their activities do in fact enhance the use of climate information. We posit that effective brokers have at least three important characteristics: contextual knowledge, interaction with producers and users, and capacity.

Contextual knowledge relates to understanding the supply and demand sides of information (i.e., producers and users of information). Understanding how the information is used by decision-makers simultaneously helps brokers fit existing information for specific groups (Kalafatis et al. 2015; Lemos et al. 2012), while also enabling brokers to inform the production of more tailored products that are in tune to the operational constraints of decision-makers. Moreover, because decision-makers may not understand the information (Stern and Easterling 1999), knowing the technical details of how it is produced helps identify the applicability and enables clear communication, which reduces the chance that brokers misconstrue the utility of the information to decision-makers and that decision-makers misapply the information.

Interactions with both producers and users is also important because they build contextual knowledge and develop mutual trust. If decision-makers do not trust their sources of information, they are unlikely to engage with that person or, even if they do, are less likely to believe the information delivered is credible (Cash et al. 2006). Having trust, on the other hand, can help overcome some cognitive and social barriers that limit the use of information (Pagano et al. 2002).

Finally, capacity relates to the time available to engage in brokering, the expertise necessary to understand the context of both information producers and decision-makers, and the know-how to locate suitable information from disparate sources. Many of the brokering activities require a substantial investment of time to, among other activities, amalgamate, synthesize, and narrate information from different sources. Often, the time needed to do these activities is characterized as a barrier (Guido et al. 2013; McNie 2013). Expertise in the form of interdisciplinary experience also helps the broker interact in the settings of both producers and users of information. Finally, expertise is needed to be able to assess the credibility of the information, identify relevant scientific information produced in other contexts, and ultimately decide what information to convey (and not to) to the decision-makers.

d. Future research directions

In research presented here, we did not trace the SCF from its production to its end use. Rather, we principally focused on forum participants who can be seen as intermediaries within their networks to the exclusion of people and organizations who receive the information and then apply it. Consequently, we described a variety of communication and translation activities but did not assess if and how those activities actually influenced use. Understanding how communication activities affect decisions, and under what conditions and sectors they do so, would improve understanding of the value of brokering climate information use. Although there have been some attempts to understand linkages between information use and outcomes in the Caribbean (e.g., Vogel et al. 2014; WMO 2008), these are narrow in scope and more thorough research is needed. Moreover, because brokering may play important roles in climate services, a thorough analysis of brokers, including their practices and the benefits and drawbacks from their intermediary positions, remain important research targets. These insights would help test and refine the conceptual model proposed in Fig. 3.

The network we present is only a snapshot and would be larger if analyzed over numerous CariCOFs. For example, 39 of the 66 attendees in Antigua did not attend the forum in Kingston, Jamaica. A longitudinal view of the CariCOF would develop a more complete view, allowing for more representative and detailed statistical network descriptions. This, coupled with assessments of information use and brokering activities noted above, could help identify how the network and actors within the network influences outcomes.

6. Conclusions

The Caribbean is large and diverse, which makes the regional production of climate services in need of processes that contextualize the information at local levels. In the Caribbean, the CariCOF is a main avenue through which seasonal climate information is presented and discussed among diverse participants. The CariCOF embodies boundary organizations, knowledge networks, and information brokering that can to help connect climate science to decision-making and help address some of the noted challenges to using climate information. Acting as a boundary organization and lead convener of the CariCOF, CIMH helps build a regional network and provides a space for mutual learning. Exchanges at the forum enable the national meteorological services to understand decision-makers' information needs, while also helping decision-makers understand what the forecasts mean. Through the network building and CariCOF venue, both the meteorological service and decision-makers become equipped to broker climate information within their networks.

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