Climate impact assessment and "islandness"

Challenges and opportunities of knowledge production and decision-making for Small Island Developing States

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Abstract

Purpose – Climate data, including historical climate observations and climate model outputs, are often used in climate impact assessments, to explore potential climate futures. However, characteristics often associated with "islandness", such as smallness, land boundedness and isolation, may mean that climate impact assessment methods applied at broader scales cannot simply be downscaled to island settings. This paper aims to discuss information needs and the limitations of climate models and datasets in the context of small islands and explores how such challenges might be addressed.

Design/methodology/approach – Reviewing existing literature, this paper explores challenges of islandness in top-down, model-led climate impact assessment and bottom-up, vulnerability-led approaches. It examines how alternative forms of knowledge production can play a role in validating models and in guiding adaptation actions at the local level and highlights decision-making techniques that can support adaptation even when data is uncertain.

Findings – Small island topography is often too detailed for global or even regional climate models to resolve, but equally, local meteorological station data may be absent or uncertain, particularly in island peripheries. However, rather than viewing the issue as decision-making with big data at the regional/global scale versus with little or no data at the small island scale, a more productive discourse can emerge by conceptualising strategies of decision-making with unconventional types of data.

Originality/value – This paper provides a critical overview and synthesis of issues relating to climate models, data sets and impact assessment methods as they pertain to islands, which can benefit decision makers and other end-users of climate data in island communities.

Keywords Decision-making, Climate change, Uncertainty, Islands, Climate models

Paper type Conceptual paper

1. Introduction

It is widely recognised that Small Island Developing States (SIDS) are among the most vulnerable to the effects of climate change (Betzold, 2015; Wang *et al.*, 2016). The Alliance of Small Island States (AOSIS) has argued that climate change negotiations should aim to hold global warming below 1.5°C (Wong, 2011). The Paris Agreement reflects growing support for this limit, with governments agreeing to hold the increase

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"well below" the 2°C threshold while "pursuing efforts" to keep within 1.5°C of warming relative to pre-industrial levels. An IPCC special report on global warming of 1.5°C is in preparation, which will address the vulnerabilities of islands and coastal areas in particular. Limiting warming to 1.5°C would reduce risks to fishery sustainability (Cheung *et al.*, 2016) and coral reefs (Schleussner *et al.*, 2016) and modelling suggests that the 1.5°C target is feasible if a temperature overshoot is allowed and large, early reductions in emissions are made (Su *et al.*, 2017). However, under Intended Nationally Determined Contributions (INDCs) as of 2016, a median warming of at least 2.6°C is anticipated by 2100 (Rogelj *et al.*, 2016). Furthermore, even under an agreement of zero emissions, inertia in the climate system commits us to further sea level rise, as much as 2.3 m per degree of warming within the next 2,000 years (Levermann *et al.*, 2013).

Methods used in global and regional climate impact assessments to assess climate change risks are poorly suited to SIDS and, especially, atoll countries, given the fundamental mismatches in the spatial scales of knowledge creation and decision-making/action. Equally, reliance on global-scale models combined with uncertainties associated with local climate impacts may obscure opportunities for adaptation as relevance and credibility of information can act as a barrier to decision-making (Moser and Ekstrom, 2010). Understanding the capacities and limitations of typical data sources used in impacts assessment is, therefore, paramount if we are to ensure that suitable information and decision-making techniques are available to support adaptation and minimize maladaptation, in island contexts.

A single, coherent definition of "islandness" is elusive. Characteristics such as isolation and peripherality are often cited; yet, island communities can be highly integrated with the mainland and the rest of the world (Grydehøj and Hayward, 2014), making them at once both open and closed (Pugh, 2016). Hay (2013) noted that characteristics such as isolation, remoteness and containment could also apply to continental locations and argued more specifically the importance of the sea in defining islandness, particularly as the source of boundedness. It has also been contended that islandness is a metaphysical sensation that arises from physical isolation (Conkling, 2007), with Hay (2006) noting the enhanced sense of place that is often associated with islands. Similarly, Taglioni (2011) distinguished between insularity as a physical feature of certain spaces and islandness as the aggregate experiences of islanders. As such, while this paper is concerned predominantly with the confluence of assumed particular physical characteristics of islands, such as smallness, land boundedness, isolation and fragmentation (Fernandes and Pinho, 2017) and the challenges these pose to climate impact assessment, it recognises that these characteristics are neither exclusive to islands nor do they amount to a comprehensive definition of "islandness".

Arguably, while smallness and land boundedness pose the technical challenge to climate modelling, the isolation and fragmentation of islands are associated with further knowledge gaps relating to observed environmental and vulnerability data, leading to a sub-optimal decision-making basis for managing climate risk, if we rely on conventional data sources alone. This paper explores these challenges of islandness in both top-down, model-led forms of climate impact assessment and bottom-up, vulnerability-led approaches. It examines the role that alternative forms of knowledge production can play in validating models, where they can match the scale of island decision-making and in guiding adaptation actions at the local level and highlights decision-making techniques that can support adaptation even when data is uncertain.

2. Perceptions of climate risk in Small Island Developing States

Risks posed to SIDS by climate change include food insecurity (Barnett, 2011), water resource issues (Dore and Singh, 2013) and a range of human health impacts (McIver *et al.*, 2016). The majority of recent extinctions have occurred on islands (Courchamp *et al.*, 2014) and the threats posed by climate change to biodiversity take on a particular urgency in light of the high levels of endemism among island species (Wetzel *et al.*, 2012). In the Republic of Kiribati and in Tuvalu, migration from rural peripheral islands to urban central islands is already being attributed, in part, to climate change, coupled with socio-economic factors (Locke, 2009). In the short-term, as rural island populations relocate to urban areas, access to housing, employment and services needs to be considered to ensure positive outcomes for those migrating (Birk and Rasmussen, 2014). In the longer-term, islanders may be faced with losing their entire territory to the sea, which would raise highly complex issues relating to sovereignty and citizenship status (Skillington, 2017; Yamamoto and Esteban, 2010) and how to preserve the "lived values" of islands (Graham *et al.*, 2013).

Community-based adaptation projects have highlighted the potential for people to be highly perceptive of and attuned to their local environment yet be unaware of the threats climate change poses within that environment (Dumaru, 2010). In part, this stems from the reality that climate change is but one issue facing SIDS (Kelman, 2014). For example, in a case study of Funafuti, Tuvalu, McCubbin *et al.* (2015) found that people were more concerned about food, water and overcrowding than climate change. Yet, there is clear potential for climate change to influence these issues, potentially exacerbating or diminishing them.

Perception and awareness of climate change and its impacts can, thus, act as a barrier to climate adaptation (Betzold, 2015). For example, in a survey of students at the University of the South Pacific, Scott-Parker *et al.* (2017) found that a majority of the respondents believed climate change risks to be overstated, which may reflect a lack of trust in scientific sources of information among a cohort that may include future regional leaders.

Empirical data have a role to play in raising awareness of impacts among communities that underestimate the effects of climate change and in defining the local scale and scope of impacts, to assist where decision-making is impeded by the perceived magnitude of the issue. Co-learning approaches, which use both local and external scientific knowledge, may help to expand community understanding of climate change, but the scope to implement such approaches is limited where fine-grained, long-term data relating to the full range of impact-relevant climate parameters is unavailable or uncertain. As noted by McCubbin *et al.* (2015), the information provided by climate models generally refers to temperature and sea level change across broad regions and, as such, provides little insight into the specific concerns of a small island community. The following section will explore the technical limitations that give rise to this information gap.

3. "Islandness" in climate impact assessment

3.1 Scale and downscaling in climate modelling

Many climate impact assessments typically follow a sequential, top-down, model-led approach (Moss *et al.*, 2010), which could also be referred to as a "predict then act" approach (Dessai *et al.*, 2009). Socio-economic scenarios inform emissions scenarios, which in turn are used to produce radiative forcing scenarios. These radiative forcing scenarios are used to run climate models and climate model outputs such as temperature, precipitation and soil moisture are ultimately used as the inputs to impact models used to assess risks and vulnerabilities, often for a specific sector. For instance, the Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP) involved global impact models for

water, agriculture, biomes, coastal infrastructure and malaria (Warszawski *et al.*, 2014), but within most sectors, there are multiple impacts models to consider also (e.g. water resources; Schewe *et al.*, 2014).

Given the central role of climate models in these types of impact assessment, it is important to consider their suitability and limitations as they pertain to islands. The state-of-the-art atmosphere–ocean General Circulation Models (GCMs) used in the Coupled Model Intercomparison Project 5 (CMIP5; Taylor *et al.*, 2011) varies in resolution, but the average is $\sim$1.85 $\times$ 2.25° [1]. For reference, at the Equator, 1° corresponds to $\sim$111 km. The small surface area of many islands, together with their land boundedness, means that the grid cells corresponding to their location are likely to be classed as ocean in the model. Furthermore, as noted by Fernandes and Pinho (2017), island geomorphology may vary greatly across a small surface area, with volcanic islands such as Hawaii showing particularly large variations in altitude and, correspondingly, in bioclimatic conditions, little, if any, of which can be captured in a GCM.

Downscaling approaches can be used to address, in part, the scale mismatch. Regional climate models (RCMs) are a form of dynamical downscaling, in which GCM outputs are "regionalised" by a model operating at a higher resolution over a limited area. Figure 1 illustrates the effect that enhancing resolution can have on land surface representation.

The Providing Regional Climates for Impacts Studies (PRECIS)-Caribbean initiative has led to significant modelling capacity and localised climate information in the Caribbean region (Taylor *et al.*, 2013). The coordinated regional downscaling experiment (CORDEX) South Asia RCM simulations use an ensemble of different models and have a spatial resolution of 0.44° ($\sim$50 km) (Ghimire *et al.*, 2015), which is high resolution relative to GCMs. Statistical downscaling, a less computationally expensive method, in which local climate parameters are related to large-scale modelled variables, can also be applied. In the USA, statistical downscaling has been used to generate climate scenarios at 1/8° ($\sim$14 km) (Ahmed *et al.*, 2013).

However, in the case of SIDS, these methods can only bridge part of the gap and may come with additional uncertainty. Enhanced resolution is not a guarantee of reliable information. Centella-Artola *et al.* (2015) analysed PRECIS RCM simulations over the Caribbean with a resolution of 50 km and found that the default configuration of the model does not capture many of the smaller islands. In configurations that include the islands, by marking the nearest or covering grid boxes as land, a difference in simulated cloud cover is noted over the eastern Caribbean, highlighting how the absence or inclusion of small islands in models has ramifications for the quality of the regional projection.

Similarly, Cantet *et al.* (2014) generated climate scenarios for the Lesser Antilles using the ALADIN – Climate RCM nested within ARPEGE GCM and noted the islands are considered as land by the RCM model, but are not resolved at all by the driving GCM, which raises an important point relating to the credibility of RCM outputs for islands. RCMs are intended to add regional detail to a global scenario and so are highly dependent on the driving conditions received from the parent GCM (Foley *et al.*, 2013; Karmalkar *et al.*, 2013). As such, the inability of a GCM to resolve island topography has the potential to significantly impact the simulative skill of the RCM.

3.2 Validating models in island contexts

Given these uncertainties, it is important to validate any type of downscaling approach against observed data. Where such data are limited, however, it may not be possible to establish an adequate record of past climate variability against which to assess the performance of models in the present. Nunn *et al.* (2014) note the tendency of impact studies
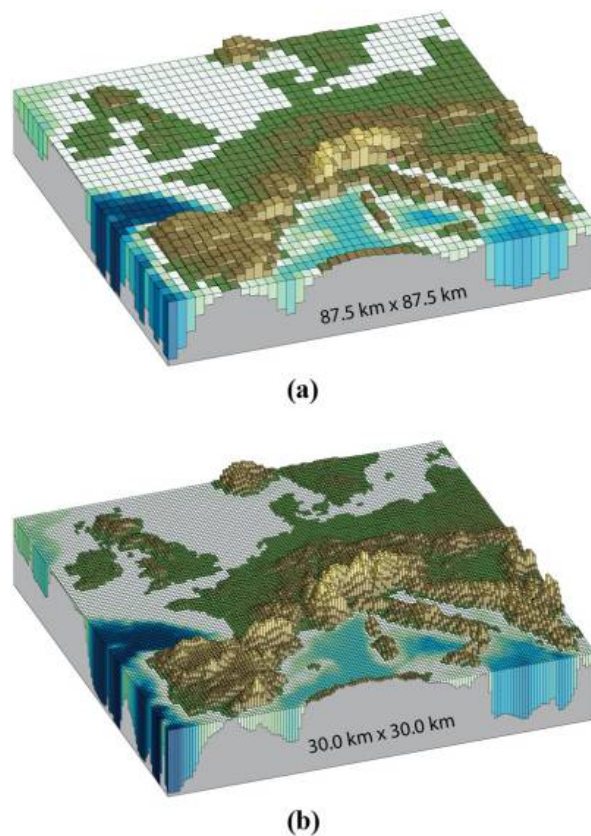
Notes: (a) Illustration of the European topography at
a resolution of 87.5 × 87.5 km; (b) same as (a) but
for a resolution of 30.0 × 30.0 km
Source: Reproduced from Cubasch *et al.* (2013,
Fig.1.14)

Figure 1.
Horizontal
resolutions
considered in today's
higher resolution
models and in very
high resolution
models now being
tested

to focus on the most densely populated areas of islands in contrast to rural communities, which is attributable to the urban bias of governance and decision-making structures (Connell, 2010). In terms of data landscapes, there is equivalence in that peripheral areas tend to be most affected by data sparsity.

For instance, in a study of temperature trends in Fiji, Kumar *et al.* (2013) note that all meteorological stations analysed were located on or near the coast, with a scarcity of data in the island interior. However, differences in topography or land use may result in significant differences in climatic conditions even over short distances. For example, where data collection is limited to densely populated areas, urban heat effects may need to be taken into account. This effect is illustrated in Figure 2, using data from Koror, the largest city in Palau and Nekken Forestry, just 12 km away.

While data sparsity can also be an issue in continental locations, it is especially important in island contexts as the spatial gaps between observations can be very large due to the isolation and fragmentation of islands (Wright *et al.*, 2016). In their study using the PRECIS RCM in the Caribbean, Campbell *et al.* (2011) noted that the sparsity of Caribbean meteorological station data hampers validation of the model; data sparsity is also cited as a

limitation in Whan *et al.*'s (2014) study of temperature extremes in the Western Pacific. In this way, challenges to validation can complicate the use of climate models, even for islands that are large enough to be adequately resolved within a model. For recent decades, satellite-based data sets such as NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA; Rienecker *et al.*, 2011) are a useful resource. However, for the purposes of establishing baselines for climate model evaluation, data are required over a longer timeframe, to sample the full range of natural climate variability.

3.3 Informing bottom-up vulnerability assessment

In the absence of specific data relating to future risks, current vulnerabilities and adaptations are often discussed as a means of exploring the potential for adapting to climate change (McCubbin *et al.*, 2015). Such an approach could be described as bottom-up, beginning with the identification of vulnerabilities, sensitivities and factors that increase resilience to climate-related threats (Falloon *et al.*, 2014; Wilby and Dessai, 2010). But climate change also creates new challenges, such as sea level rise and ocean acidification, which are unprecedented on human timescales and for which there are no traditional adaptations, or for which the limits of existing adaptations may be unknown (Weir *et al.*, 2017). Hence, the absence of appropriate data about future climate, against which to test adaptation strategies, may lead towards underestimation of future vulnerability.

Furthermore, while bottom-up approaches may not rely on climate data, they must use other kinds of data to gauge the impact of and vulnerability of communities to, past hazards. Here, similar themes emerge around the mismatch in spatial scales of knowledge and action on SIDS. For instance, in the aftermath of natural hazards, community level impacts can go unnoticed when local data (e.g. relating to numbers dead, injured and homeless) is combined and analysed at the national scale, potentially resulting in missed opportunities for effective intervention (Méheux *et al.*, 2007). Preston *et al.* (2011) finds that reliance on secondary data is common in vulnerability assessments, with none of the 45 studies reviewed incorporating primary data regarding biophysical factors and only nine per cent including primary data regarding socio-economic factors. Turvey (2007) also notes the challenges that data quality and availability issues pose in the creation of the composite vulnerability index (CVI) and particularly highlights the need for more information on the vulnerability of coastal environments to seasonal and interannual climate variability.
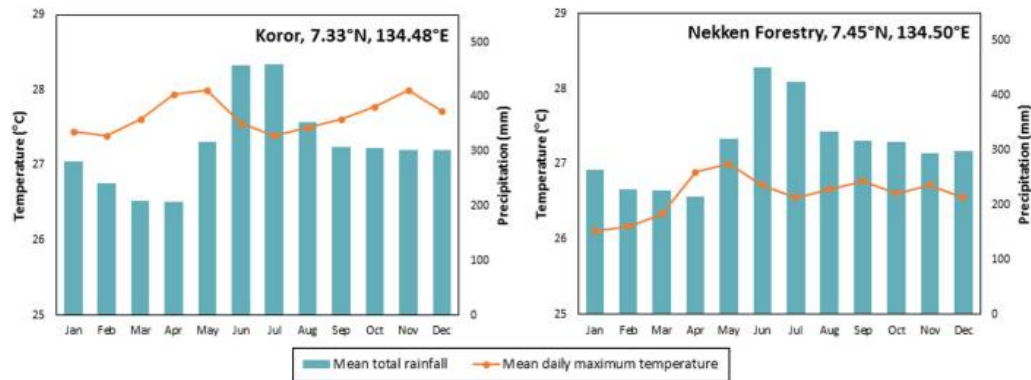

Figure 2.
1981-2010 climatological averages for rainfall and average temperature at two sites in Palau

Source: NOAA's Climate Normals (Arguez *et al.*, 2010)

4. Addressing the scale mismatch

4.1 Applications of alternative data sources

Developing a robust understanding of past climate change in islands is key, so that models can be evaluated appropriately and so that current sensitivities to change can be more clearly apprehended. Combining modern and historical data has the potential to produce novel insights into the links between local conditions and the larger, changing climate system.

Arguably, the strong sense of place associated with islands privileges and aids in the preservation of local knowledge on environmental risk. Local knowledge cannot provide the same types of information to decision makers such as GCMs and so cannot directly compensate for the issues identified around small island representation at model scales. However, it can provide important, additional information, which may relate not only to environmental change but also to potential human responses. For example, Fritz and Kalligeris (2008) highlight the case of the 1 April 2007 Solomon Islands tsunami, during which islanders knew to flee to higher ground after an earthquake based on ancestral knowledge of past events. Similarly, it may be informative to make use of narrative accounts and oral traditions (e.g. poetry and songs) of past climate and environmental changes (Janif *et al.*, 2016) to develop a long-term view of local contexts. In this manner, the cultural capital of island communities can connect with modern scientific knowledge.

Adger *et al.* (2013) argue that cultural aspects are infrequently incorporated into climate change analyses due to the challenge of merging the qualitative approaches more often used to study culture and the quantitative methods common in natural science. However, there are some examples. In a study of shoreline recession in the Solomon Islands, Albert *et al.* (2016) used historical aerial photography, satellite imagery and local historical insight to explore the interaction between sea level rise and other factors contributing to coastal recession, such as sea walls and extreme events. The merging of science and indigenous knowledge can also directly support adaptation in creative and unconventional methods. Hirsch (2015) described how Maldivians are embracing inter-island mobility and reimagining ancestral practices, giving the example of the smartphone app Nakaiy Nevi, which combines the indigenous Maldivian calendar system of *nakaiy* with weather observations. Weather-related traditional knowledge, relating plant and animal behaviours to meteorological phenomena, such as tropical cyclones, can also be incorporated into scientific forecasting tools (Magee *et al.*, 2016), although Chand *et al.* (2014) noted that the verification of traditional knowledge as a forecasting method is hindered by the lack of historical records for phenological responses (e.g. flowering times of mango trees as a predictor of cyclone activity).

Data rescue activities, including digitisation of historical meteorological records, facilitate such research. The Climate Data for the Environment (CliDE) system, a web-based climate data management tool, supports such activities and has been deployed in 14 Pacific island states (Martin *et al.*, 2015). Workshops and peer-to-peer data exchange have also been successfully used in the Western Pacific to extend existing data sets and build research capacity in the region, although the length and quality of some of the datasets identified remain an issue (McGree *et al.*, 2014). Citizen science strategies can also play a part here, building two-way collaborations between local communities and research teams, to not only disseminate research findings and inform decision makers but also harness local knowledge and experience and build synergies with existing priorities (Petridis *et al.*, 2017).

4.2 Robust decision-making strategies
Advances in computing capacity and climate modelling will inevitably enhance the quality of future climate projections that can be made for SIDS, but decisions about climate adaptation strategies will still have to be made against a backdrop of uncertainty. At each stage of the sequential process described previously, uncertainties and inconsistencies accumulate, widening the envelope of uncertainty associated with specific impacts. Even variation in methods and interpretations of uncertainty assessment can lead to different policy outcomes (Wesselink *et al.*, 2015). Uncertainty may also impact how adaptation actions are perceived; for example, if a community decided to migrate in response to potential, but as yet unobserved, effects of climate change, would the available evidence base impact the level of international support they might receive (Kelman, 2015)?

Uncertainty can be perceived as a barrier to decision-making or used as a rationale to avoid decision-making, but in reality, it should not preclude action as uncertainties and unknowns are inevitable in any decision-making scenario. While computation strategies, using conventional decision-support tools such as multi-criteria analysis and cost–benefit analysis, would have to be based on an uncertain knowledge base, compromise, judgement or inspiration strategies could be more appropriate choices (de Boer *et al.*, 2010) and may better reflect the important socio-political factors that shape the SIDS vulnerability. Within such strategies, robust decision-making could be applied to help decision makers understand the conditions under which a particular proposed policy would fail and ultimately identify policies that will endure under a range of scenarios (Lempert, 2013). A similar concept is decision scaling, introduced by Brown *et al.* (2012), which seeks to identify broadly the climate states that favour a particular decision and then establish the probability of occurrence using GCM data, thus lessening the specificity of information required from the models while enhancing the relevance of the data to the decision.

4.3 Visualising and communicating future climates
Given the inevitability of uncertainty, it is also worth considering how best to convey information about possible future climates. Communication of climate data relies heavily on visualisation; yet, there has been limited research into the effectiveness of different approaches, particularly in the context of understanding deep uncertainty (Spiegelhalter *et al.*, 2011). Kaye *et al.* (2012) noted that Web-based interfaces could offer innovative ways to explore uncertainty, compared to static approaches, proposing visualisations in which the user can specify an acceptable level of uncertainty, generating a map that only displays regions meeting that criteria. Wesselink *et al.* (2015) advised referring to processes and trade-offs when communicating results rather than relying on numerical ranges alone.

Links between spatial scales of data and risk perception may also benefit from further study. In a study of volcanic hazard mapping methods on Montserrat, Haynes *et al.* (2007) found that perspective photographs were significantly more effective than other visualisations, as people could better identify features and their orientation. Daly *et al.* (2010) subsequently used large-scale aerial photographs, with landmarks identified, in participatory research on coastal vulnerability in Samoa, allowing islanders to make links between the visualisations and their own perceptions and experiences of hazards. It has been suggested that map users may associate a high level of visual realism in geospatial images, with higher confidence in the quality of the data underlying those image (Kettunen *et al.*, 2012). How, then, might the inability of a model to adequately resolve an island, or indeed, resolve it at all, impact the perceived trustworthiness of data and communication of risk? Is a coarse map better or worse than no map at all? Questions such as these are

particularly relevant in the context of islands, considering the strong sense of place shared by many island communities (Baxter *et al.*, 2015; Coulthard *et al.*, 2017).

5. Conclusions

This paper has outlined some of the ways in which characteristics commonly allied with "islandness", such as smallness, land boundedness and isolation, may limit the applicability of global and regional climate impact assessment methods to SIDS and, particularly, to atoll countries. Small island topography can be too detailed for current GCMs to resolve, but equally, local meteorological station data can only represent a point and records may be sparse or short in island peripheries. As well as the technical limitations of climate models and data sets, the absence or unreliability of local-level vulnerability data may be perceived as a barrier to adaptation actions.

Yet, there is a need for a robust decision-making basis in light of the kinds of climate adaptation policies under consideration. Climate science is increasingly harnessing big data (Schnase *et al.*, 2017) and by comparison, the decision-making basis for SIDS may seem limited on account of the constraints discussed, but this would be an oversimplification. Rather than viewing the issue as decision-making with big data versus with little or no data, a more productive discourse can emerge by conceptualising strategies of decision-making with *different* data. While climate models can still provide scenarios of future change, decision-making that uses those scenarios must recognise the inherent uncertainties. Continued recovery of historical observations, both of climate parameters and associated environmental phenomena identified through traditional knowledge, can aid in formulating baselines against which to assess models and evaluate long-term change. Looking forward, there is potential for crowdsourcing of climate data using citizen weather stations (Meier *et al.*, 2017) and smartphones (Mass and Madaus, 2014), which could play an important role in monitoring and understanding the onset of climate impacts. Alternative forms of knowledge production and robust decision-making can aid in raising awareness and enhancing the perception of climate change in island communities. The hybridization of science and indigenous knowledge offers much potential provided that the strengths and limitations of all forms of information are suitably acknowledged (Lebel, 2013) and that the merging of knowledge takes place in a culturally compatible manner (Mercer *et al.*, 2007).

Note

1. https://portal.enes.org/data/enes-model-data/cmip5/resolution

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