frontiers in Marine Science

PERSPECTIVE
published: 22 July 2021
doi: 10.3389/fmars.2021.670089

A Roadmap for Policy-Relevant Sea-Level Rise Research in the United Arab Emirates

Hannah Melville-Rea[1,2], Clare Eayrs[1], Nasser Anwahi[2], John A. Burt[3], Denise Holland[1], Fatin Samara[4], Francesco Paparella[5], Ahmed Hassan Al Murshidi[6], Maryam Rashed Al-Shehhi[7] and David M. Holland[1,8]*

[1] Center for Global Sea Level Change, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates, [2] Department of Political Science, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates, [3] Water Research Center and Center of Genomics and Systems Biology, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates, [4] Department of Biology, Chemistry and Environmental Sciences, College of Arts and Sciences, American University of Sharjah, Sharjah, United Arab Emirates, [5] Center for Stability, Instability, and Turbulence, Division of Science, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates, [6] College of Humanities and Social Sciences, United Arab Emirates University, Al-Ain, United Arab Emirates, [7] Department of Civil, Infrastructural and Environmental Engineering, Khalifa University, Abu Dhabi, United Arab Emirates, [8] Courant Institute of Mathematical Sciences, New York University, New York City, NY, United States

OPEN ACCESS

Edited by:
Julie Billy,
Bureau de Recherches Gologiques et Minières, France

Reviewed by:
Helena Granja,
University of Minho, Portugal
Lei Ren,
Sun Yat-Sen University, China

****Correspondence:***
Hannah Melville-Rea
hannah.melvillerea@nyu.edu

Specialty section:
This article was submitted to Coastal Ocean Processes, a section of the journal Frontiers in Marine Science

Received: *20 February 2021*
Accepted: *21 June 2021*
Published: *22 July 2021*

Citation:
Melville-Rea H, Eayrs C, Anwahi N, Burt JA, Holland D, Samara F, Paparella F, Al Murshidi AH, Al-Shehhi MR and Holland DM (2021) A Roadmap for Policy-Relevant Sea-Level Rise Research in the United Arab Emirates. Front. Mar. Sci. 8:670089. doi: 10.3389/fmars.2021.670089

The United Arab Emirates (UAE) has a long-term policy horizon, the financial capital, and a vision for a sustainable knowledge-based economy. These characteristics uniquely situate it as a potential leader for sea-level rise research. Climate science is already growing, and at the center of the UAE's pivot toward climate research is a burgeoning concern for sea-level rise. Over 85% of the UAE's population and more than 90% of the nation's infrastructure is within a few meters of present-day sea-level. With its low-lying and shallow-sloping geography (about 35 cm per km), this high-value coastline, including the rapidly expanding cities of Dubai and Abu Dhabi, is particularly vulnerable to sea-level rise. Meanwhile, limited regional research and data scarcity create deep uncertainty for sea-level projections. We set out a potential roadmap for the UAE to capitalize on its strengths to create usable and relevant sea-level projections for the region. With a newly established Climate Change Research Network, the UAE government is beginning to draw together universities and research centers for "furthering effective data collection and management, and advancing policy-relevant research on climate impacts and adaptation[1]." By consolidating ideas from the science community within the UAE, we identify promoters and barriers to data gathering, information sharing, science-policy communication, and funding access. Our paper proposes pathways forward for the UAE to integrate sea-level science with coastal development and form best practices that can be scaled across climate science and throughout the region.

Keywords: sea-level rise, climate change, adaptation, United Arab Emirates, Arabian Gulf

[1] https://www.moccae.gov.ae/en/climate-change-research-network-about.aspx (accessed 2 Feb 2021).

1. INTRODUCTION

Obscured by the dominance of pandemic-related news, the world set new records for global temperatures, hurricanes, wildfires, and Arctic sea ice loss in 2020 (World Meteorological Organization, 2021). Meanwhile, incontrovertible evidence of the climate crisis can be observed in a shrinking Greenland Ice Sheet (IPCC, 2019), increased ocean heat content (Trewin et al., 2020), and poleward shifts of temperature-sensitive species (Hastings et al., 2020). Among such disasters, rising sea-levels already impact shorelines around the world and are projected to worsen for centuries to come (IPCC, 2013). How much and how fast will coastal communities be impacted? At present, our limited scientific understanding of the Antarctic Ice Sheet (IPCC, 2019), a tipping element within the climate system (Lenton et al., 2008), drives deep uncertainty for sea-level projections. Some studies predict as much as 7.5 m of sea level rise by 2200 in the case of instabilities (Bamber et al., 2019). Other work suggests that upper-end contributions from West Antarctica are unlikely (Ritz et al., 2015). The uncertainty in future contributions of the West Antarctic Ice Sheet to sea-level rise is highlighted by two, recent studies. Edwards et al. (2021) show a wide range of model responses, including some where increased snowfall could balance out a warming atmosphere and ocean. Whereas, DeConto et al. (2021) demonstrate a potential order of magnitude increase in global mean sea-level rise within the next 30 years. Untangling these uncertain dynamics, translating the impacts to local contexts, and taking rapid resilience measures are key to saving countless lives and dollars.

Amid this deep uncertainty, building the necessary tools to adapt to sea-level rise requires unprecedented levels of collaboration. Climate services are models and information that aid decision-making on climate change (Hewitt et al., 2012). Seamless climate services can give decision-makers reliable tools to analyze and manage climate risks, both under current hydro-meteorological conditions and in the face of climate variability and change (World Meteorological Organization, 2020). In response to observable climate impacts and advances in modeling capabilities, climate science has slowly expanded to include a major focus on usability and communication (Dilling and Lemos, 2011). Tight integration between scientists and the decision-making community is key to safeguarding populations from climate impacts for three major reasons.

First, scientific understanding of sea-level rise is advancing at a rapid pace. Projections of future sea-level rise have increased substantially (e.g., Siegert et al., 2020; Slater et al., 2021) and these projections will continue to change as scientific understanding rapidly advances. The planet as a physical system is more sensitive than previously thought (Lenton et al., 2019). The IPCC's projections for 2100 under strong warming involve the ice sheets providing less than 1% of their potential contribution (IPCC, 2019). Adapting to sea-level rise clearly needs to be flexible in the face of uncertain and changing projections, posing challenges for decision makers seeking to anticipate, identify, manage, and communicate risks (Ramm et al., 2018a,b). This requires close communication from scientists to policy makers.

Second, projecting regional sea-level faces unique knowledge gaps and requires local information gathering. Relative sea-level change, the local change in the time-average height of the sea-surface above the sea floor, displays complex patterns along coastlines due to land altitude, ocean dynamics, gravitational forces, subsidence, and susceptibility to extreme sea-level events—the combination of tides and storm surges that lead to flooding (Tebaldi et al., 2012; Wahl et al., 2017). For any given location, local sea-level rise may deviate significantly from the global mean. For example, sea-level rise in New York is more than three times the global average (Gornitz et al., 2019). Further, sea-level rise interacts with other changes and there is a need to couple sea-level projections with geomophological, ecological, economic, and population models to provide a more realistic representation of exposure and vulnerability (Kopp et al., 2019). Thus, adaptation planning needs comprehensive, localized information gathering and science which governments must often support and oversee.

Third, policy makers need to work with the science community to ensure the usability of sea-level projections. Governments and policy makers must employ two-way engagement with researchers to ensure that sea-level projections and hazard maps are provided in appropriate formats and contexts. Often, the most useful approaches to summarizing scientific knowledge are not the most useful approaches for public policy decision makers (Kopp et al., 2019).

While collaboration between sea-level researchers and decision-makers poses coordination challenges, the benefits of investing in science are clear. Damage and disruption from natural disasters annually cost at least $390 billion in low- and middle-income countries, but investing in more resilient infrastructure can provide a net benefit of $4.2 trillion (Hallegatte et al., 2019). Similarly, $1 spent on disaster prevention can save $15 in future damages (Healy and Malhotra, 2009). Therefore, developing scientific models to predict and prepare for sea-level rise has distinct economic benefits.

Given the need for greater science-policy interface, how can we achieve these collaborations? Previous scholarship has delved into how to create linkages between science and policy for climate adaptation. For instance, uncertainties in sea-level projections are most useful to decision makers when communicated as ranges (Hinkel et al., 2019). In addition, scientists may adopt a trans-disciplinary iterative approach to ensure that the results of scientific studies are "legitimate, relevant, and credible for coastal stakeholders" (Kopp et al., 2019). Ultimately, efforts must be context-specific, a need that we focus on here.

This paper is written from the perspective of climate scientists, to identify ways that the United Arab Emirates (UAE) can rapidly advance regional sea-level rise research. We aim to identify opportunities for scientists and governments to collaborate on sea-level research, thereby kick-starting discussions around science-policy integration in the newly launched UAE Climate Change Research Network. In doing so, we highlight best practices for regions with significant data gaps, centralized government systems, and newly established research structures. In particular, insights from this paper can be scaled throughout the Arabian Gulf.

We begin by providing context on the scientific gaps and policy landscape of the UAE, in relation to the region. Next, we recommend steps that the UAE can take to build and leverage sea-level science for coastal adaptation. Finally, we discuss linkages between our recommendations and possible next steps.

2. CONTEXT

2.1. Knowledge Gaps in the Arabian Gulf

Sea-level rise is both a global and local issue. The overwhelmingly dominant driver of future flood risk is the melting of land-based ice (IPCC, 2019). The fate of the Antarctic Ice Sheet represents by far and wide the largest uncertainty in future global sea-level rise (Ritz et al., 2015; DeConto and Pollard, 2016; Edwards et al., 2019). In particular, Thwaites Glacier in West Antarctica may have already passed a threshold for a shift to a reduced state that will likely involve more than 3 m of sea-level rise (Alley et al., 2014). However, there is a lack of consensus on the future rate of this change, and unless fundamental observational research is carried out in West Antarctica to address the physical understanding of ice mass change, there is no possibility of ever producing a credible projection of sea-level rise over the coming century.

Global sea-level rise will determine the order of magnitude of sea-level rise, but regional and local sea-level changes can vary substantially from the global mean (Milne et al., 2009). Baseline studies to understand the status of the UAE coastline, to identify vulnerable regions,and to determine the key processes driving shoreline change are an essential first step. There is also much to learn about catastrophic events, such as the large-amplitude seiche that flooded the Iranian cities of Dayyer and Asaluyeh in 2017 (Salaree et al., 2018; Heidarzadeh et al., 2020). However, understanding and responding to local impacts requires suitable datasets. Deficiencies in the availability and quality of datasets for the region prevent rigorous assessment of current changes and further preclude the ability to develop models to understand future change. Alothman et al. (2014) estimated sea-level rise in the western Arabian Gulf during 1979–2007 at 0.22 $\pm$ 0.05 cm/year which is below the global estimate for 1993–2010 (IPCC, 2013, 0.32 cm/year). However, land subsidence caused by groundwater pumping and oil extraction can play a significant role (Alothman et al., 2014, up to 0.07 cm/year in the western Gulf). There is also a lack of information on how the shoreline will change as a result of erosion and accretion. Alothman et al. (2014) showed atmospheric pressure changes of the order of 10 mbar in the Arabian Gulf, which corresponds roughly to an annual variation of 10 cm in sea level (Mathers and Woodworth, 2004). Bold programs are critical to provide the scientific evidence needed to support policy needs across the region.

2.2. The UAE as a Case Study

Within the Arabian Gulf, the UAE is particularly vulnerable to sea-level rise and faces similar knowledge gaps. Much of the low-lying UAE coastline is shallow-sloping (about 35 cm per km) and therefore highly susceptible to potential flooding. With over 85% of the population and more then 90% of the UAE's infrastructure situated within several meters of present-day sea level (Al Ahbabi, 2017), the UAE is susceptible to flooding, erosion, saltwater intrusion, impeded drainage, and change/loss of coastal ecosystems. Two highly developed areas that will be particularly affected by future flooding include the cities of Abu Dhabi and Dubai (**Figure 1**).

Despite climate vulnerabilities and major data gaps, the UAE is particularly suited to science-policy collaborations. Firstly, the UAE is a high-income country with the means and commitment to invest in preventative measures against sea-level rise. Already the UAE has demonstrated its interest in sustainable infrastructure by investing US$16.8 billion in renewable energy ventures across 70 countries, and allocating US$400 million in aid and concessional loans for clean energy projects.[2] Meanwhile, the UAE is able to implement policies with long-term horizons, unconstrained by short political cycles. This is demonstrated by its readiness to take upon agendas that set the future trajectory of the nation, such as the Environment Vision of 2030 as well as the UAE's Centennial Vision of 2071, both of which pursue sustainable and, most of all, efficient systems. Finally, part of the UAE's vision is to transition from an oil-based to knowledge-based economy. In doing so, the nation positions itself to build up its scientific capacity in order to lead regional sea-level science, a trajectory that places the UAE at the forefront of scientific research while prioritizing the cultivation of human capital and scientific discourse. Thus, the UAE presents a unique landscape for the progression of climate research and development.

The UAE's approach to climate adaptation has been defined by several developments. In 2006, the UAE established the Ministry of Environment and Water. Among many responsibilities, the Ministry oversaw issues related to climate change, food and water security, and agriculture.[3] However, it should be acknowledged that much of the UAE's research into sea-level rise has been also conducted by private contractors and semi-private entities. A prominent example of such a case is Nakheel, a property developer responsible for the development of the famous Palm Islands. Upon construction, Nakheel was required to assess the longevity of the Palm Island project and dispute allegations of the possibility of a failed project due to sea-level rise.[4] Similarly, there are numerous cases where private firms have contributed, to an extent, toward climate change research to solve the various context-specific issues they respectively faced. A major reason for this is that the UAE has developed at exceptional speed, learning to adapt and reshape in response to a dynamic global context. As Feary et al. (2013) and Burt and Bartholomew (2019) observe, this rapid development sometimes meant that swiftness superseded diligence . As the nation built up its own technical capacity, much of this research was sub-contracted

[2]https://www.moccae.gov.ae/en/media-center/news/30/12/2020/uae-announces-ambitious-climate-commitments-as-part-of-second-nationally-determined-contribution.aspx#page=1 (accessed 23 Jan 2021).

[3]https://www.moccae.gov.ae/en/about-ministry/about-the-ministry.aspx (accessed 21 Jan 2021).

[4]https://www.thenationalnews.com/business/property/palm-is-not-sinking-says-nakheel-1.498047.aspx (accessed 23 Jan 2021).

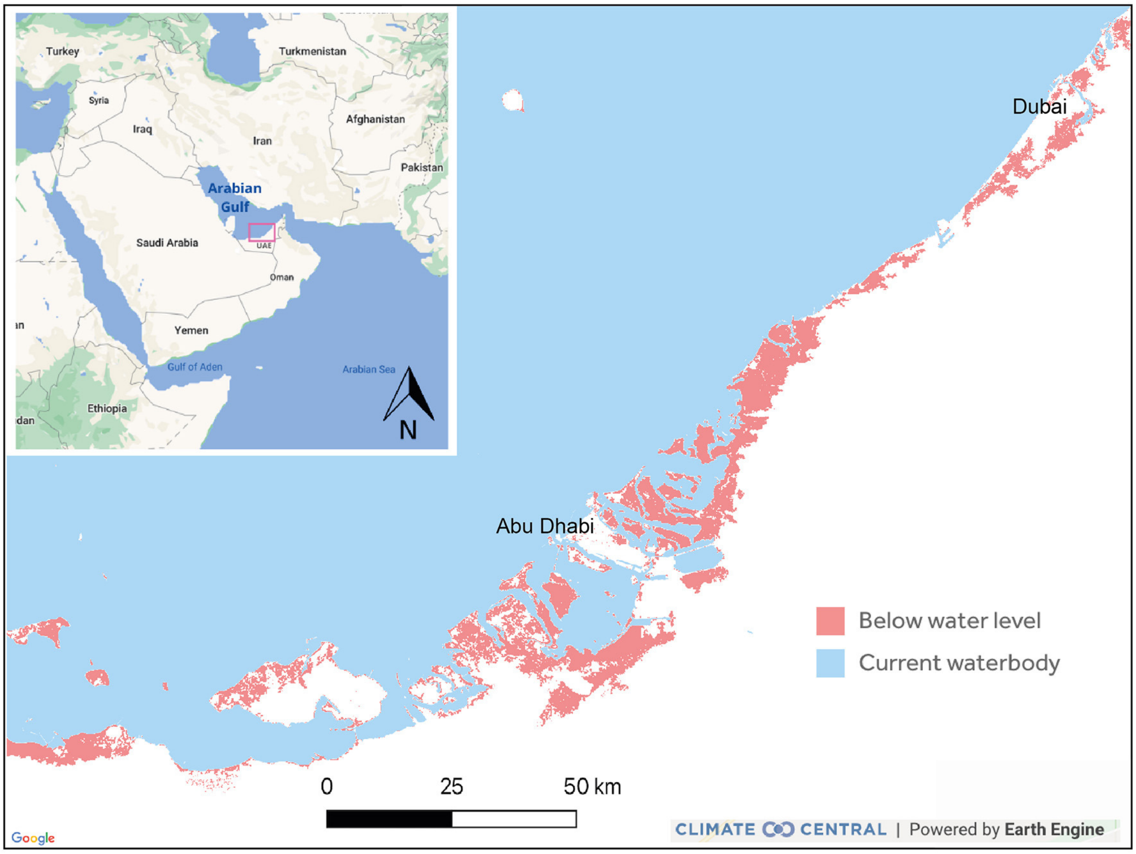

FIGURE 1 | Extent of projected Sea-Level Rise for two major cities in the UAE from Climate Central CoastalDEM (Kulp and Strauss, 2019). Red shading shows regions expected to experience flooding by 2100 under a moderate 2° Celsius warming scenario (RCP 4.5) and a Kopp et al. (2014) mid-range projection.

to consultants from outside of the region who may not have familiarity with the local environment, data sources or cultural context for decision-making.

However, the past 5 years triggered a paradigm shift in policy-making, in which a swift approach was no longer suitable. In 2016, in order to ensure a more specific policy-making approach that would do justice to the most pressing issues, the UAE announced the establishment of a dedicated Ministry of Climate Change and Environment. Shortly after, the country announced the appointment of the Minister of Food and Water Security, highlighting the country's intention to foster more stable food and water systems. This is reflected through the trajectory of government-led initiatives. For instance, the Ministry of Climate Change and Environment conducted four sector-specific climate risk assessment reports in 2019, and took stock of national climate science in a State of the Climate Report in 2020. These national bodies oversee sub-national agencies that have collected much of the country's environmental data and have conducted climate research.

Furthermore, the COVID-19 pandemic has crystallized such sentiments, as the UAE was exposed to vulnerabilities that have been echoed in its history yet overlooked by its dynamic present. The novel pandemic temporarily threatened the provision of goods in the UAE.[5] Being exposed to such vulnerability allowed the UAE to question and enhance existing systems. As such, the UAE is now prioritizing mending the gap between science and policy, a gap that becomes costlier as variability around the world increases. The UAE aims to leverage its current infrastructure, industries, academic networks, and policy acumen in order to propagate regenerative systems that can create a more circular economy.

If the UAE is successful at leveraging its potential to lead in collaborative sea-level science, the lessons it develops can transcend its borders. Firstly, neighboring countries along the Arabian Gulf face a similar major sea-level risk for which regional data sets and models developed in the UAE can provide crucial information. Meanwhile, lessons can be shared across the region. Coordination between the eight nations bordering the Arabian Gulf is paramount to understanding and addressing the environmental pressures facing this shared body of water (Sale et al., 2011; Van Lavieren et al., 2011). Abdulla and Naser (2021) found that developing a system of understanding between those governing and benefiting from the marine environment is

[5]https://www.khaleejtimes.com/coronavirus-pandemic/UAE-has-learnt-from-Covid-to-boost-food-security-Sheikh-Mohammed--.aspx (accessed 23 Jan 2021).

a key component in addressing growing marine environmental challenges in Bahrain. Similarly, McEvoy et al. (2021) highlight that sharing approaches and experiences across countries can help vulnerable nations plan for adaptation. The globe is simultaneously navigating the uncertainty of sea-level rise, which demonstrate the necessity for countries similar to the UAE to participate and be a part of the frontier. As the UAE continues to build and establish a knowledge-based economy and gathers researchers from its universities to develop sea-level projections and science-based adaptation policies, the Gulf can become a standard bearer for coastal cities around the world.

Moreover, tackling climate change is multifaceted. As demonstrated by Hummel et al. (2020), it is not enough to understand risk—interactions between adaptation measures and infrastructure networks can have surprising results on the overall impact on the system. In addition, policy plays an interconnected and integral role in determining the success of implementation and strategy. Instead of assuming the exclusivity of science in tackling sea-level rise challenges, it would be advantageous to take into account the development and implementation of policy within a country.

The UAE can position itself to be one of the first in the region to properly understand the nexus of academia, industry, and government, which transcends the country's contribution beyond coastal cities of similar topographies. Already, the Gulf is demonstrating new appetite for communication and collaboration between the science, regulatory and policy communities for the purposes of understanding and addressing environmental challenges. For example, ecosystem-based management approaches that require integration of perspectives across these stakeholders are increasingly being employed in the region (Fanning et al., 2021; Mateos-Molina et al., 2021). By pursuing scientifically informed coastal management, the UAE can spur a dialectical approach of research and development, which will help in tackling many other challenges that require the conjoint effort of science and policy.

3. PATHWAYS FORWARD

The following recommendations are synthesized from ideas collected from consultations with the climate science community within the UAE, on how to drive sea-level research forward. The suggestions are aimed at generating discussions to shape future support and interactions between science and policy stakeholders. While the recommendations emerged with a focus on the UAE and sea-level science, they are largely applicable to research throughout the Arabian Gulf on broader environment or climate issues.

3.1. Science and Policy Coordination

1. Build trust between government and the research community by pursuing the following initiatives:

   (a) Draw scientists and government together in conferences and forums to integrate impacts and adaptation options following best practice (e.g., Haasnoot et al., 2020), and to identify research priorities. For instance, the Gulf Environment Conference can continue to demonstrate the impact of research and the benefits of cooperating with the research community, including with industry and international partners.

   (b) Build a scientific collective voice to highlight cutting edge scientific concerns. For instance, the Mohammed Bin Rashid Academy of Scientists[6] can emulate the US National Academy of Scientists model, to provide a forum for leading experts to promote key scientific issues.

2. Invest in the next generation of scientists by providing research opportunities to youth and establishing graduate programs in environmental science. There are currently few graduate-level environmental science programs, which stymies the growth of technical capacity in the local citizenry (Sale et al., 2011). Capacity building is essential to achieve sustained observations that meet internationally-agreed standards; these observations can in turn be transformed into information that can support decision making (Miloslavich et al., 2018).

3.2. Data Collection and Sharing

1. Pursue Gulf-wide campaigns for data collection. To date, only five Gulf-wide campaigns have taken place in 1965, 1977 (Al-Yamani and Naqvi, 2019), 1992 (Reynolds, 1993), 1998 (Yoshida et al., 1998), 2000, 2001, and 2006 (Polikarpov et al., 2016), with no Gulf-wide observations after 2006. A 2018–2019 campaign collected data across the northern Arabian Gulf (Saleh et al., 2021). These datasets are not readily available to the research and management community—to date, researchers in the UAE have not been able to access data post-1998.
2. Streamline approval processes and requirements for scientific data collection by pursuing the following:

   (a) Facilitate the import and export of scientific equipment for environmental measurements.

   (b) Fast-track systems for approving fieldwork (including licensing information).

3. Create a national data archive of ocean, land, and atmospheric measurements. Such an archive could be extended to potentially host Gulf-wide datasets as part of the Regional Organization for the Protection of the Marine Environment (ROPME[7]). The archive should:

   (a) Evaluate existing data, and unless it poses serious security concerns, make it available to the public. In addition, encourage the sharing of new data collected, excluding any appropriate embargo.

   (b) Follow best practice principles of Findability, Accessibility, Interoperability, and Reusability (Wilkinson et al., 2016) to maximise reuse of data.

[6]https://mbras.ae/ (accessed 2 Feb 2021).
[7]http://ropme.org/home.clx (accessed 2 Feb 2021).

4. Require local research on climate impacts and preparedness to be published as open-access articles and provide funding support to do so.

3.3. Funding and Cost Savings

1. Build a public inventory to facilitate the sharing of instruments, equipment and computing resources between universities, research entities, and local agencies.
2. Link research labs with private sector partners, such as real-estate developers, to fund relevant research. In addition, recognize open-access research funded by companies as corporate social responsibility.
3. Launch a competitive national funding program for technical research on priority areas, and require public level communication of results by researchers. Use this program to prioritize continuous data sampling to build up time-series.
4. Expand upon ROPME to coordinate funding for regional climate measurements in the Arabian Gulf.
5. Collaborate on in-kind multinational projects to efficiently participate in regional and global data gathering. Some of the most challenging and important scientific questions require resources that no one country can provide and multinational projects can spread these costs. For instance, Antarctic expeditions share logistic and data collection costs. To ensure that the UAE has the boundary conditions needed to understand how future sea-level rise will impact coastal communities, consider collaborating on the following major initiatives:

   (a) Establish the first National Antarctic Research Program in the Middle East, to coordinate research with global leaders in the field (e.g., USA, UK, China, Russia, Australia, and South Korea).
   (b) Invest in a Polar Class 1 icebreaker to facilitate critical sea-level research in the waters surrounding Antarctica.
   (c) Set up a year-round research outpost in Antarctic to facilitate continuous observations of sea-level change.

4. DISCUSSION

While we aim to separate out themes in our recommendations, many of them are interconnected. For instance, a regional funding program could support capacity building at a shared cost throughout the region. In addition, data co-production and sharing are fundamental tools of capacity building. A national funding program could target priority research questions that are needed to drive sustainable policy decisions and require that data and publications are made publicly available to further future research.

These recommendations range from small and immediate (sharing scientific equipment between research entities) to long-term and global (entering the Antarctic science arena). Significant financial commitments are needed for research, observations, information products, literacy and science policy interactions at both national and regional levels. Sea-level science across the globe is lacking vital understanding of how fast ice sheets will melt and these questions call for international commitment. The United Nations Decade of Ocean Science for Sustainable Development 2021–2030 (Ryabinin et al., 2019), a global effort to create collaborations across disciplines, geographies and generations, provides an ideal opportunity to launch observation programs to fill the regional data gaps.

Climate services are being developed at an ever-increasing rate across the world (Hewitt et al., 2020). Comparatively, climate services for the Arabian Gulf are constrained by a short record of scientific measurements and limited protocols for data collection. Yet, the nascent nature of climate research in the region also provides a clean slate to build upon, with best practices. The Gulf can pursue a demand-driven, trans-disciplinary, data-informed approach to tackle sea-level rise and other climate-related risks (Lourenço et al., 2016).

The UAE is no stranger to investing in ambitious science questions, for example, the development of the Mohammed Bin Rashid Space Center and its Mars Mission, Hope Probe (Extance, 2014). By committing to regional and international collaborations, the UAE can leverage in-kind funding and obtain the data needed to base future sea-level projections. Subsequently, the UAE Climate Change Research Network can provide a strategic building block to bring together scientists and policy makers and develop climate services for coastal adaptation. Ensuring the involvement of the beneficiaries of climate services leads to better-informed decision-making (Hewitt et al., 2020). Sustained communication between researchers and decision makers will be key to delivering seamless integration of climate knowledge into policy decisions for the UAE.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

HM-R coordinated the research project and is the primary author. CE supported the research process and is the primary contributor to section 2.1. NA is the primary contributor to section 2.2. All authors participated in rounds of discussions to shape section 3, and provided feedback on drafts of the manuscript and responses to reviewers' comments.

FUNDING

This work was supported by the Center for global Sea Level Change (CSLC) of NYU Abu Dhabi Research Institute (G1204) in the UAE. Funding to JB was provided by the NYU Abu Dhabi Water Research Center grant (project CG007).

ACKNOWLEDGMENTS

Special thanks is due to the UAE Ministry of Climate Change and Environment for launching the Climate Change Research Network, which inspired this collaboration. We thank Philip Rodenbough and the Scientific Writing Program at NYU Abu Dhabi for insightful feedback and proofreading.

REFERENCES

Abdulla, K. H., and Naser, H. A. (2021). Protection of marine environmental quality in the Kingdom of Bahrain. *Ocean Coastal Manag.* 203:105520. doi: 10.1016/j.ocecoaman.2021.105520

Al Ahbabi, F. (2017). Department of Urban Planning and Municipalities. Plan Maritime: Abu Dhabi coastal and marine framework plan. Abu Dhabi, p. 238.

Alley, R. B., Anandakrishnan, S., Christianson, K., Horgan, H. J., Muto, A., Parizek, B. R., et al. (2014). Oceanic forcing of ice-sheet retreat: west antarctica and more. *Ann. Rev. Earth Planet. Sci.* 43, 1–25. doi: 10.1146/annurev-earth-060614-105344

Alothman, A., Bos, M., Fernandes, R., and Ayhan, M. (2014). Sea level rise in the north-western part of the Arabian Gulf. *J. Geodynamics* 81, 105–110. doi: 10.1016/j.jog.2014.09.002

Al-Yamani, F., and Naqvi, S. W. (2019). Chemical oceanography of the Arabian Gulf. *Deep Sea Res. II Top. Stud. Oceanogr*. 161, 72–80. doi: 10.1016/j.dsr2.2018.10.003

Bamber, J. L., Oppenheimer, M., Kopp, R. E., Aspinall, W. P., and Cooke, R. M. (2019). Ice sheet contributions to future sea-level rise from structured expert judgment. *Proc. Natl. Acad. Sci. U.S.A*. 116, 11195–11200. doi: 10.1073/pnas.1817205116

Burt, J. A., and Bartholomew, A. (2019). Towards more sustainable coastal development in the Arabian Gulf: opportunities for ecological engineering in an urbanized seascape. *Marine Pollut. Bull.* 142, 93–102. doi: 10.1016/j.marpolbul.2019.03.024

DeConto, R. M., and Pollard, D. (2016). Contribution of Antarctica to past and future sea-level rise. *Nature* 531, 591–597. doi: 10.1038/nature17145

DeConto, R. M., Pollard, D., Alley, R. B., Velicogna, I., Gasson, E., Gomez, N., et al. (2021). The Paris Climate Agreement and future sea-level rise from Antarctica. *Nature* 593, 83–89. doi: 10.1038/s41586-021-03427-0

Dilling, L., and Lemos, M. C. (2011). Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. *Glob. Environ. Change* 21, 680–689. doi: 10.1016/j.gloenvcha.2010.11.006

Edwards, T. L., Brandon, M. A., Durand, G., Edwards, N. R., Golledge, N. R., Holden, P. B., et al. (2019). Revisiting Antarctic ice loss due to marine ice-cliff instability. *Nature* 566, 58–64. doi: 10.1038/s41586-019-0901-4

Edwards, T. L., Nowicki, S., Marzeion, B., Hock, R., Goelzer, H., Seroussi, H., et al. (2021). Projected land ice contributions to twenty-first-century sea level rise. *Nature* 593, 74–82. doi: 10.1038/s41586-021-03302-y

Extance, A. (2014). UAE fires up space agency with Mars mission. *Phys. World* 27, 11–11. doi: 10.1088/2058-7058/27/11/19

Fanning, L. M., Al-Naimi, M. N., Range, P., Ali, A.-S. M., Bouwmeester, J., Al-Jamali, F., et al. (2021). Applying the ecosystem services-EBM framework to sustainably manage Qatar's coral reefs and seagrass beds. *Ocean Coastal Manag*. 205:105566. doi: 10.1016/j.ocecoaman.2021.105566

Feary, D. A., Burt, J. A., Bauman, A. G., Al Hazeem, S., Abdel-Moati, M. A., Al-Khalifa, K. A., et al. (2013). Critical research needs for identifying future changes in gulf coral reef ecosystems. *Mar. Pollut. Bull.* 72, 406–416. doi: 10.1016/j.marpolbul.2013.02.038

Gornitz, V., Oppenheimer, M., Kopp, R., Orton, P., Buchanan, M., Lin, N., et al. (2019). New York city panel on climate change 2019 report chapter 3: sea level Rise. *Ann. N.Y. Acad. Sci*. 1439, 71–94. doi: 10.1111/nyas.14006

Haasnoot, M., Biesbroek, R., Lawrence, J., Muccione, V., Lempert, R., and Glavovic, B. (2020). Defining the solution space to accelerate climate change adaptation. *Reg. Environ. Change* 20:37. doi: 10.1007/s10113-020-01623-8

Hallegatte, S., Rentschler, J., and Rozenberg, J. (2019). "Sustainable Infrastructure," in *Lifelines* : *The Resilient Infrastructure Opportunity*. Washington, DC: World Bank.

Hastings, R. A., Rutterford, L. A., Freer, J. J., Collins, R. A., Simpson, S. D., and Genner, M. J. (2020). Climate change drives poleward increases and equatorward declines in marine species. *Curr. Biol.* 30, 1572.e2–1577.e2. doi: 10.1016/j.cub.2020.02.043

Healy, A., and Malhotra, N. (2009). Myopic voters and natural disaster policy. *Am. Pol. Sci. Rev*. 103, 387–406. doi: 10.1017/S0003055409990104

Heidarzadeh, M., Šepić, J., Rabinovich, A., Allahyar, M., Soltanpour, A., and Tavakoli, F. (2020). Meteorological Tsunami of 19 March 2017 in the Persian Gulf: observations and analyses. *Pure Appl. Geophys*. 177, 1231–1259. doi: 10.1007/s00024-019-02263-8

Hewitt, C., Mason, S., and Walland, D. (2012). The global framework for climate services. *Nat. Clim. Change* 2, 831–832. doi: 10.1038/nclimate1745

Hewitt, C. D., Allis, E., Mason, S. J., Muth, M., Pulwarty, R., Shumake-Guillemot, J., et al. (2020). Making society climate resilient: international progress under the global framework for climate services. *Bull. Am. Meteorol. Soc*. 101, E237–E252. doi: 10.1175/BAMS-D-18-0211.A

Hinkel, J., Church, J. A., Gregory, J. M., Lambert, E., Le Cozannet, G., Lowe, J., et al. (2019). Meeting user needs for sea level rise information: a decision analysis perspective. *Earths Future* 7, 320–337. doi: 10.1029/2018EF001071

Hummel, M. A., Siwe, A. T., Chow, A., Stacey, M. T., and Madanat, S. M. (2020). Interacting infrastructure disruptions due to environmental events and long-term climate change. *Earths Future* 8:e2020EF001652. doi: 10.1029/2020EF001652

IPCC (2013). "Climate Change 2013: The Physical Science Basis," in *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. (Cambridge, UK; New York, NY: Cambridge University Press)

IPCC (2019). *Special Report on the Ocean and Cryosphere in a Changing Climate*. Available online at:https://www.ipcc.ch/site/assets/uploads/sites/3/2019/12/SROCC_FullReport_FINAL.pdf.

Kopp, R. E., Gilmore, E. A., Little, C. M., Lorenzo-Trueba, J., Ramenzoni, V. C., and Sweet, W. V. (2019). Usable science for managing the risks of sea-level rise. *Earths Future* 7, 1235–1269. doi: 10.1029/2018EF001145

Kopp, R. E., Horton, R. M., Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., et al. (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earths Future* 2, 383–406. doi: 10.1002/2014EF000239

Kulp, S. A., and Strauss, B. H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nat. Commun*. 10:4844. doi: 10.1038/s41467-019-12808-z

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S., et al. (2008). Tipping elements in the earth's climate system. *Proc. Natl. Acad. Sci. U.S.A*. 105, 1786–1793. doi: 10.1073/pnas.0705414105

Lenton, T. M., Rockstrm, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., et al. (2019). Climate tipping points too risky to bet against. *Nature* 575, 592–595. doi: 10.1038/d41586-019-03595-0

Lourenço, T. C., Swart, R., Goosen, H., and Street, R. (2016). The rise of demand-driven climate services. *Nat. Clim Change* 6, 13–14. doi: 10.1038/nclimate2836

Mateos-Molina, D., Ben Lamine, E., Antonopoulou, M., Burt, J., Das, H., Javed, S., et al. (2021). Synthesis and evaluation of coastal and marine biodiversity spatial information in the United Arab Emirates for ecosystem-based management. *Mar. Pollut. Bull*. 167:112319. doi: 10.1016/j.marpolbul.2021.112319

Mathers, E. L., and Woodworth, P. L. (2004). A study of departures from the inverse-barometer response of sea level to air-pressure forcing at a period of 5 days. *Q. J. R. Meteorol. Soc*. 130, 725–738. doi: 10.1256/qj.03.46

McEvoy, S., Haasnoot, M., and Biesbroek, R. (2021). How are European countries planning for sea level rise? *Ocean Coastal Manag*. 203:105512. doi: 10.1016/j.ocecoaman.2020.105512

Milne, G. A., Gehrels, W. R., Hughes, C. W., and Tamisiea, M. E. (2009). Identifying the causes of sea-level change. *Nat. Geosci*. 2, 471–478. doi: 10.1038/ngeo544

Miloslavich, P., Seeyave, S., Muller-Karger, F., Bax, N., Ali, E., Delgado, C., et al. (2018). Challenges for global ocean observation: the need for increased human capacity. *J. Operat. Oceanogr*. 12(Suppl. 2):S137–S156. doi: 10.1080/1755876X.2018.1526463

Polikarpov, I., Saburova, M., and Al-Yamani, F. (2016). Diversity and distribution of winter phytoplankton in the Arabian Gulf and the Sea of Oman. *Continental Shelf Res*. 119, 85–99. doi: 10.1016/j.csr.2016.03.009

Ramm, T. D., Watson, C. S., and White, C. J. (2018a). Describing adaptation tipping points in coastal flood risk management. *Comput. Environ. Urban Syst*. 69, 74–86. doi: 10.1016/j.compenvurbsys.2018.01.002

Ramm, T. D., Watson, C. S., and White, C. J. (2018b). Strategic adaptation pathway planning to manage sea-level rise and changing coastal flood risk. *Environ. Science Policy* 87, 92–101. doi: 10.1016/j.envsci.2018.06.001

Reynolds, R. M. (1993). Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman Results from the Mt Mitchell expedition. *Mar. Pollut. Bull*. 27, 35–59. doi: 10.1016/0025-326X(93)90007-7

Ritz, C., Edwards, T. L., Durand, G., Payne, A. J., Peyaud, V., and Hindmarsh, R. C. A. (2015). Potential sea-level rise from Antarctic ice-sheet instability constrained by observations. *Nature* 528, 115–118. doi: 10.1038/nature16147

Ryabinin, V., Barbire, J., Haugan, P., Kullenberg, G., Smith, N., McLean, C., et al. (2019). The UN decade of ocean science for sustainable development. *Front. Mar. Sci*. 6:470. doi: 10.3389/fmars.2019.00470

Salaree, A., Mansouri, R., and Okal, E. A. (2018). The intriguing tsunami of 19 march 2017 at bandar dayyer, iran: field survey and simulations. *Nat. Hazards* 90, 1277–1307. doi: 10.1007/s11069-017-3119-5

Sale, P. F., Feary, D. A., Burt, J. A., Bauman, A. G., Cavalcante, G. H., Drouillard, K. G., et al. (2011). The growing need for sustainable ecological management of marine communities of the persian Gulf. *AMBIO* 40, 4–17. doi: 10.1007/s13280-010-0092-6

Saleh, A., Abtahi, B., Mirzaei, N., Chen, C.-T. A., Ershadifar, H., Ghaemi, M., et al. (2021). Hypoxia in the persian Gulf and the strait of hormuz. *Mar. Pollut. Bull*. 167, 112354. doi: 10.1016/j.marpolbul.2021.112354

Siegert, M., Alley, R. B., Rignot, E., Englander, J., and Corell, R. (2020). Twenty-first century sea-level rise could exceed IPCC projections for strong-warming futures. *ONE Earth* 3, 691–703. doi: 10.1016/j.oneear.2020.11.002

Slater, T., Lawrence, I. R., Otosaka, I. N., Shepherd, A., Gourmelen, N., Jakob, L., et al. (2021). Review article: earth's ice imbalance. *Cryosphere* 15, 233–246. doi: 10.5194/tc-15-233-2021

Tebaldi, C., Strauss, B. H., and Zervas, C. E. (2012). Modelling sea level rise impacts on storm surges along US coasts. *Environ. Res. Lett*. 7:014032. doi: 10.1088/1748-9326/7/1/014032

Trewin, B., Cazenave, A., Howell, S., Huss, M., Isensee, K., Palmer, M. D., et al. (2020). Headline indicators for global climate monitoring. *Bull. Am. Meteorol. Soc*. 102, E20–E37. doi: 10.1175/BAMS-D-19-0196.1

Van Lavieren, H., Burt, J., Feary, D., Cavalcante, G., Marquis, E., Benedetti, L., et al. (2011). *Managing the Growing Impacts of Development on Fragile Coastal and Marine Ecosystems: Lessons From the Gulf*. Technical Report, United Nations University.

Wahl, T., Haigh, I. D., Nicholls, R. J., Arns, A., Dangendorf, S., Hinkel, J., et al. (2017). Understanding extreme sea levels for broad-scale coastal impact and adaptation analysis. *Nat. Commun*. 8:16075. doi: 10.1038/ncomms16075

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., et al. (2016). The FAIR guiding principles for scientific data management and stewardship. *Sci. Data* 3, 160018. doi: 10.1038/sdata.2016.18

World Meteorological Organization (2021). *State of the Global Climate 2020*. Technical report, World Meteorological Organization.

World Meteorological, O.rganization, (2020). *2020 State of Climate Services*. Technical report, World Meteorological Organization.

Yoshida, J., Matsuyama, M., Senjyu, T., Ishimaru, T., Morinaga, T., Arakawa, H., et al. (1998). "Hydrography in the RSA during the RT/V Umitaka-Maru cruises," in *Offshore Environment of ROPME Sea Area after the War-related Oil Spill*, Tokyo. 1–22.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2021 Melville-Rea, Eayrs, Anwahi, Burt, Holland, Samara, Paparella, Al Murshidi, Al-Shehhi and Holland. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.