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Fit for purpose? Transforming National Meteorological and Hydrological Services into National Climate Service Centers

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ABSTRACT

Climate services are becoming an important strategy for delivering climate information to users around the world. In many countries, National Meteorological and Hydrological Services (NMHSs) are charged with providing climate services to diverse audiences. Climate services are important to foster adaptation to climate risks and in reducing vulnerability in developing world contexts. However, the production and delivery of user-oriented climate services place new burdens on NMHSs and require new skillsets, partnerships, and infrastructure. In this paper, we assess the capabilities of 22 NMHSs in Caribbean Small Island Developing States (SIDS) to understand whether and how NMHSs are fit for the purpose of providing climate services. Our assessment is framed around the five core pillars of the World Meteorological Organization's Global Framework for Climate Services. We find that the NMHSs face key capacity gaps in the technical production, translation, transfer, and facilitation of the use of climate information. Some of these gaps have historical roots and relate to the overarching legal, political, and institutional settings in which NMHSs were established and currently operate. Others relate to an increased emphasis on users in ways that contrast with traditional NMHSs' engagement with stakeholders. These results suggest that investments that support the co-production of climate information while also addressing prevailing legal, political, and institutional disconnects and human resource constraints can strengthen the provision of climate services in Caribbean SIDS.

Practical implication

Climate services are becoming an important strategy for delivering climate information to users around the world and are now encouraged by the UN World Meteorological Organization (WMO) in its Global Framework for Climate Services (GFCS). In many countries, National Meteorological and Hydrological Services (NMHSs) are charged with providing climate services to diverse audiences. These climate services are important to foster adaptation to climate risks and reduce vulnerability. However, the production and delivery of climate services place new burdens on NMHSs and require new skillsets, partnerships, and infrastructure. This study examines the capacity of NMHSs in the Caribbean to implement the core pillars of the WMO GFCS. We find that Caribbean NMHSs are experiencing resource, knowledge, and expertise gaps in their implementation of climate services that predominantly relate to the production, translation, transfer, and the facilitation of the use of climate knowledge. We posit that these challenges are likely common in NMHSs serving in the developing world context, which like Caribbean NMHSs, have

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focused historically on weather services, particularly for aviation. This suggests that many NMHSs, especially those in the developing world are not yet fit for the purpose of climate services, in large part because they were not originally built for this purpose. Strategic investments to acquire and cultivate human resources and expertise that complement the meteorological sciences are needed. We offer three major recommendations to meet the most critical issues we found in this research:

Recognizing the link between history and current realities. The development and advancement of climate services in the Caribbean, like other developing countries, suggests attention to historical roots which influence the prevailing legal, political, and institutional framework in which NMHSs operate. Recognizing the links between history and the present will help identify opportunities and constraints that could otherwise go unnoticed.

Investing in the technical, and beyond. While gaps in "hard" technical infrastructure such as observation networks exist, so do gaps in "soft" infrastructure related to human resources, communication, policy, and governance. Balanced investments should be made in both types of infrastructure. It is particularly important to address gaps on the Capacity Development pillar which serve to upgrade capacity in operational areas that support the co-production, translation, and application of user-oriented climate information, as well as, the strategic institutional framework within which this work takes place.

Fostering the opportunity presented by inter-scalar partnerships. Regional partnerships have and will continue to play a large role in supporting differentiated NMHS capacity by reducing the financial and human resource burden at the national level. Investment in resource constrained national climate services should strategize around the connections between the national and the regional.

1. Introduction

Nearly all sectors of society are influenced by weather and climate, with extreme events routinely causing large losses in life, property, and productivity. Consequently, international and national activities are prioritizing efforts that develop resilience to climate variability and change, particularly as they secure important progress made in developing countries (Hewitt et al., 2012). Within this context, climate services have emerged as one strategy to achieve this goal, and major programs in the World Bank, the World Meteorological Organization (WMO) and the United Nations International Strategy for Disaster Reduction are increasingly supporting a global thrust towards scaling up climate services. In 2014–15 alone, US 56 billion was spent on climate and weather information services (Georgeson et al., 2017). Some notable climate service efforts include the Pilot Project for Climate Resilience (CIF, 2015), the Climate Risk and Early Warning Systems (CREWS) Initiative (WMO, 2017a), and the Multi-Hazard Early Warning Systems (MHEWS) for Meteorological, Hydrological and Climate Hazards Programme (WMO, 2018a). These initiatives, among others, target resilience building in Small Island Developing States (SIDS) and Least Developed Countries that stand to be the most affected by the adverse effects of climate variability and change (IPCC, 2014).

Climate services span a diverse portfolio of activities and can be broadly thought of as incorporating, and at times linking, the production, translation, transfer, and use of climate knowledge (Brasseur and Gallardo, 2016; Vaughan and Dessai, 2014). Within academic discourse, climate services draw from insights and methods from diverse fields spanning geography, climate science, communication, behavioral science, social science, environmental governance, and studies on science, technology, and policy, among others. Both weather and climate services are geared at providing actionable information on how environmental conditions and associated hazards might affect a broad range of societal activities and the environment. Climate services are different from weather services in answering questions pertaining to longer timescales, while weather services focus on atmospheric conditions from minutes to two weeks. By contrast, climate services focus on: (1) which weather conditions typically occur at a given time of the year based on historical records ("climatology"), (2) conditions of the atmosphere and the oceans within a period of weeks to a number of years ("climate variability"), or (3) changing conditions of the atmosphere, the oceans, vegetation, ice and soils on earth at timescales beyond a decade ("climate change"). Climate services also include climate forecasts which focus on seasonal climate conditions that are anticipated several months in advance.

In an effort to better link climate science and decision-making and bring the best practices within climate services to the global community, the WMO and its partners formulated the Global Framework for Climate Services (GFCS) in 2009. The GFCS can be seen as an international response to the need for user-driven climate services (Vaughan and Dessai, 2014). While individuals and organizations in all sectors could benefit from climate services, the GFCS prioritizes the agriculture and food security, disaster risk reduction, health, water and energy sectors (WMO, 2017b, 2012). The GFCS' core functions are to help increase the awareness of climate services, inform research and funding agendas, and provide guidance on the implementation of climate services (Zeid et al., 2011). Additionally, the GFCS has a focus on SIDS, Least Developed Countries and Developing Countries and has emphasized the support of National Meteorological and Hydrological Services (NMHSs) which are often implicitly charged—by virtue of their historical function to monitor and forecast the weather—with developing climate services at national and subnational scales (WMO, 2018b, 2012). However, the production and delivery of user-oriented climate services place new burdens on NMHSs and require new skillsets, partnerships, and infrastructure. Consequently, important questions emerge regarding how to shepherd the expansion in function of NMHSs.

This research examines the capacity of the NMHSs network in the Caribbean countries that have participated in the Caribbean Climate Outlook Forum (CariCOF) to implement the GFCS vision. This network includes at its central position the Caribbean Meteorological Organization and its technical arm, the Caribbean Institute for Meteorology and Hydrology (CIMH)—a newly established WMO Regional Climate Center (RCC)—as well as 31 NMHSs that serve a collectively diverse set of Caribbean SIDS and overseas territories (Guido et al., 2016). To date, few studies have assessed the capacity of NMHSs to provide climate services in the developing world, less so in SIDS, and none in the Caribbean region. This is despite the fact that Caribbean SIDS are recognized to be one of the most climate-sensitive and disaster prone regions in the world (IPCC, 2014; UNISDR, 2013). Assessments have been done for weather services (e.g. Zillman, 2004; Zillman and Freebairn, 2001) and on international climate services and climate consulting agencies (Medri et al., 2012). In this study, we frame our inquiry around Caribbean NMHSs' strengths and challenges in executing the core tenets of climate services identified by the GFCS. We specifically ask: (1) What is the level of capacity of Caribbean NMHSs to effectively deliver on the five pillars of the GFCS? (2) What are the main gaps and barriers in producing climate information, connecting this information to decision-making and developing climate service capacity? and finally, (3) What is required to transform Caribbean NMHSs to fulfill the new proposed role of National Climate Service Centers?

2. Implementation of the GFCS in the developing world context

The GFCS states that "providing effective, needs-based climate services requires mechanisms that allow for user needs to inform the

development and provision of climate services; a physical means of communicating climate information; accurate observations and monitoring of climate and relevant non-climatic variables; an understanding of the climate system and its impacts and how they can be predicted; and sufficient capacity in all parts of the process of climate service development, delivery, evaluation and use…" (Zeid et al., 2011, P 18) Thus, the Framework is conceptualized as five interdisciplinary and integrated pillars that support the development and delivery of climate services to users (Zeid et al., 2011). Three GFCS pillars underpin the production of climate information. The "Observations and Monitoring" pillar is the foundation on which "Research, Modelling, and Prediction" is built, while the "Climate Services Information System" supports processes to steward data collation, analysis and dissemination. These three pillars are centered on the technical aspects of climate science. A fourth pillar—the User Interface Platform (UIP)—focuses on enabling end use of the information produced in the previously mentioned three pillars through creating spaces for people to interact in some form; the UIP can range from passive websites to more focused participatory activities. A fifth pillar supports capacity development across the four other pillars.

The implementation of the GFCS requires coordination of climate services at national, regional, and international scales (Medri et al., 2012; WMO, 2014). This can take many forms. Generally, at the national and regional levels, RCCs support NMHSs to accomplish tasks germane to their context. The activities of the RCCs are therefore shaped in large part by the capacities and needs of the users the NMHSs serve. RCC activities often involve data acquisition and management, research, and development of specialized products and decision-support tools (Vaughan and Dessai, 2014). The RCCs utilize data and products from WMO Global Producing Centers to help track the latest climate conditions affecting their regions and/or predictions that are downscaled for their regions. These inter-scalar relationships are advanced in part by the financial support of an increasing set of initiatives from development agencies directed at NMHSs and RCCs.

NMHSs are considered well suited by the WMO (WMO, 2018b, 2012) for the task of climate services provision in large part because they already perform the tasks of a National Climate Services Centre (NCSC). For example, they are often the stewards of the observational network and the data which form the foundation for climate services within their countries (Hunt, 2013). They often possess the technical skillsets to analyze this data into basic and complex derived climate products, applications, and services (Martin et al., 2015; Page et al., 2004). They are also the front-line communicators of climate and weather early warning information to stakeholders.

There are, however, drawbacks. In the developing world context, the NMHSs often have small operational budgets and have difficulty maintaining suitable expertise. Moreover, many NMHSs lack the requisite digitized historical climate data and metadata (Page et al., 2004) that limit even basic climatological understanding and analyses, while a lack of appropriate software architecture (Martin et al., 2015) and trained personnel (Brasseur and Gallardo, 2016) further limit possibilities. Additionally, the training of NMHSs personnel is not geared towards user-oriented aspects of climate services such as user needs assessments, stakeholder engagement, and translational activities. These skills are more emphasized in social science and interdisciplinary curriculums. Nonetheless, the needs of user communities served by NMHSs are growing, as are the demands to expand the functions within NMHSs to meet these needs. To meet these demands, NMHSs draw from the hydro-meteorological activities and approaches they have always applied despite some situations calling for different techniques.

The NMHSs, therefore, experience both strengths and challenges in the implementation of climate services. In recognition of differential capacity at national levels, the WMO categorizes the functional capabilities of national climate service providers on a four-tiered scale. Category 1 corresponds to the ability to deliver a basic range of climate data and products, to participate in regional climate forums, and to engage in limited interactions with end-users. Category 2 corresponds to the ability to deliver a basic range of climate services and products, as well as, to provide climate predictions. Category 2 organizations also participate in climate forums, interact with end-users from different sectors, and gather feedback on the information that end-users provide. Category 3 corresponds to the ability to be able to provide a comprehensive range of climate data services and information, such as specialized climate products for major sectors and downscaled long-term climate projections. Finally, Category 4 organizations have the capacity to cover activities in categories 1–3; they also possess the ability to conduct research, run Global and Regional Climate Models, and serve as an RCC or part thereof. Thus, while Category 1 organizations engage in basic climatology (related to the pillars focused on the technical aspects of climate science), the second to fourth levels incorporate capacity that spans all five GFCS pillars.

2.1. Climate services in the Caribbean

In the Caribbean Climate Outlook Forum (CariCOF) grouping, there are 31 countries and territories; 16 of which are independent countries and the remaining 15 are dependencies of France, the United Kingdom, the Netherlands, and the United States. The Caribbean states encompass a wide diversity in culture, economic, social, and geographic conditions that help shape vulnerability to weather and climate risks (Table 1).

Caribbean countries have high exposure to climate-related risks, including tropical cyclones, droughts, floods and heatwaves, which elevates the need for early warning information systems which most Caribbean NMHSs offer in the context of severe weather systems. While most countries and dependencies have their own NMHSs, some countries provide weather forecasting services for NMHSs in other countries. For example, Barbados provides meteorological services for St. Vincent and the Grenadines and Dominica. Caribbean NMHSs primarily focus on providing information on historical climate, as well as on the weather to seasonal timescales, with less emphasis on climate change. This is not surprising since the development of climate change projections do not qualify as operational climate services work. Moreover, the human, technological and financial resources required to run and analyze climate change projections are far beyond the reach of many Caribbean NMHSs. The Caribbean Community Climate Change Centre, research groups at the University of the West Indies and the Instituto de Meteorología de Cuba (INSMET) help meet user demands on longer-term, climate change information.

The CIMH plays a central role in seasonal climate early warning and supports the NMHSs within the region (Guido et al., 2016). CIMH's stewardship is reflected in its mandate to build capacity, archive regional climate data, conduct research, and develop and provide specialized services and advice to national governments and industry. Within the region, there are several CIMH-led climate service activities worth highlighting. Since 2012, the CIMH has convened the CariCOF. Meteorologists and climatologists from NMHSs receive seasonal forecasting and analytical training prior to the Forum. At the Forum, sector practitioners and decision makers from around the region attend alongside the meteorologists and climatologists where they discuss early warning information including seasonal climate forecasts, other experimental products, and share experiences (Gerlak et al., 2017). Climate information is also developed by specialized climate service projects such as the CIMH implemented 3-year Caribbean Agrometeorological Initiative (CAMI) which focused on climate information for farmers (Vogel et al., 2017). More recently, the three year Programme for Building Regional Climate Capacity in the Caribbean expanded CIMH's thrust to support the NMHSs and end-user communities in six climate-sensitive sectors in developing sectoral Early Warning Information Systems across Climate Timescales (EWISACTs). The Sectoral EWISACTs program which seeks to co-design, co-develop and co-deliver sector-specific climate information to better adapt to the challenges associated with climate variability and change, is noteworthy. These

Table 1
Select national information for the countries and territories included in this study.

Country/Territory	Status	Surface Area[a] (km^2)	Population[a] (000, 2017)	GDP Per Capita (US $)[a]	Main Economic Sectors (% of GVA, 2017)	Climate Exposure Index Category[b]
Anguilla	British overseas territory	91	15	21879.6	Agriculture = 2.3; Industry = 15.7; Services and other activity = 82.0	n.a.
Aruba	Dutch overseas territory	180	105	26005.4	Agriculture = 0.5; Industry = 15.4; Services and other activity = 84.1	n.a.
Antigua and Barbuda	Independent	442	102	14764.5	Agriculture = 1.9; Industry = 18.3; Services and other activity = 79.8	high
Barbados	Independent	431	286	15429.4	Agriculture = 1.7; Industry = 12.1; Services and other activity = 86.2	low
Belize	Independent	22,966	375	4789.4	Agriculture = 14.6; Industry = 18.5; Services and other activity = 66.9	high
British Virgin Islands	British overseas territory	151	31	30144.5	Agriculture = 1.0; Industry = 11.1; Services and other activity = 87.8	n.a.
Cayman Islands	British overseas territory	264	62	62132.0	Agriculture = 0.3; Industry = 7.5; Services and other activity = 92.2	n.a.
Cuba	Independent	109,884	11,485	7656.6	Agriculture = 5.0; Industry = 20.5; Services and other activity = 74.5	extreme
Dominica	Independent	750	74	7051.1	Agriculture = 15.4; Industry = 13.2; Services and other activity = 71.5	extreme
Dominican Republic	Independent	48,671	10,767	6373.6	Agriculture = 6.6; Industry = 28.0; Services and other activity = 65.4	extreme
Grenada	Independent	345	108	8933.8	Agriculture = 8.3; Industry = 13.9; Services and other activity = 77.8	low
Guyana	Independent	214,969	778	4278.8	Agriculture = 17.6; Industry = 31.7; Services and other activity = 50.6	low
Haiti	Independent	27,750	10,981	793.7	Agriculture = 16.7; Industry = 38.2; Services and other activity = 45.1	extreme
Jamaica	Independent	10,990	2890	5105.8	Agriculture = 7.1; Industry = 22.3; Services and other activity = 70.5	extreme
Montserrat	British overseas territory	103	5	11553.4	Agriculture = 1.4; Industry = 12.7; Services and other activity = 85.9	n.a.
Puerto Rico	U.S. territory	8868	3663	27939.0	Agriculture = 0.8; Industry = 50.0; Services and other activity = 49.1	n.a.
St. Kitts and Nevis	Independent	261	55	15771.9	Agriculture = 1.2; Industry = 28.1; Services and other activity = 70.7	extreme
Saint Lucia	Independent	616	179	7839.4	Agriculture = 2.7; Industry = 12.9; Services and other activity = 84.4	low
Sint Maarten	Dutch overseas territory	34	40	28241.7	Agriculture = 0.1; Industry = 12.3; Services and other activity = 87.6	n.a.
St. Vincent and the Grenadines	Independent	389	110	6739.2	Agriculture = 7.5; Industry = 17.2; Services and other activity = 75.3	low
Suriname	Independent	163,820	563	8985.3	Agriculture = 11.4; Industry = 27.4; Services and other activity = 61.1	low
Trinidad and Tobago	Independent	5127	1369	19062.9	Agriculture = 0.5; Industry = 42.5; Services and other activity = 57.0	medium

Note: n.a. = Not available.
[a] United Nations (2017).
[b] Mapplecroft (2014). The Climate Exposure Index (CEI) evaluates the current risk of a territory being impacted by extreme climate-related events (drought, wildfires, tropical cyclones, storm surge, severe local storms, precipitation induced landslides, flooding, and sea level rise). The CEI also incorporates risk posed by the projected changes in baseline climate parameters.

activities help fill critical knowledge and service gaps at national levels.

3. Methods

The research design employed a multiple methods approach, using document analysis, a survey of key informants, and semi-structured focus group discussions. The use of multiple methods allows for triangulation to produce more comprehensive analyses and robust results (Nightingale, 2009). For the document analysis, we reviewed relevant and accessible secondary source materials including NMHSs websites and the WMO Country Profile Database to assess NMHSs' institutional arrangements. For the survey, we purposefully contacted the Directors or high-level administrators of the NMHSs within the CariCOF grouping who could answer questions about the challenges and opportunities of implementing climate services at a national level through the perspective of strategic decision-makers. We received responses from 22 Caribbean NMHSs, representing 15 countries and 7 overseas territories. The survey responses were collected via a telephone or Skype call between August – December 2015 that lasted no more than 60 minutes.

To add detail to the survey responses and to hear from NMHSs personnel engaged at the operational level of climate services, we conducted four focus group discussions at two CariCOFs in 2016. At the May 2016 CariCOF in Dominica, 18 practitioners representing 17 NMHSs participated in two separate focus groups. The majority of these participants were directly responsible for the production of climate information products in their respective countries. Both focus groups followed the same open-ended question protocol, facilitating discussions on the challenges and opportunities NMHSs personnel face in their efforts to develop and disseminate climate information. While broadly following the protocol, facilitators also explored respondents' perceptions more deeply as needed. At the CariCOF in Grenada in December 2016, 22 practitioners from 21 NMHSs participated in two focus groups. Here, the discussions were expanded from the challenges in climate services to explicitly include the resources that have helped the NMHSs personnel provide climate services. A member of the research team facilitated the focus groups and discussions were audio recorded and transcribed.

In general, responses reflect the weather and seasonal timescales which are the main operational and technical focus of Caribbean NMHSs. Moreover, the results are based on subjective perceptions and self-reports of capacity versus an objective, independent third party judgment, which is a limitation of this research. We analyzed the survey responses and focus groups transcripts under themes corresponding to the 5 pillars of the GFCS. Because the WMO conceptualizes the GFCS pillars as holistic, integrated and inter-connected and does not prioritize any particular GFCS pillar over another, we conducted a balanced evaluation of the five GFCS pillars, giving equal weight to the investigation of each pillar. Given the broad scope of the assessment, we sought to reduce respondent burden and fatigue by relying on secondary sourced material for already public and available information, wherever appropriate. We present and discuss both descriptive statistics from the survey and qualitative evidence obtained from the focus groups.

4. Results

4.1. NMHSs profiles

There is substantial diversity in the functions and institutional arrangements of the NMHSs in the Caribbean. While all 22 NMHSs deliver on their nation's meteorological services, only 17 countries deliver on climatology and four countries also focus on hydrology. Most NMHSs operate as meteorological departments within government ministries or statutory bodies, the most common of which relate to Civil Aviation, Agriculture, and Ports.

Eleven of the NMHSs have been in operation for more than 50 years, while the remaining NMHSs have been in operation for 28–36 years. By contrast, of the 17 NMHSs that answered this question, it is clear that NMHSs have been delivering climate services for a shorter period, ranging from 1 to 3 years ($n = 5$), 6 to 10 years ($n = 3$), and greater than 10 years ($n = 9$).

The legal mandate of operation of the NMHSs and their position in government vary widely across countries and territories. NMHSs generally do not have legal status as many were not established under a specific legal instrument. Where there is a legal instrument guiding NMHS operations, this is likely narrow in terms of Civil Aviation, thus impacting the type and scope of services offered. For example, Antigua and Barbuda report that a primary legislative act, the "Civil Aviation Cap 86, Part 3," provides a legal mandate for their service. Generally, national laws, decrees or other legislative acts on meteorology or climatology do not exist.

Human resources involved in weather and climate services differ. Eight of the NMHSs have more than 20 technical staff. These correspond to some of the larger countries. The majority, however, have fewer than 20 technical staff. We did not differentiate staff working only on weather related activities from those working only on climate services because, given the limited human resources, most NMHSs staff do both and the lines between the two portfolios are often blurred. As meteorology is the main activity for the NMHSs, fewer staff resources are focused on climate.

Financial resources across Caribbean NMHSs also vary by as much as a factor of five. Budget expenditures per capita (in 2013 year dollars) range from a low of US$1.63 to a high of US$8.23 per capita (WMO, Country Profile Database, 2016). The majority of NMHSs ($n = 16$) report that their main source of funding is the national government, with additional finances sourced from projects funded by international agencies.

4.2. NMHS climate service capacity

The WMO categorizes the functional capabilities of national climate service providers on a four-tiered scale from providing basic climate services to more advanced forms that include the creation of tailored decision support analytical tools. As shown in Fig. 1, of the 21 NMHSs that answered this question, six NMHSs identified themselves as being able to meet only the basic climate services (Category 1), while 11 NMHSs reported being able to provide a higher level of service including, among other things, routinely producing climate predictions (Category 2). Three NMHSs reported being able to provide a comprehensive range of climate data services and information (Category 3), and only one NMHS possessed capacity to cover activities in all 3 aforementioned categories and also the ability to conduct research, run global and regional climate models, and serve as an RCC or part thereof (Category 4).

The survey also indicates that the NMHSs personnel perceive themselves to be best equipped to perform climate observations, climate data management, and climate monitoring which form activities in the Observation and Monitoring pillar. On the other hand, they are less equipped to perform climate data rescue, data mining, and impacts reporting, which are also activities encompassed by the GFCS Observation and Monitoring pillar. They also perceive their capacity to be relatively lower to perform activities within the Research, Modeling and Prediction pillar, the Climate Services Information System pillar, and the User Interface Platform pillar (Fig. 2).

4.3. Capacity and barriers in producing climate information

All countries are engaged in some form of climate information production, although there is substantial diversity in the number and type of information and services offered (Fig. 3).

Since the large majority of NMHSs (17 countries) fall into Category 1 and Category 2 service provision, the products produced at the

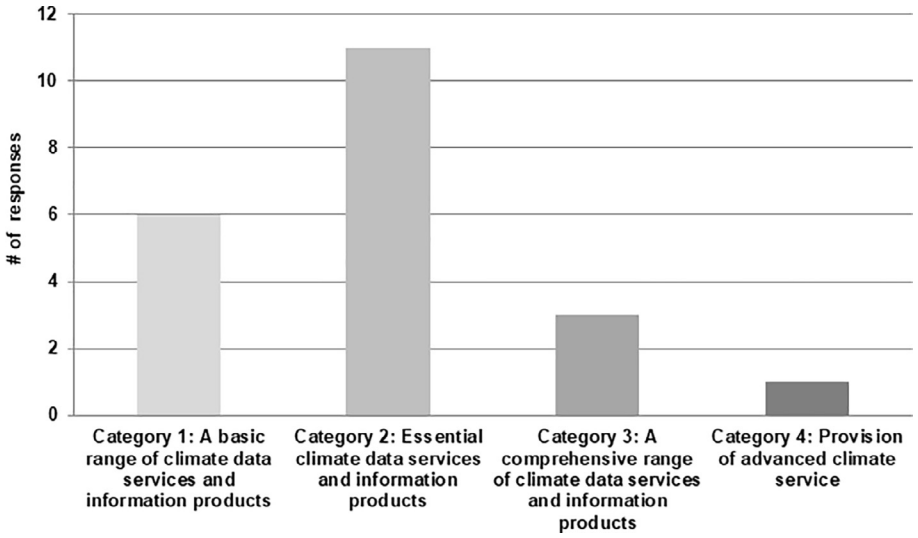

Fig. 1. NMHSs' self-rating of national climate service capabilities.

national level reflects this dynamic. Most NMHSs are engaged in summarizing and providing climate data, providing climate monitoring information, as well as, seasonal climate forecasts, while very few are engaged in producing specialized products for major sectors. Fig. 3 makes clear that specialized products that target the agriculture sector dominate the national climate product portfolio, with this sector currently benefiting from a tailored product in 9 countries. Only a minority of NMHSs are producing products tailored specifically to sectors other than agriculture. Only one NMHS for example produces a hydro-meteorological bulletin for the water resources sector, while only one other NMHS offers specialized climate information services for the health sector.

Many senior NMHSs personnel highlighted gaps in data collection and management which have prevented some products from being generated. For example, 13 NMHSs respondents reported that their organizations do not collect the full spectrum of data necessary for developing sector-specific products, while 18 reported that finer resolution data is needed to provide tailored climate services. Additionally, some NMHSs respondents noted that long-term climate records, particularly those on temperature, humidity, sunshine duration and solar radiation did not meet the recommended 30-year timespan for robust climatological analysis. Only 13 NMHSs reported hosting and managing a climate database management system with some NMHSs relying instead on Excel spreadsheets to share and analyze data. Many countries have yet to completely digitize their historical climate data, while in some countries, failures of equipment and inconsistent maintenance create time series gaps that undermine the quality of more contemporary data.

NMHSs personnel also identified a lack of historical climate impacts data (eg. statistics on sectoral damage and loss attributed to climate-related hazards) as another major barrier. Less than half the NHMSs collect data on climate impacts and, when the data is collected, it seems to depend on the individual motivation of an NMHSs representative rather than being a mainstreamed operational activity. While the development of an online platform by the CIMH to routinely upload climate impacts data is a recent attempt to overcome this limitation, the database will only be able to stimulate product development with frequent contributions over time.

A lack of sectoral time-series datasets was also highlighted in both the survey and focus groups as a limiting factor in providing user-

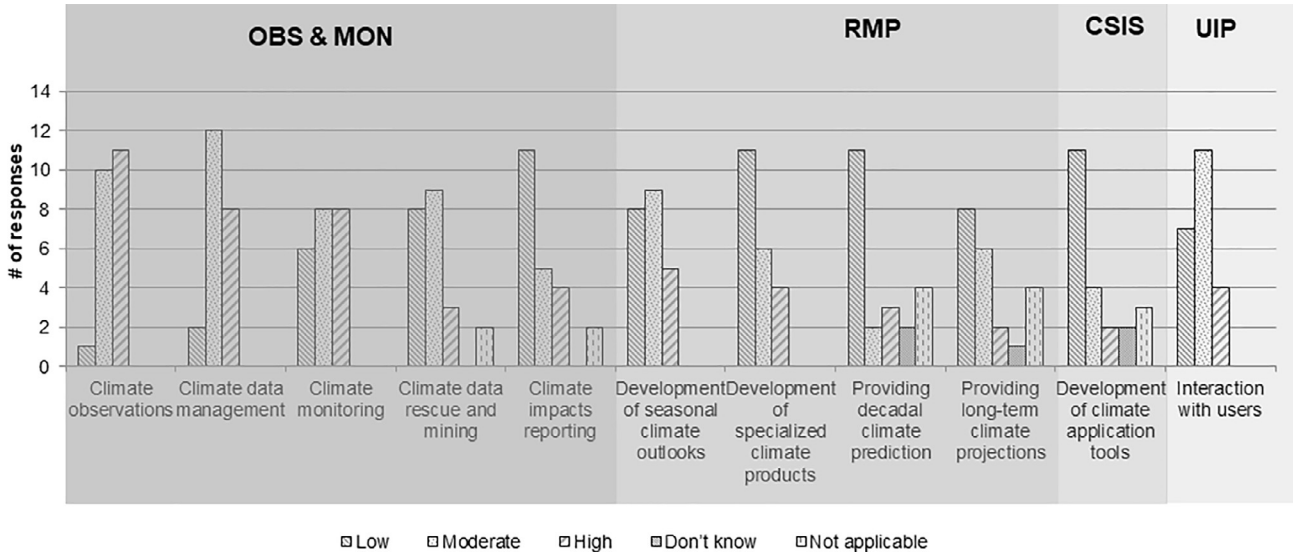

Fig. 2. Perceived capacity across 4 GFCS pillars. Note: OBS & MON = Observation and Monitoring; RMP = Research, Modeling and Prediction; CSIS = Climate Services Information System; UIP = User Interface Platform. Due to its all encompassing nature, we do not present the results of perceptions on the Capacity Development pillar as distinctly independent in Fig. 2.

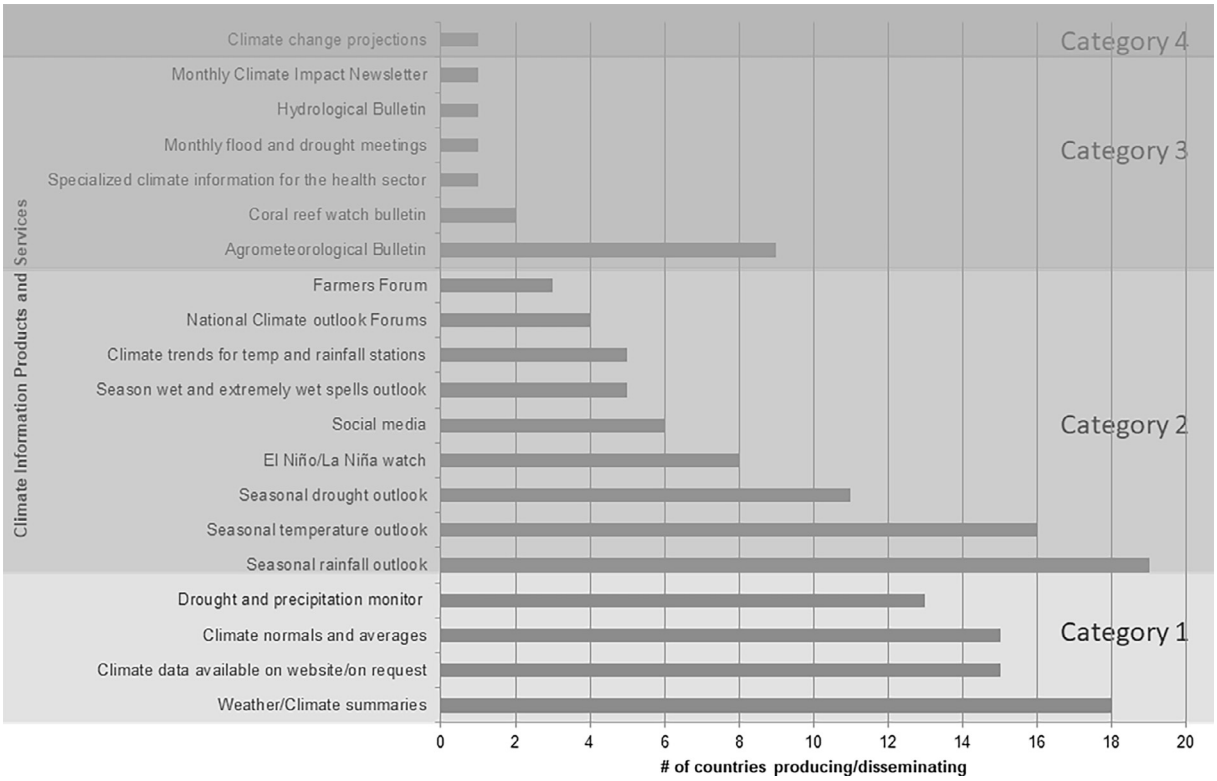

Fig. 3. Climate Information Products and Services provided by the NMHSs.

oriented climate services. Sectoral time-series are key inputs for the development of the next generation of user-oriented climate information (e.g. irrigation index). However, in many cases, the historical data on variables such as crop-specific agricultural output may not exist. As one respondent explained, "…they [the sectors] don't have [sectoral] data, so even if we want to provide climate services for them, there is nothing to find those correlations against. The data gathering on their side is sometimes lacking, so that is the challenge there." In other instances, sectoral data may exist, but may be in analog form and in need of digitizing.

Finally, while the majority of NMHSs respondents believe that having the NMHSs conduct research is needed to improve climate services, many of the NMHSs personnel reported they are unable to engage in basic and applied climate research. Only four NMHSs have a research division and only two have a formalized long-term research strategy. Focus group participants indicated that better connections to research groups or research conducive policies can help promote research within the NMHSs. However, only five NMHSs have formal collaboration with an outside research group other than the CIMH.

4.4. Capacity and barriers in connecting climate information to decision-making

Although today the NMHSs generally serve six climate-sensitive sectors (agriculture, water, disaster risk management, tourism, health and energy), NMHSs have historically interacted most actively with the agriculture, water and disaster risk management sectors. Moreover, focus group discussions highlighted the dominant focus on the agricultural sector by climate information providers. As one participant explained, "The usual is just the agriculture thing, and, I guess, the other sectors, a lot of them are not even aware of what products we provide or that are available for them."

The engagement and communication between NHMSs and sectoral stakeholders takes many different forms. Among NMHSs survey respondents, 19 reported that their interactions include answering basic climatology questions, while 14 of the NMHSs personnel reported interacting with information users to identify climate information needs or assisting users in interpreting and using climate predictions and products. However, only eight report that they routinely obtain feedback on the usefulness and effectiveness of the information and services provided.

NMHSs interact with users via email, SMS, phone calls, surveys, online discussion forums, seminars, and workshops. The level of effort and resources needed to engage in these activities differ. At one end of the spectrum is the National Climate Outlook Forum (NCOF). The NCOFs are modeled after the CariCOF and involve convening national providers and users to discuss climate. The NCOF was highlighted by focus group participants as an opportunity for two-way dialog, mutual learning, and a means to identify climate information needs. One participant stated: "We have a national climate outlook forum where we talk with the farmers and we describe the weather events and so on. They need to understand what we are providing to them. And we need to ensure that we are providing them with the right services." However, to date, only four NMHSs have been able to convene NCOFs. Other exchanges have taken on a more ad hoc approach to identify user needs. As one respondent explained, "… what I do is based upon requests that come into our office, I will determine whether or not I should create a product to satisfy that need so that whenever a request comes in, I don't have to go scampering to try and figure out what is going on… I try to use that approach in the interim of not having the national forum." Yet, for many NMHSs, establishing and maintaining routine interactions is challenging and a work in progress. As one respondent described, "… the distance between the met office and the stakeholders is too big."

4.5. Barriers to developing climate service capacity at the NMHSs

The Capacity Development pillar encompasses all other aspects of the GFCS vision of climate services. In both survey data and the focus groups, three challenges to developing capacity consistently emerged. They relate to legal mandates for the NMHSs to provide climate

services, the national policy and procedural context within which NMHSs operate, and the human and financial resources available to the NMHSs.

All 22 NMHSs are responsible for their nation's meteorological services, but in only 17 countries are there formal mandates for climatology. Moreover, four of the NMHSs are part of the Airport Authorities, making aviation meteorology the overwhelming priority. Competing priorities and limited staff levels, particularly for the smaller islands, sidelines even the most basic climate service activities. A meteorologist stated, for example, that "…technically, by the letter of the law, we have no national met service, so to speak. What exists is the Airports Authority; [it] has a Met department which provides for the airport, and by extension, the country……. But by legislation, there is not a national met service. So, in the absence of that, my management is rather hesitant to go and spend a lot of money to update data, to go and put rain gauges all over the country because that's not their mandate, as passed in law.... So, climate services are seen as an additional extra."

A lack of policies and procedures related to the production and transfer of climate services is another barrier. For example, with the exception of a national level governance mechanism for climate services in Trinidad and Tobago (in the form of the Climate Services Panel for Trinidad & Tobago) and its associated documentation, we found no other clear examples in our sample of 22 NMHSs. Nor did we find national level guidance or policies that outline how NMHSs should interact with national stakeholders in their role as climate service providers. Additionally, there appears to be no regional nor national level policies for data sharing across sectors in Caribbean countries. There was considerable agreement among respondents that the production of climate information is negatively impacted by a lack of open data access. About half of the respondents believe better data sharing policies are needed. However, this may be easier said than done as trust is an issue for some sectors. For example, one respondent stated: "the farmers are very tight lipped about what they produce and when they produce…. If they declare what they produce, the government could see that as a way to tax them." Another respondent shared that "one of the biggest problems is we don't own the data. We can't get the data from the water authority." Due to the proprietary nature of some sectoral data, the need for formal inter-institutional agreements with sectors to generate sector-specific climate information may be necessary. Despite the absence of a conducive national policy context, we found a few examples of NMHSs in the Caribbean that have established organizational level memoranda of understanding to facilitate data sharing. In one country, an NMHSs brokered an agreement to use the rain gauges of a water management agency, a move that significantly boosted the spatial coverage of the NMHSs monitoring network.

In terms of human resources, focus group participants identified a lack of dedicated trained climatologists or applied climatologists working on climate services. In many cases, there is no climatologist on staff and no incentives for staff to specialize in climate. Often, meteorological forecasters are tasked with work fit for a climate scientist and do so more on a voluntary basis than based on job mandate. Moreover, these officers follow the same pay scale despite further climate training and specialization. As one representative describes, "… we are being forced to wear many hats in the offices… In my case, I can clearly state that we need more staff at the met office. You cannot put out a 110% when you're only given 50% of the tools to do the job. It just will not happen." New positions appear to be needed within the NMHSs organizational staffing structure. NMHSs representatives also called for specialized technical assistance and training in several areas, including long-term climate monitoring and prediction; climate impact reporting, risk modeling and assessment; forecasting; Geographic Information System mapping; and risk communication. Increased opportunities for learning with institutions that possess this expertise were also seen as an important step forward.

Finally, NMHSs representatives stressed the importance of being empowered to engage in long-term institutional visioning. One NMHSs representative put it this way, "I think we also have to think about structuring our offices and planning strategically for the challenges ahead. I think we need, at least for the small offices, we need that help to brainstorm as to how we should look as a service 10, 20 years down the road to meet the present-day challenges…" In this regard, they called for institutional strengthening through the development of a policy framework for climate services, complemented by strategic plans and associated financing for NMHSs that explicitly address capacity gaps.

5. Discussion

5.1. Gaps in NMHSs' capacity to provide climate services in the Caribbean SIDS context

Representatives of the NMHSs in the Caribbean identified several gaps in the provision of climate services across all five GFCS pillars. For example, although relatively moderate to high capacity levels were reported on aspects of the Monitoring and Observations pillar, many Caribbean NMHSs are still grappling with less than robust climate time-series data and ad hoc climate database management systems, even after decades of investment. Since meteorological observations and climate data are the fundamental basis for the development of any climate product or service, this limitation negatively feeds back on the other pillars. Additionally, the capacity to conduct independent research, modeling, and prediction is largely absent in many NMHSs. Finally, while some components of a climate information system are in place across the Caribbean region, they are not always coherently managed or responsive to needs. These gaps in the Caribbean are similar to Pacific SIDS (Martin et al., 2015; Page et al., 2004), and reflect other developing world contexts more generally (Dinku et al., 2014).

The literature on climate services identifies the UIP and connecting climate information with decision-making as one of the greatest challenges in the development and improvement of climate services (e.g. Lemos et al., 2012; Lúcio, 2016). Results from the survey and focus groups with NMHSs representatives revealed mixed results regarding perceptions of this component of climate services. On the one hand, participants in the Grenada focus group stated that their interactions with users have increased in recent years. On the other hand, some senior level survey respondents perceived that NMHS staff do not sufficiently interact with users to meet basic information requests, provide advice, and aid in the interpretation of information. In general, however, many NMHSs personnel have contact with stakeholders through phone calls, personal interactions, or meetings, and it appears that these interactions are informing climate service activities. For some, the CariCOF and NCOFs, along with activities such as social media, have provided NMHSs with opportunities to make connections with users. Nonetheless, given the small staff in some NMHSs, we suspect that requests for information may outpace the ability of the NMHSs to satisfy the demand. Moreover, the NMHSs do not serve all sectors in the same way. Historically, the agriculture, water, and disaster risk management sectors have been engaged the most, and, even for sectors that have been well served, mass distribution of information over the internet will have limited reach to specific subgroups. This was seen in a recent evaluation of climate outlook bulletins for farmers in the Caribbean where the digital distribution of climate information failed to reach older farmers with little education (Vogel et al., 2017). The "user interface" is a challenge because routine interactions require time, effort and skillsets that many NMHSs personnel do not have (Brugger et al., 2016; Dinku et al., 2014; Vogel and O'Brien, 2006).

We find that the biggest concern of NMHSs personnel in the region relates to the Capacity Development Pillar. This result mirrors a recent international survey of both producers and users of climate services that prioritized capacity building in climate services over the other GFCS pillars. While this outcome was hypothesized by Vaughan et al. (2016) to be a result of researchers focusing more on climate change

communication and on identifying information needs rather than on capacity building, our results suggest an additional explanation. We posit that the historical context is a significant prevailing factor shaping present-day capacity. More specifically, the history of Caribbean NMHSs as meteorology-centric organizations is influencing the development of contemporary climate services activities to be focused more on technical elements and less on user engagement and critical areas of capacity development. In the Caribbean case study, climate services have been built upon a meteorological foundation and persistent gaps in that foundation are likely shaping the nature and direction of the implementation of new initiatives such as the GFCS. Many of the challenges present today in the Caribbean were present 50 years ago. For example, in assessing the state and practice of applied climatology in the Caribbean, Smedley (1966) noted that meteorology in the Caribbean was hampered by sparse networks of met stations, financial barriers, insufficient political buy-in, and the dominance of the aviation meteorology portfolio. Today, when assessing the implementation context for climate services, we find similar gaps in national observation infrastructure resourcing, as well as the policy and institutional arrangements for climate services delivery.

5.2. Inter-scalar partnerships in support of differentiated capacity

To address differentiated capacity across the five GFCS pillars, Caribbean countries rely on partnerships to achieve a critical mass of operational capacity, just as islands in the Pacific have partnered and relied on each other for gaps in data (Avellan and Castonguay, 2015). Examples of these partnerships include bilateral working arrangements between NMHSs in the provision of meteorological warnings, as well as partnership with the CIMH.

The Caribbean experience has demonstrated that there are two models of climate service delivery in the SIDS context. The first model is idealistic. It assumes a sufficiently capable and even strong NMHSs acting in the role of a NCSC that is the direct provider of nationally produced local information or downscaled regional information. The second model recognizes the limitations of NMHSs in carrying out their expanded role as NCSCs and the strong supporting role that a RCC can play in compensating for this. This model requires that the RCC have access to national databases to effectively support the needs of national stakeholders, and have a good knowledge of and the confidence of national stakeholders. Thus, inter-scalar partnerships between regional and national entities become particularly important.

For example, the CIMH in its role as the WMO Caribbean RCC, invests in and coordinates a collaborative operational research, modeling, and prediction program across regional NMHSs in order to build capacity in climate prediction methodologies and develop tools and products. The CIMH also mediates connections between climate information providers and users through the CariCOF (Guido et al., 2016). Most NMHSs personnel indicated that the CariCOF gave them the opportunity to engage the user community, increase awareness within sectoral communities, and build mutual understanding and trust with various stakeholders. Another example is the development of the CariCOF Outlook Generator (CAROGEN) (http://carogen.cimh.edu.bb/index.php/about), which is an online platform that automates the generation of climate outlooks and allows forecasters to perform a series of homogeneous experiments nationally and across the Caribbean. CAROGEN, therefore, facilitates the production of regional climate outlooks that would otherwise be considerably more difficult to produce in its absence.

Given the constraints on national government funding in many Caribbean SIDS, the substantial opportunity that exists for increased efficiency and quality of service through regional cooperation in the provision of services cannot be overlooked. The evidence suggests that investment into national climate services should strategize around the connections between different spatial scales of climate services – and particularly the connection between the national and the regional.

5.3. Fit for purpose? Transforming NMHSs into National Climate Service Centers

The provision of climate services by NMHSs in the Caribbean is advancing and by many accounts, Caribbean NMHSs are rising up to a difficult challenge. With programs like the GFCS, NMHSs are now being tasked with activities that go beyond their traditional aviation and hydro-met portfolios. We posit that a similar challenge is likely common in NMHSs serving in other developing world contexts, which like Caribbean NMHSs, have focused historically on meteorology. Limits in staffing, gaps in data, competing mandates, and weak ties to research, among other barriers, present critical hurdles to overcome. As such, Caribbean NMHSs are not yet fit for their new role of developing and delivering climate services, in large part because they were not originally built for this purpose.

Notwithstanding this, Caribbean NMHSs may well be the most appropriate focal point at the national level for climate services provision for a number of reasons. This includes their presence in most Caribbean SIDS, their role as the custodians of the national observational network and the climate data needed to develop climate information products, as well as their existing interactions and trust built with the public with respect to weather services. Of course, it should be noted that in some of the smaller Caribbean countries, there is no other existing organization to fill this role.

It is possible to transform from traditional NMHSs into NCSCs, to meet these new climate service needs. In order to do so, existing NMHSs leadership, along with governments, funding agencies and collaborative programs must invest in building and strengthening capacity across all five pillars and move beyond the traditional narrow focus on technical capacity elements. More specifically, strategic investments that acquire and cultivate human resources and expertise that complement the meteorological sciences are needed. This may be easier said than done since historically the NMHSs have been a technical agency.

Additionally, the challenges currently faced by Caribbean NMHSs stem from historically rooted gaps and inefficiencies across the legal, political, and institutional framework in which the NMHSs operate. We find that this dynamic is not well articulated within the current framing of the GFCS pillars. This is a missed opportunity since clearer recognition of the macro legal, political, and institutional context for the development and delivery of climate services would help to identify opportunities and constraints that would otherwise go unnoticed.

In the Caribbean, to address the lack of a legal mandate and political buy-in, some NMHSs representatives have called for political recognition as a NCSC, suggesting that this designation would be the most significant step forward for the development and delivery of climate services at the national level. One respondent stated, “If we get that government thrust or that input at a higher level, which could turn us into the established climate center for the island that would be the biggest step we need. We have everything that it takes. We have the training, all the data, and all the expertise, but it’s just that by the letter of the law, we are not mandated to do it.” Transforming NMHSs into NCSCs will require strengthening the governance of climate services, including laws and policies that mandate NMHSs to provide climate information. Additionally, continued emphasis and advancement related to user-interactions is needed. Therefore, more focus on the development of systematic feedback mechanisms and protocols, interactions with a wider audience, and assessments of good practice could help advance climate services. However, this requires resources, and interacting with end-users bears a high burden that will create tensions with other needs. In effect, climate services are an emerging portfolio, now expected to co-exist alongside more traditional aviation and hydro-met portfolios. Whether this co-existence manifests itself as a collaboration or competition for a stagnant or declining pool of resources remains an open question in some countries and territories. Regional partnerships have and will continue to play a large role in supporting climate services, and can reduce the financial and human resource

burden at the national level, but only to some degree.

6. Conclusion

In this study, we set out to understand in what ways National Meteorological and Hydrological Services in the Caribbean are fit for the purpose of implementing climate services. We used the World Meteorological Organization's five GFCS pillars as our analytical frame. The development of the GFCS and global investments in climate services, as well as the severe socio-economic consequences of climate variability and change, is leading to an expansion of the NMHSs' service portfolio to include forecasts for longer seasonal timescales, as well as to engage more sectoral stakeholders to produce user-driven climate information. Our comparative study of NMHSs in the Caribbean demonstrates the challenges NMHSs face in expanding their more traditional aviation and hydro-meteorological portfolios to include climate services, and the challenges to GFCS implementation at a national level. Our research suggests that Caribbean NMHSs are not yet fully fit for the purpose of providing climate services. Rather, these organizations have focused historically on meteorology and therefore face knowledge and expertise gaps most prominently related to the translation, transfer, and the facilitation of the use of climate information. Many of these gaps are rooted in the legal, political, and institutional frameworks in which NMHSs operate, that constrain their development of capacity. Developing national climate services capacity goes beyond investment into climate science; it requires investment into the legal, political and institutional framework, as well as, human resources specific to climate services. In such a context, Regional Climate Centers can play a strong but limited supporting role building NMHSs capacity for user oriented climate services production and delivery. We suggest ways to improve NMHS capacity to better meet the challenges of providing climate services. Further research that illuminates macro legal, political, and institutional challenges and how these challenges are changing over time in specific developing world contexts is needed to enhance the literature base and provide recommendations and best practices to implement the GFCS vision at regional and national levels.

Conflict of interest statement

The authors have no competing interests to declare.

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Appendix A. Supplementary data

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