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How can climate predictions improve sustainability of coastal fisheries in Pacific Small-Island Developing States?

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A B S T R A C T

Climate and weather have profound effects on economies, the food security and livelihoods of communities throughout the Pacific Island region. These effects are particularly important for small-scale fisheries and occur, for example, through changes in sea surface temperature, primary productivity, ocean currents, rainfall patterns, and through cyclones. This variability has impacts over both short and long time scales. We differentiate climate predictions (the actual state of climate at a particular point in time) from climate projections (the average state of climate over long time scales). The ability to predict environmental conditions over the time scale of months to decades will assist governments and coastal communities to reduce the impacts of climatic variability and take advantage of opportunities. We explore the potential to make reliable climate predictions over time scales of six months to 10 years for use by policy makers, managers and communities. We also describe how climate predictions can be used to make decisions on short time scales that should be of direct benefit to sustainable management of small-scale fisheries, and to disaster risk reduction, in Small-Island Developing States in the Pacific

1. Introduction

Variability in weather and climate across spatial and temporal scales has a range of human and ecological impacts. Variability over long time scales (centennial and longer) has impacted viability of human civilizations [93] and redefined the distribution of major biomes [24]. At seasonal and interannual time scales, biomes, animal movements and human agricultural practices are influenced by climatic events [40], while daily and monthly variations in weather, including extreme events, also lead to dramatic impacts on people and environments [30,76,82]. These patterns of variability are superimposed on long-term, global climate change trends. Oceans are warming and altering environmental conditions in many regions, with impacts apparent across all sectors of the blue economy, from fishing to transport to energy generation [43,69].

The well-being of Pacific Island countries and territories (PICTs) is tightly linked to oceans and climate. PICTs can largely be thought of as small-island, large-ocean, developing states: combined, the area of their landmasses is only 2% of that of their exclusive economic zones (EEZs). Marine resources often provide the majority of income and protein for coastal communities [13]. A recent study estimates the production of Pacific Island coastal fisheries (i.e., those that harvest wild demersal fish and invertebrates from inshore coastal habitats and pelagic fish from nearshore waters for either commercial or subsistence purposes) to have been around 163,936 mt in 2014, worth approximately US$453 million [31]. Consumption rates of fresh fish among Pacific coastal communities are among the highest in the world, with average consumption in the majority of PICTs being 2–4 times the global average and with 50–90% of dietary animal protein in coastal, rural areas being derived from fish [12]. Coastal fisheries also provide many livelihoods across the region, with an average of 50% of surveyed coastal households in 17 PICTs receiving their first or second income from activities related to fishing [70].

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food security and livelihoods of communities, throughout the Pacific Island region [14]. Patterns of climate variability on the scale of days to years affect these communities in different ways. The most well-known oceanographic pattern affecting Pacific Island communities is the El Niño-Southern Oscillation (ENSO) [76]. Multi-month El Niño and La Niña events cause: (i) variation in the distribution, and hence regional catch, of tuna [54,55]; (ii) extensive coral bleaching events that reduce local fish abundance [46,72]; and (iii) influence the distribution of tropical cyclones, which can result in severe impacts to fish habitats and fishing infrastructure.

The ability to understand and anticipate changes in key climatic variables, e.g., sea surface temperature (SST) and circulation patterns, and predict weather events over the scale of months to decades offers immediate opportunities to governments and coastal communities to mitigate climate impacts and increase adaptive capacity. Development of models to forecast future climate states are developing quickly [61,64,75] and may allow predictive skill from six months out to a decade [9,60,80,81,91]. This will require the development of new approaches to designing and implementing climate adaptation policies, as management decisions respond to changing conditions over a range of time scales. Further, by taking advantage of the ability to mitigate, adapt and plan for change on inter-annual time scales, communities will be more able to respond to changes that occur over longer time scales [41].

In this paper, we outline the potential for climate predictions to support the adaptation and development of coastal fisheries in Small Island Developing States, focusing primarily on the Pacific Islands. We clarify the differences between climate prediction and projection, and which climate conditions might be skillfully predicted. We review documented examples of weather impacts on fisheries in the Pacific Islands region and identify how predictions could inform management. We then use this information to identify how predictions of climate variability can help forge policies to reduce the impacts of climatic variability on, and increase the adaptive capacity of, coastal fisheries.

2. Difference between prediction and projection

The terms ‘climate prediction’ and ‘climate projection’ are often confused as being the same. With regard to modelling the future, they are different activities with substantially different objectives. A *climate prediction* is aimed at describing the actual state of the climate system at a particular point in time, whereas a *climate projection* is aimed at describing the average or statistical properties of the climate system over a future time window.

For example, seasonal climate predictions attempt to forecast climate anomalies several months ahead, such as describing the actual state of large-scale modes of the climate system (e.g. La Niña conditions) or environmental conditions (e.g. surface temperatures) at a particular point in time. This is an initial-value problem that requires the climate model to start off in the same state as the real climate system and track the evolution of ENSO and other climate modes as they progress through particular phases. Initialization of the correct ENSO phase allows global climate prediction systems to forecast the evolution of tropical SSTs and the average weather over the next month or season. A climate projection, on the other hand, characterises the change in statistical properties of climate modes such as ENSO over a future period. A projection does not attempt to specify the ENSO phase at a given time, but rather whether one phase of ENSO will tend to be favoured more than another, or average temperatures, in a future timeframe, typically on the scale of decades and longer. Models used to make climate projections evolve in response to external forcing of the climate system (e.g., increasing CO_2). They do not need to be initialised to a particular ENSO phase when they start because they are not intended to track specific changes in that phase [75].

Skillful climate predictions may be extended to longer time scales than months by exploiting and focusing on slower processes in the climate system [61,64], such as the Pacific Decadal Oscillation (PDO). The basic principal is the same as weather forecasting – a longer-term climate prediction will be initialised to the current phase of the PDO and will attempt to track and predict the phase of the PDO. Climate projections by contrast, do not, and cannot, keep track of the particular phase of processes like the PDO [75].

3. Current understanding of climate variability and extremes in the Pacific

The heat content of the ocean is dynamic and SST varies on multiple temporal and spatial scales, with (for example) seasonal cycles being generally larger at higher latitudes (see [29]) for the Australian region). Although well studied, SST is not easily predicted and a notable source of uncertainty comes from the onset, severity and duration of ENSO [83]. Extreme and prolonged variations in SST unrelated to seasonal variations constitute events known as marine heatwaves [42]. The dominant driver of marine heatwaves in the subtropical and tropical Pacific Ocean is ENSO [83]. The Oscillation forces marine heatwaves in the central and eastern Pacific directly as an expression of El Niño and elsewhere either directly or indirectly through the processes that ENSO influences, including modified wind patterns and cloud coverage, which in turn impact air-sea heat fluxes.

Rainfall variability in tropical regions varies in conjunction with local convective processes and organised larger-scale convection in convergence zones. It is also influenced by the proximity to the tracks of tropical cyclones, which can deliver extreme rainfall in some years. Throughout the Pacific basin, variability of rainfall is strongly linked to the ENSO cycle, driven by shifts in the positions of large-scale convective zones. In the tropical Indian Ocean, precipitation is influenced by local monsoon circulations and by ENSO and the Indian Ocean Dipole (IOD).

Outside the tropics, variability in rainfall is set mainly by variations in atmospheric jet streams and storm tracks. These respond in part to tropical features such as ENSO and the IOD, but also to internal modulations and to changes in high latitudes that affect meridional temperature gradients in the atmosphere and the formation of genesis zones for storms. The Southern Annular Mode (SAM) represents north-south variations in the storm tracks, while the major blocking regions of the Southern Hemisphere [63] represent the east-west variation in storm track activity [74]. Both SAM and blocking high pressure systems modulate rainfall over the Southern Hemisphere extratropics.

Variability in rainfall is partly predictable on longer time scales when it relates to slower varying modes in the oceans and cryosphere [61]. For example, rainfall variations related to ENSO are partly predictable on time scales of months, whereas variations due to the PDO may have predictability spanning years [64]. These patterns are reflected in the large-scale spatial variations of upper ocean salinity, which integrates rainfall, thereby offering scope for enhanced predictability [65]. The controls of long-period variations in blocking and associated extreme rainfall events are still not well understood, but may also offer some scope for predicting rainfall [74].

The ENSO state offers some predictability of the frequency and potential location of cyclones in the southwest Pacific Ocean region [8,25,58,86]. During El Niño conditions, cyclones occur most frequently between Vanuatu and Fiji, and chances of occurrence are also high further east towards Samoa, southern Cook Islands and French Polynesia [52]. Under La Niña conditions, tropical cyclones are more frequent in the Coral Sea, and absent from Cook Islands eastwards [25].

4. Climate impacts on small-scale fisheries – case studies from the Pacific Islands region

4.1. Marine heatwaves

Marine heatwaves, defined as ‘a prolonged discrete anomalously