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Spatial and temporal ways of knowing sea level rise: bringing together multiple perspectives

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Abstract

Sea level rise presents risks to ecosystems, populations and infrastructure in low-lying areas. This paper considers diverse ways of knowing, understanding and experiencing these risks. It explores differences and connections between knowledge produced through the technological methods of scientific research and that which emerges through the experiences and insights of local people. For example, while scientific assessments measure and forecast, among other things, the height and rate of vertical change in the sea level using instruments such as tide gauges and radar-firing satellites, for local populations sea level rise is largely perceived and knowable through everyday processes and lived experiences of coastal changes as sea waters encroach onto the land. The paper reveals this diversity of knowledge and how it is produced. It considers how these different forms of knowledge might coalesce in ways that can more effectively inform understandings of, and responses to, the varied effects of sea level rise. Focusing specifically on spatial and temporal understandings of sea level rise – as the vertical rise of sea levels and inward encroachment of sea water, and timescales from the everyday to the decadal and centennial – this paper concludes by arguing the importance of integrating scientific measurement and modelling with local knowledge. It suggests that local and Indigenous knowledge should not merely represent an enrichment of scientific facts, but rather that bringing together local/Indigenous and scientific knowledge can provide significant ways of knowing and sensing the world that can build the resilience of social-ecological systems.

1. Introduction

Satellite altimetry measures the time taken by a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver. Combined with satellite location data, altimetry measurements yield data on sea-surface heights (Aviso+, n.d.).

The day we moved the kitchen was knee-deep with water. It is so unsettling when things happen like that. Before it was OK, it only flooded during the king tide. But then even the normal high tide started to flood our houses (Woman from relocated village of Vunidogoloa, Fiji; cited in McMichael & Katonivualiku, 2020: 289).

In the past two decades, sea level rise (SLR) has become a major concern for scientific and social science researchers, decision-makers, affected communities and climate change campaigners. To date, however, global and public understandings and debates about SLR have largely been driven by knowledge produced in the physical sciences. Scientific studies have found that during the past century (i.e. 1902-2010), the global mean sea level increased by 0.16 (0.12-0.21) metres, and that global mean SLR will likely be in the range of 0.29-1.10 metres by the end of this century compared with the 1986-2005 baseline (IPCC, 2019). Future rates of SLR will be determined largely by greenhouse gas emission trajectories and the rate of ice mass loss from the Greenland and Antarctic ice sheets (IPCC, 2019; Jevrejeva et al., 2016). Scientific estimates and forecasts that quantify the scale, rates and impacts of SLR provide an important evidence base for policy prescriptions and adaptation planning in coastline areas (Yusuf et al., 2016).

Given current and anticipated exposure of populations to SLR, research has also been undertaken to understand how people perceive change along the land-sea interface in the places they live (Matless, 2018; Thomas et al., 2015). Numerous studies have explored social and cultural dimensions of coastal change, including local knowledge and perceptions of SLR (Gelcich et al., 2014; Harvatt et al., 2011), shifting everyday practices and adaptive responses to SLR (Alexander et al., 2012; Fincher et al., 2014) and anticipated environmental futures in the context of rising seas (Dolan & Walker, 2006; McMichael & Katonivualiku, 2020). Local understandings often diverge from scientific assessments as they tend to place greater emphasis on the impacts of SLR on everyday lives. Indeed, people may not understand climate in scientific terms, but rather as a 'social-ecological-atmospheric construct' that is knowable through everyday processes and lived experience (Clifford & Travis 2018: 8). Yet local knowledge provides insight, enrichment and a corrective for the knowledge of mainstream science (Engels, 2019; Nowotny, Scott & Gibbons, 2003).

This paper responds to Martin-Nielsen's (2015: 465) call to '*shed light on the diversity of knowledge practices surrounding climate change'*. Specifically, it brings together varied understandings and ways of knowing SLR exposure and vulnerability to coastal hazards among 'scientists' and 'local' people. We define SLR as an increase in the height of sea level, and sea level change as encompassing both rising and falling seas; these terms can refer to global or local changes that occur at seasonal, annual, or longer time scales (IPCC, 2019). We note that, in addition to SLR, many coastal changes are linked to human activity: e.g. the removal of coastal vegetation, sand mining, or maladaptation involving seawalls (Ratter et al., 2016). And yet SLR is a high-profile concern.

Our aim is not to homogenise scientists or local people, nor to suggest that there are clear distinctions between them. Instead, we recognise the internal heterogeneity of these bodies of knowledge, that local people can be scientific in their approach and scientific endeavour can acknowledge and address socio-cultural issues, such that these ways of knowing can inform each other. Yet, there remain sufficient dissimilarities in perspectives and approaches that justify, at least analytically, invoking these distinctions. This paper explores different knowledges – 'scientific' and ‘local’ – about the spatial and temporal dynamics of SLR. Building on this, it discusses why these different knowledges might be usefully brought together. While science does not have a monopoly on knowledge production, or on guiding responses to environmental and social problems, it is often relied on in global assessments such as the Intergovernmental Panel on Climate Change (IPCC). With the Sixth Assessment Report for the IPCC well underway, identifying why integration between these valuable knowledge sets should be pursued is timely and critically important for enhanced understandings of SLR, its impacts and ways of responding.

In section two below, we begin with a brief review of literature on ways of knowing, and the distinctions forged between scientific and local knowledge. To illustrate, this section discusses ways of knowing the sea-land border. The subsequent two sections draw on scientific assessments of SLR and community-level case studies. Specifically, section three focuses on the ways in which SLR is measured and observed spatially, distinguishing between SLR as understood in vertical terms (i.e. sea level height) or in horizontal terms (i.e. encroachment of seawater inland). Section four explores how time and temporality are variously represented and shaped by scientific measurements and lived experiences of SLR and its effects. We then discuss why integrating these forms of knowledge can provide a more complete picture of how the sea level is perceived to be changing, and with what effects. While there remains a plurality of forms of knowledge about SLR, and these are sometimes in tension, we argue that they can coalesce in ways that are meaningful and productive.

2. Ways of knowing

Knowledge is produced in multiple ways. There can be profound differences between scientists and local people who may hold ‘*different worldviews and perceptions of knowledge and how it can be generated and transmitted*’ (Hakkarainen et al., 2019: 282). Scientific, technocratic and expert understandings have often been set apart from local and Indigenous knowledge (Agrawal, 1995; Mistry & Berardi, 2016). Escobar (1995) maintains that a ‘principle of authority’ exists whereby the expert is legitimised in identifying problems, categorising and labeling them, and intervening to resolve them. He writes that this principle shapes ‘*who can speak, from what points of view, with what authority, and according to what criteria of expertise; it sets the rules that must be followed for this or that problem, theory or object to emerge and be named, analysed, and eventually transformed into a policy or plan*’ (Escobar, 1997: 87). Through this process, prestige and authority are granted to scientific disciplines and experts (Hulme, 2011), embedding an exclusivity of knowledge.

And yet the views and ideas of local people, or ‘non-experts’, may entail ‘*contradictory or conflicting needs, desires and interest*’ to that of science (Felli & Castree, 2012: 2). Narratives that marginalise ‘non-expert’ knowledge are gradually being challenged, opening up questions ‘*of whose and what sorts of environmental knowledge count/s, and in what circumstances*’ (Head et al., 2019: 398). Local knowledge is increasingly understood as providing alternative understandings and insights. No longer viewed as a fixed commodity that people intrinsically possess, local knowledge is ‘*constructed, reaffirmed or reworked through the social encounters, experiences and dilemmas of everyday life*’ (Long, 2001: 171). It evolves through adaptive processes, practices and beliefs that are often handed down through generations (Berkes et al., 2000) and adjusted as part of daily routines. This local knowledge is variously referred to as Indigenous knowledge (for Indigenous populations), traditional knowledge, or traditional ecological knowledge. Importantly, local knowledge is not restricted to Indigenous people or the insights of people in the so-called Global South; it might include, for example, the worldviews and insights of people living in the UK, US, Australia and elsewhere (c.f. Graham et al., 2014; Reineman et al., 2017; Thomas et al., 2015). Local knowledge is recognised as critical for detecting, understanding, responding and adapting to environmental and climatic change (Ford et al., 2016; Head et al., 2019; Shawoo & Thornton, 2019).

These fundamental differences are reflected in distinctions between scientific and local knowledge of SLR and, more broadly, the sea-land edge. To illustrate, there are diverse scientific and local perceptions of where the sea and the land meet, and the extent to which the edge is fixed or dynamic (see Steinberg, 2011; 2013). With reference to geographic mapping of oceans and land, Steinberg argues that scientific representations of our world clearly demarcate borders where the sea meets the land; '*the categorical divide between land that is covered by water and land that is not covered by water*' (2013: 159). Certainly, some scientific assessments reflect the dynamism of coastal zones; e.g. transitional coastal and intertidal zones between land and marine environment are understood to be vulnerable to the effects of climate change (Bellafiore et al., 2014; Neumann et al., 2015). However, there is a dominant focus within science on an upper limit of rising and extreme sea levels that meet with the land as a hard 'edge' (Steinberg, 2011). This is at odds with the experiences of people living near 'watery edges', where the spatial limits of the sea are fluid. For example, Hasan and Nursey-Bray (2018) studied perceptions of climate change and SLR among artisanal fishing villages on coasts and river embankments of Bangladesh that are vulnerable to flooding, cyclones, erosion and storm surges. For people in these villages, the distinction between land and water is dynamic; people describe how whenever lands erode on one side of the river, new lands emerge on the other side. Many Indigenous cultures dissolve the division between land and sea into integrated and permeable 'scapes' (Howitt, 2001; Matsuda, 2007); coasts '*are not lines of separation but zones of interaction'* (Howitt, 2001: 240). This is evident in Indigenous Bawaka storytelling in North East Arnhem Land, Australia, where connections between land and sea are evoked through stories of people, song, ceremony, spirits and kin-animals (Lloyd et al., 2010). Similarly, Morphy and Morphy (2006), suggest that Indigenous people in Arnhem Land, northern Australia, observe the flow of fresh, brackish and saltwater across, through and between land-sea waterscapes. And with reference to the Pacific Islands, Matsuda (2007) argues that islands are understood not as bounded territories but rather places situated in dynamic geographies of land and sea. These studies suggest that there are different scientific and local ways of knowing where the boundaries between land and sea lie (Petzold et al., 2017).

Consequently, scientific endeavor and local insight produce different ways of knowing the sea, and sea level change, and land-sea boundaries. In the sections that follow we further consider the spatial and temporal dimensions of measuring and understanding SLR from both scientific and local perspectives. We recognise that spatial and temporal dimensions are interconnected: for example, scientists forecast the spatial extent of SLR over given time periods; local people perceive spatial changes in sea 'edges' over time. Nevertheless, we distinguish between the spatial and the temporal to analyse convergences and divergences between different knowledges.

3. Spatial perspectives: vertical rise and horizontal encroachment of the sea

Spatial ways of understanding sea level change by scientists and those living in local sites of coastal vulnerability and risk are varied, but also often complementary. Here, we explore perceptions of SLR as a vertical rise of water levels and as a horizontal encroachment of water across the land.

Scientific assessments of the rate and amount of increase in sea level depend on sea surface water level data. Tide gauges are used to measure and record sea levels over time. The number of tide gauges has increased from just a handful in northern Europe in the 18th century to more than 2000 along the world's coastlines today (see Figure 1) (IPCC, 2019). Globally, data from active tide gauges are supplied to the Permanent Service for Mean Sea Level (PSMSL) that holds information from 2067 stations that are supplied by approximately 200 data authorities (Holgate et al., 2013). The tide gauges document global mean SLR of ~2.8 mm/year calculated between 1993 and 2009 (Church & White, 2006; Church & White, 2011; Church et al., 2013). However, the sea level also responds to natural changes of the climate system, such as variability related to El Niño–Southern Oscillation (ENSO), and this hampers detection of the global warming signal (Cazenave et al., 2014).

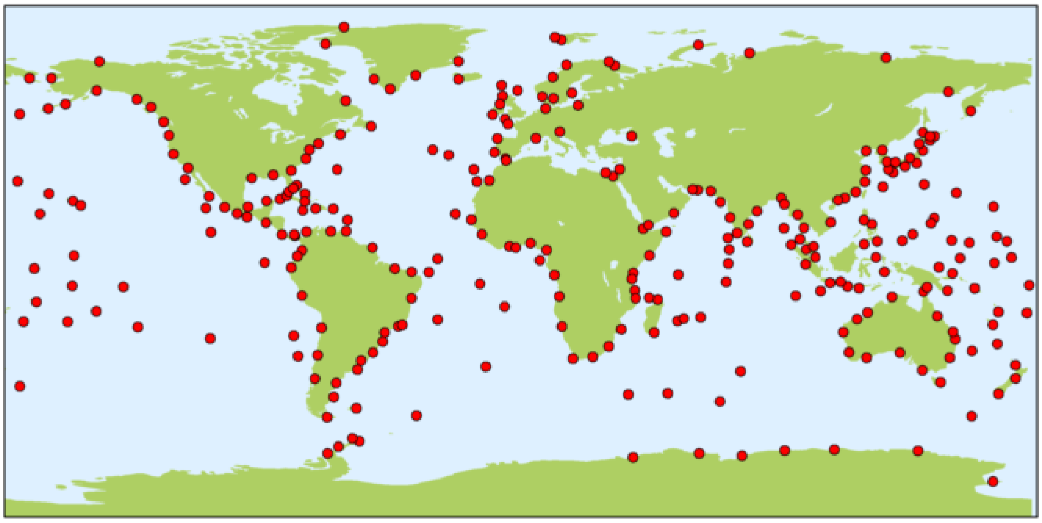

Figure 1: Map of the global distribution of tide gauges (GLOSS, 2010)

Scientists also use shuttle radar topography to measure global mean sea level. The altimetry records they produce, together with the longer-term tide-gauge data, enable estimates of the scale and rate of global mean SLR (Church & White, 2006). Satellite altimeters have produced measurements of near global (66°S to 66°N) sea level from 1992 onwards. They measure the time taken by a radar pulse to travel from a satellite to the sea-surface and back, and this yields data on sea-surface heights. These measurements are often combined with gridded population datasets to identify human settlements that are vulnerable to SLR (Covi & Kain, 2015).

While tide gauges and satellite altimeters measure the vertical rise in sea level, scientists also measure the inward, horizontal, movement of water. They focus on coastal flood risk under current and anticipated SLR (Hinkel et al., 2014). Estimates of flood risk use gridded datasets of land elevation as produced by space shuttle radar systems, referred to as a Digital Elevation Model (DEM). However, a satellite radar is unable to identify the object returning the signal. It measures the elevation of upper surfaces rather than earth terrain and thus has large positive errors particularly in densely vegetated and built environments. Globally, the mean error in satellite radar in the 1–20 metre elevation is 1.9 metre leading to overestimates of surface elevation and, accordingly, underestimates of land and population exposure to SLR and flooding (Kulp & Strauss, 2019). This problem has been ameliorated with the recent production of digital elevation datasets that adjust for key variables including building elevation, land slope, population density, vegetation density and canopy (Kulp & Strauss, 2019).

Quantification of flooding due to sea level change and storm surges is also produced through the Global Tides and Surge Reanalysis (GTSR) dataset that dynamically simulates tides and storm surges (see Muis et al., 2020). At a more localised scale, flood-plain mapping and risk assessment can be informed by remote sensing data from aircraft-based sensor technologies that produce local topographic information and flood extent maps (Di Baldassarre et al., 2010). And scientists have developed dynamic models to account for site-specific parameters of tides, storms, short-term climate variability, erosion and flooding (see Jackson & Jevrejeva, 2016; Barnard et al., 2019).

While much of this analysis relies on satellite and other remote sensing data and tide gauges, scientists have also developed other novel ways to monitor extreme changes to water levels. For example, one study of coastal flood levels in Oman measured maximum flood levels by using the physical marker of 'wrack lines' from human-produced litter made of durable, solid matter (Hoffman & Reicherter, 2014). The study documented wrack lines that contained (among other things) plastic and glass bottles, food wrappers, plastic plates, drinking straws, cigarette lighters and butts, medical waste such as blister packs, petrol and oil containers, sandals, and toothbrushes. These deposits contained information on production and/or expiry dates that were used to reconstruct the timing of high tides and flooding. A wrack line located 1.97 metres above mean high water was estimated to have formed after 9 January 2007 (based on the production date on a potato crisp packet) and gave evidence of the maximum flooding level for tropical cyclone Gonu (landfall 5 June 2007). In this study, human-produced debris marked the maximum flooding level and was used to calibrate storm surge and tsunami inundation models.

Turning to accounts of sea level change among local people, some reports – in sites as diverse as the Outer Hebrides in Scotland, the Sundarban delta in India and Bangladesh, and low-lying atoll islands in Tuvalu – refer to vertical increases in the height of the sea or tides. Yet local residents refer more often to the inward movement of the sea including as is evident through encroaching seawater, coastal erosion and accretion, and breached coastal barriers and river embankments (c.f. Dubey et al., 2017; Gray et al., 2014; Lazrus, 2015; Rey-Valette et al., 2015).

Pascoe et al. (2019) documented experiences of coastal change in Papua New Guinea, in the Milne Bay Province. One person noted, '*the waves are taking the land away. Before the land is some metres away from the sea, but now it's like digging away the soil and the sea level is coming close…. We can see coconut trees and some other big trees are out in the sea, so that makes it like the climate is changing'* (Pascoe et al. 2019: 4). In the Marshall Islands, Rudiak-Gould (2014) found that while people mentioned 'higher' tides, physical effects were described in terms of shoreline erosion, expressed by some as the ocean 'eating' the land. Residents variously explained, '*the islands are getting smaller. You see them getting smaller and smaller'* (2014: 78), and '*the islands are thinner now….Not just in Majuro but in outer islands too there are problems. It's happening very much, from what they call oktak in mejatoto ("climate change")*' (2014: 78). Similarly, people living in a low-lying village in Fiji spoke of the waves and sea coming closer, coastal erosion, and saltwater intrusion; as one village resident stated, '*we know, we experience it, we feel it, from what we're seeing in the coastal area, the food. We can feel it. The small crab that used to be out at sea, now is around here near the houses. They are coming up because the sea is underneath. When we dig a little bit we see the sea-water*' (McMichael, Katonivualiku, & Powell, 2019: 6). Gray et al. (2014) found that residents of Tralee Bay in southwest Ireland and the Outer Hebrides in Scotland predominantly expressed concerns about SLR in terms of loss of land and erosion affecting coastal roads and infrastructure. And in a study with Indigenous elders on Erub Island in the Torres Strait region of Australia, experiences of SLR and coastal changes centred on the inward movement of water. One Aunty (female elder) recalled, '*When I was young, we used to go further out on the beach, the beach was right out… But now, it changes a lot and the water comes right in, right up to the back door, I mean, my laundry and the back step in the house*' (McNamara & Westoby, 2011: 235). Plate 1 shows how households on Erub Island in the Torres Strait use buried tyres, sandbags and wooden fences to try and limit the removal of beach sediment due to tides and wave action and slow down the inward expansion of the sea.

Plate 1: Attempts to protect home from the sea on Erub Island in the Torres Strait, Australia (photo by XXXXX, 2009)

As these examples illustrate, empirical research that focuses on local people's knowledge reveal spatial understandings of coastal changes that focus on the inward movement of seawater, movement that is widely attributed to SLR. Further, there is significant focus on what this means for everyday lives, including: loss of land, loss of mangroves and other trees, damage to people's homes and infrastructure, managing debris brought in with tidal surges, the impact of saltwater intrusion on crops and water sources, and movement of people away from sites of risk and coastal change.

In sum, scientists and local populations understand and perceive the spatial dynamics of sea level change in varied yet overlapping ways. Scientists use satellite data, tidal gauges and even human-produced litter to measure and forecast quantitative estimates of changes in the height of the sea (Covi & Kain, 2015). While scientific methods measure inward movements of seawater through flooding and tidal surges, the more prominent scientific reports and media headlines define SLR through vertical parameters. For example, an article in The Guardian Weekly entitled '*Sea level rise accelerating along US coastline*' reports that there may be as much as an 8.2ft increase in sea levels by 2100, compared with 2000 levels (Milman, 2020). While local populations living in low-lying sites allude to the vertical motion of rising tides and higher waters, they more often describe coastal changes in spatially horizontal terms, namely the inward encroachment of seawater. They are 'on the ground', directly observing and experiencing the physical environment that satellite radars only coarsely scan. This encroachment of seawater is knowable and notable for its impact on the everyday lives, livelihoods and anticipated futures of local people (Clifford & Travis, 2018; Harvatt et al., 2011; Covi & Kain, 2015).

4. Time-based perspectives: understanding 'explicated' and 'implicated' timeframes and temporalities

In addition to the spatial dimensions of SLR, scientists and local communities also invoke different, albeit sometimes intersecting, temporal scales when explaining environmental change, including SLR (Edensor, Head & Kothari, 2020). In this section, we explore differences between the 'explicated' time of scientifically quantified SLR risks and the 'implicated' time of local understanding and experience of SLR that draws on temporal rhythms of everyday life, the past, and imagined futures. We also consider overlapping temporal elements as local and scientific ways of knowing refer to historical markers, attempt to understand and measure current impacts, and consider and prepare for potential futures.

Within climate science, the 'explicated' time of quantified SLR risk takes the shape of specified dates for present, future, epochal and periodic changes. The physical sciences forecast rates and levels of change for specific and often extended time horizons, such as the years 2000, 2030, 2060, and 2100 (see Nicholls et al., 2011; Neumann et al., 2015). As Norbert and Pelling (2017: 124) write, the physical sciences have '*temporalised climate change and its related hazards into an explicated time problem*' by inputting specific time points into computer models and quantitative estimates. For example, Nicholls et al. (2011) estimate that warming of 4°C or more by 2100 will lead to up to 2 metres of global mean SLR. These scientific assessments of rates of change compare time periods to show, for example, that Global Mean Sea Level (GMSL) has been rising faster in recent decades, increasing from 1.4mm yr^{-1} during 1901–1990 to 3.6mm yr^{-1} over the period 2006–2015 (IPCC, 2019). These estimates show that SLR is widely expected to accelerate in coming years and decades (IPCC 2019), with forecasts considering scenarios for different greenhouse gas emission trajectories. While scientists acknowledge the uncertainty associated with SLR, particularly beyond 2050, climate modelling forecasts possible environmental futures for given warming scenarios that subsequently inform risk planning and management (IPCC, 2019).

Other scientific assessments focus on how incremental processes of SLR can translate into abrupt and discrete events, such as coastal flooding and tidal surges (Hallegate et al., 2013). Neumann et al. (2015) estimate the global land area and population exposed to 1-in-100-year flooding - taking account of SLR, at three points in time, 2000, 2030, and 2060 – and use mapping techniques to show the extent of change as floodwaters submerge land. There is an inherent temporality to this probabilistic modelling. For example, the 1-in-100-year flood metric implies that flooding events will occur once on average in any 100-year period (or that a 100-year flood event has a 1-in-100 chance of occurring in any given year and location). This metric, however, has been criticised as an inappropriate way to convey risk under a changing climate; it gives a return rate which is spuriously precise given that the 100-year floodplain will change (typically increasing) in a warming world (Gilleland et al., 2017).

SLR and extreme incidents are not experienced in such a temporally distinct manner by local people. Extreme events '*leave an imprint in public memory and are typically characterized by a complex chain of processes, often extending well beyond the local event itself*' (Zscheischler et al., 2018: 470). Storm surges and coastal flooding, for example, shape local environments and their effects tend to cumulate, linger, and disperse over time. Local populations commonly relate to 'implicated' time, inherent to everyday life (Norbert & Pelling, 2017) and to the ways in which this can change or be disrupted. Pascoe et al. (2019) found that people living in Suau, Papua New Guinea, view tides as less predictable in a warming world such that, '*time doesn't work out*'. One villager stated, '*before, in the time of the bubus [grandparents], tides were their calendar and seasons. Now this isn't working like before. The tides don't follow the same patterns'* (Pascoe et al. 2019: 6). Similarly, research with Indigenous elders in the Torres Strait, Australia, documented concerns about shifting seasonal indicators: '*We used to read the landscape. But now it changes, you have to guess now. Everything changes, make it so hard… You never know, it just change like that, even the tide*' (McNamara & Westoby, 2011: 235). And a study of perceptions of sea level change in the Severn Estuary in the UK, a place that scientists have assessed as highly vulnerable to future SLR, found that local people expressed little concern about future sea level change as it did not currently affect their lives (Thomas et al., 2015). Similarly, research in The Comoros Islands found that some people destroy the protective character of the sandy beaches, coral reefs, and mangroves as they seek to generate income through sand-mining, thereby increasing the longer-range risks of coastal erosion risks and SLR (Ratter et al., 2016). As these examples illustrate, local people observe and experience how SLR and environmental changes disrupt daily life and everyday rhythms or attend to more pressing daily concerns than the long-range risks of SLR.

Histories and anticipated futures also have changing significance under altered climatic conditions. For some, local histories matter in new ways. In Alaska, residents of Shishmaref experience permafrost thawing, coastal erosion, flooding and changes in weather. While they inhabited coastal areas for thousands of years, with the flexibility to move with seasonal and ecological changes, more recent colonial histories of Indigenous settlement produced sedentary smaller communities and immobile infrastructure; residents understand that this colonial history and their now sedentary settlements amplifies their vulnerability to climate risks, including SLR (Marino, 2015). And local populations consider the significance of future SLR for everyday realities (Barnett & McMichael, 2018; Fincher et al., 2014; Kothari & Arnall, 2019). For example, research with residents of low-lying coastal villages in Fiji found that anticipated climate futures shape the present. As an elderly man said, '*I was thinking about renovating the house, but what's the point? In five years' time it could be filled with sea water. We need to move to higher land'* (McMichael & Katonivualiku, 2019: 291). These studies of local ways of knowing SLR emphasise temporal rhythms and time scales that are different to those produced through scientific modelling. Both are concerned with histories, current conditions and environmental futures. Yet people living in sites of potential and/or emerging exposure to SLR invoke personal and intergenerational timescales, and are concerned with recalling, sensing and anticipating changes to everyday lives rather than focusing on environmental parameters at specified and arbitrary points in time (Arnall & Kothari, 2015; Fincher et al., 2014).

5. Discussion: bringing together ways of knowing sea level change

Scientific measurement and modelling and local/Indigenous knowledges provide diverse, albeit at times over-lapping, ways of knowing sea level change (Makondo & Thomas, 2018). But how can, and should, scientific and local/Indigenous knowledges around sea level change be brought together? First, some research explicitly challenges the separation between scientific assessment and local knowledge of environmental change, including SLR (Carey, 2005; Arnall & Kothari, 2015). It points out that, while there is often a considerable gap between local and Indigenous ways of knowing environments and scientific evidence that drives climate change policy and adaptation, there is also appreciable complementarity between them and potential for integration (see Byg & Salick, 2009; Ifejika Speranza et al., 2010; King et al., 2008; Lefale, 2010; Matera 2020; McNamara & McNamara, 2011; Mercer et al., 2007; Postigo, 2019; Riedlinger & Berkes, 2001). Indeed, there is often mutual recognition among scientists and local people of the value of these different ways of knowing and the various ways in which they can complement and strengthen each other to produce new ways of understanding and sensing the world that go beyond the basic task of enrichening and enlivening scientific 'facts' about environmental change (Alexander et al., 2011; Gagné et al., 2014; Klenk et al., 2017; Shawoo & Thornton, 2019).

Local knowledge informs some scientific assessments. As Hakkarainen et al. (2019: 282) write, '*scientists are increasingly participating in activities beyond knowledge production such as multi-way interactions and knowledge co-production with decision makers and other beneficiaries of science'*. For example, Ignatowski and Rosales (2013) argue that Alaskan Indigenous knowledge enriches scientific assessments that Arctic coasts are retreating at a rate of two to three meters per year due in large to declining sea-ice and rising sea level; in this study an Indigenous Alaskan resident explained, '*we have lost a lot of coast line… some of the trails we walked on are in the ocean now due to erosion. The high cliffs are losing ground. There is no more beach due to many of the waves, the pounding'*. And scientific knowledge informs some local understanding. For example, Rudiak-Gould (2014) argues that Marshallese observation of the environment is influenced by climate science communication. And Graham et al. (2014) suggest that people living in areas in Australia prone to coastal flooding overlay scientific assessments of SLR with social values and outcomes such as security and belonging. Studies such as these underscore the ways in which different bodies of knowledge can overlap to produce insightful socio-environmental understandings of climatic and environmental change.

Second, at the level of adaptation planning, communities can be valued as agents of change with important knowledge and adaptive capacity (Hiwasaki et al., 2014; Finucane, 2009; Nunn et al., 2017; McNamara et al., 2020; McNamara & Westoby, 2011; Mercer et al., 2007). Local knowledge can add insight through its focus on the human dimensions of climate change, how changing local environments affect customs and practices, and dynamic real-time observations of changing environments (Berkes, 2018; Ignatowski and Rosales, 2013). The value of local knowledge and skills has been demonstrated in the Pacific Islands, where traditions of coastal stonework to adapt to sea level changes and maintenance of coastal vegetation to control erosion can support climate adaptation (Bridges & McClatchey, 2009; Nunn et al., 2017). There is a need to enhance '*thoughtful and respectful integration*' so that local knowledge can inform science and so that local people, including Indigenous peoples, '*can use the tools and methods of science for the benefit of their communities if they choose to do so*' (Alexander et al., 2011: 477; Hakkarainen et al., 2019: 282). Studies report a wide range of techniques for achieving this integration and improving dialogue between scientists and local communities. These include approaches based on visualisation (Lieske et al., 2015), public participation (Molina & Neef, 2016), engagement strategies to improve understanding about SLR and response options (Uittenbroek et al., 2019), and multi-method research (Crate & Fedorov, 2013; Pennesi et al., 2012).

These changing approaches and priorities are, to some extent, reflected at the international level in recent global-level agreements and initiatives. Thus, attempts to ensure the inclusion of local and Indigenous knowledge as a corroboration and corrective to scientific assessments of climate change are evident in IPCC Assessment Reports and the United Nations Framework Convention on Climate Change (UNFCCC) platform (Ford et al., 2016; Shawoo & Thornton, 2019). The recent IPPC special report on the Ocean and Cryosphere states that '*awareness and understanding about SLR risks and responses can be improved by drawing on local, indigenous and scientific knowledge systems, together with social learning about locality-specific SLR risk and response potential*' (Oppenheimer et al., 2019: 325). Conversely, the report warns that lack of recognition and loss of local and Indigenous knowledges around sea level change may increase vulnerability to SLR (Oppenheimer et al., 2019: 374). These are positive developments within international policymaking circles, albeit ones that fall somewhat short of explicitly recognising the intrinsic value of local / Indigenous knowledges for their own sakes.

The above argument, that integrated knowledge can better support effective and appropriate decision-making, is a relatively utilitarian position. However, valuing and integrating local and Indigenous knowledge is also a matter of agency, rights, justice and meaningful engagement in policy and practice. As Lidström (2018: 23) warns, predicting '*sea-level rise primarily through natural science accounts may steer public understanding and attention away from relevant societal and political considerations, and lead to reductive and even unjust conclusions*'. Further, she argues that '*reducing the complexity of sea-level rise to predictions made by natural sciences can decrease people's sense of agency and interest in relevant policy-making*' (2018: 25). So, another reason for the integration of local and scientific knowledge is that, where demands for integration are led by Indigenous people, incorporation of these knowledge systems can help advance Indigenous people's agency and rights and achieve development goals (Naess, 2013). This is less a matter of enhancing understanding of climate change and more one of climate justice, participation and inclusion, and specifically the need to give proper recognition to those most affected by climate change (Arnall et al., 2019; Walker, 2012). If the views and ideas of local populations and Indigenous groups have traditionally been marginalised in climate change debates at national and local levels, the reasoning goes, then sensitive and respectful incorporation of their knowledge with Western-based systems of knowing will raise their status and visibility accordingly.

There are, however, competing perspectives that suggest that the integration of scientific and local knowledge is difficult and/or undesirable. The obstacles to knowledge integration are considerable given: different forms of knowledge can diverge or disagree, and they encompass diverse temporal and spatial dimensions; indicators and ways of systemising knowledge are difficult to compare and align; and the rapid pace of climatic and ecological changes (such as Arctic ice-melt) can limit the relevance of long-standing local and Indigenous knowledge (Betzold & Mohamed, 2017; McMillen et al., 2014; Nunn, 2009; Nunn et al., 2014; Oppenheimer et al., 2019; Ulloa, 2019: 75). Socio-political challenges need to be considered such as: who decides which local knowledge should be integrated, according to what ethical and epistemological frameworks, and how does this integration affect the integrity of local knowledge (Shawoo & Thornton, 2019). In one example, a project in coastal areas of Indonesia, the Philippines and Timor-Leste aimed to integrate local/Indigenous knowledge with scientific knowledge to increase community resilience to disaster and climate change: communities and scientists identified local/Indigenous knowledge that could be 'validated' by and integrated with science (e.g. coastal planting coastal to mitigate impacts of high waves and erosion), but knowledge that was not supported by science but that helped build community resilience was categorised as unable to be integrated with science (e.g. ritual practices such as offerings to the divine) (Hiwasaki et al., 2014). This points to socio-political challenges from a process that assesses local knowledge and practice against the authority of science. There is the risk of local knowledge '*being parsed and transformed to fit within the epistemological and ontological premises of western science*' (Klenk et al., 2017: 2). So, there may be significant tensions and disagreements that make integration difficult in some contexts.

Importantly, knowledge integration is not just about scientists integrating relevant local and Indigenous knowledge with scientific evidence. As stated above, many local populations draw on climate science and indicators to make sense of their observations of environmental and coastal changes (Cutler et al., 2020; Marin & Berkes, 2012; Milfont et al., 2014; Reser & Bradley, 2020; Rudiak-Gould, 2013). Some local people in coastal regions draw on methods typically associated with science - such as forms of modelling, experimentation and verification – to understand and predict sea level change (Rudiak-Gould, 2014). And local and Indigenous populations have an important role to play in identifying priority areas for scientific research. For example, Huntington et al. (2019) call for decolonising methodologies whereby Arctic residents are not merely local experts who contribute context and local insight to climate science endeavours, such as quantitative measures of sea-ice extent or coastal erosion; rather Arctic residents identify areas for scientific research that matter to them. This approach is evident in the Alaskans Sharing Indigenous Knowledge (AKSIK) science and advocacy project that documented the climate impacts and adaptation needs for Indigenous people in Savoonga and Shaktoolik and co-produced knowledge between scientific/academic researchers and Indigenous people (Ignatowski & Rosales, 2013). The aim, then, is to preserve, draw on and draw together different knowledge to produce new and nuanced insights and innovations without extracting or undermining local knowledge. This is not just a matter of '*integration of local and indigenous knowledge with science*' (Hiwasaki et al., 2014: 25) but also integration of scientific knowledge with local and Indigenous knowledge, values and priorities.

Integration of knowledge around coastal change and SLR is occurring by local/Indigenous populations and scientists, at the level of adaptation planning, and within regional and global frameworks and initiatives (often as stated intentions to value and integrate lay and Indigenous knowledge). Arguably, the key value of integrating scientific and local/Indigenous knowledge lies in development of adaptation strategies that are responsive to the situations, values and priorities of coastal-based populations. Adaption initiatives need to consider scientific assessment of SLR and geomorphological features of coastal risk, but also local perception and experience of those changes and risks, and adaptation measures that are appropriate for the socio-ecological context (Ratter et al., 2016). However, we also need to be cognisant that knowledge integration, while often possible and desirable, is not a panacea, particularly if it is conducted superficially, or in a manner that does not respect people's priorities and rights. The authority of science is often deeply embedded and presumed; attempting to rebalance this relationship in relation to climate change and SLR is therefore an ongoing project.

6. Conclusion

Sea level rise is a measurable phenomenon at a global, regional and local scale, but its impacts (lived, perceived, and anticipated) are produced through encounters between people and land-sea scapes. The aim of this paper has been to assess different ways of knowing SLR with a focus on scientific and local knowledge. We have shown how scientists have tended to focus on the vertical dimensions of SLR while local populations living at the land-sea interface are more concerned with horizontal inundation and, accordingly, its effects on landscapes, lives and livelihoods. Moreover, whereas the scientific approach is to explicate the temporal dimensions of SLR, relating changes to particular points in time, local-based knowledges are more implicated in nature, related to memory of place, everyday life, and future aspirations and anxieties. Of course, these are not clear cut distinctions. It is important to recognise that scientific research is never entirely 'neutral' and even the most rigorous scientific work is culturally located and shaped by the milieu within which it takes place in ways that is commonly associated with local/Indigenous way so knowing and being. Similarly, local / Indigenous people often perceive and measure environmental changes in the places in which they live in ways that resemble 'scientific' methods of problem solving. Nonetheless, the scientific and local/Indigenous are sufficiently different in outlook and emphasis to justify, at least in an analytical sense, invoking them in this paper.

In considering ways in which these related knowledges can be complimentary, integrated and mutually constitutive, the paper has illustrated how the bringing together of diverse perspectives can help extend and deepen understandings of SLR and its impacts. As McMillen et al. (2014) argue, social-ecological resilience to climate change requires knowledge at both local and global scales that can respond to the dynamic nature of human-environment encounters. However, despite this need, lasting and meaningful integration between scientific and local knowledge around climate variability remains limited with the former continuing to dominate global assessments, such as IPCC reports. External scientific knowledge and perspectives remain the preference of donors on which to base their local adaptation policies and implementation (Alexander et al., 2011; McNamara et al., 2020; Smith & Sharp, 2012; Ulloa, 2019). As this paper has shown, this situation is deficient. In addition to the utilitarian need to enhance integrated knowledge to better support effective and appropriate decision-making, it is increasingly recognised that taking seriously local/Indigenous knowledge is important *per se* if people's agency and rights are to be recognised, upheld and promoted. This means valuing local/Indigenous knowledge in its own right, as well as seeing its usefulness relative to formal, scientific knowledge.

Our review found that there are many scientific assessments of SLR and related impacts, many studies that document local insight and observation of coastal change, and some studies that refer to the ways in which local perception and knowledge of SLR and coastal change confirm or complement scientific evidence. However, the body of research that seeks to concurrently view both local and scientific knowledge of SLR, and to consider complementarities and contradictions is limited. Further work on SLR and coastal change is needed that draws on the insight of science and that also actively engages with and is led by actors and organisations that produce and represent local knowledge (Tengö et al., 2017). This could provide an enriched picture of how we understand and address SLR and associated impacts across diverse contexts. This has potential to widen the scope of knowledge and enhance the relevance of knowledge for a wide range of actors. We have also shown, however, that it is necessary to remain cognisant of where the limits to this merging project lie and that, for ontological and epistemological reasons, greater integration might not always be feasible or possible.

Moreover, greater integration between scientific and local/Indigenous knowledges in isolation is unlikely to be sufficient to meet the global climate change challenge. Despite considerable scientific evidence of the biophysical impacts of SLR, and local knowledge and lived realities of low-lying coastal populations, greenhouse gas emissions continue to rise (Sarewitz 2011). The challenge to limit anthropogenic climate change will not be addressed by increasing the availability of scientific knowledge, nor by making visible local observations and experiences of climate risk; it will also require socio-political engagement and political will and leadership at multiple levels (Hulme, 2009). This is not to undermine the need for facts, figures and data visualisation of scientific climate assessments, and local understanding and accounts of climate impacts, or a combination of knowledges. It highlights the urgent need for deeper understanding of the nature and impact of SLR – through local knowledge and experiences, alongside scientific measurement and modelling – to push political will and action.

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Spatial and temporal ways of knowing sea level rise: bringing together multiple perspectives

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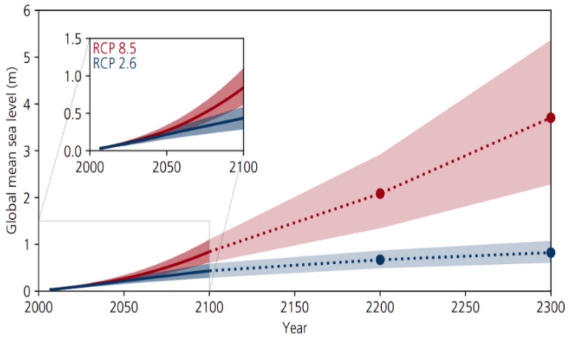
Graphical / visual abstract



Ways of knowing sea level rise: scientific measurement and modelling of global mean sea level rise (Figure: IPCC 2019) and local knowledge and experience of changes in the land-sea interface (Plate: previous location of a relocated coastal village in Fiji, photo by Celia McMichael, 2015)

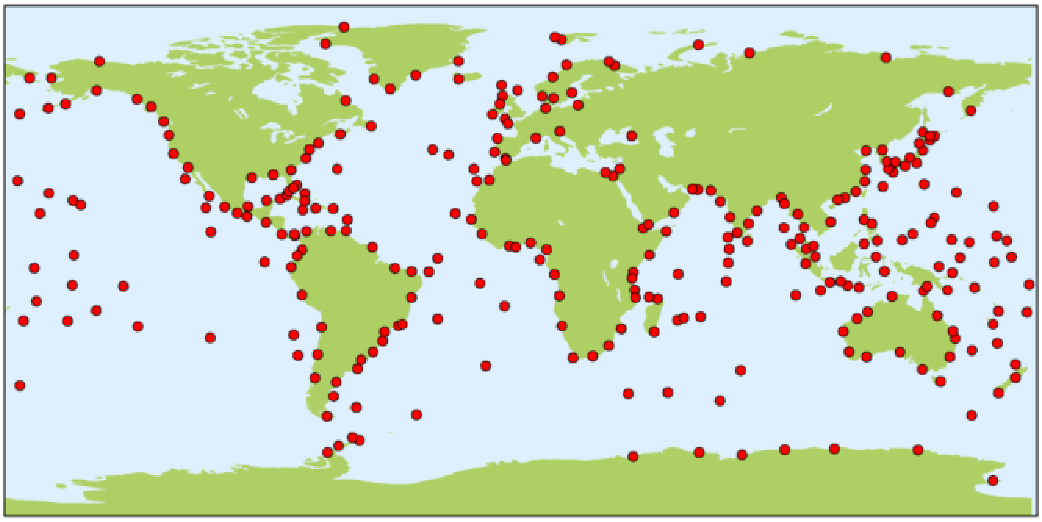


Figure 1: Map of the global distribution of tide gauges (GLOSS, 2010)

Plate 1: Attempts to protect home from the inward and horizontal encroachment of the sea on Erub Island in the Torres Strait, Australia (photo by XXXX, 2009)