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Review Paper

Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific — A regional assessment

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ABSTRACT

This paper reviews the current understanding of the effect of climate change on extreme sea levels in the South Pacific region. This region contains many locations that are vulnerable to extreme sea levels in the current climate, and projections indicate that this vulnerability will increase in the future. The recent publication of authoritative statements on the relationship between global warming and global sea level rise, tropical cyclones and the El Niño-Southern Oscillation phenomenon has motivated this review. Confident predictions of global mean sea level rise are modified by regional differences in the steric (density-related) component of sea level rise and changing gravitational interactions between the ocean and the ice sheets which affect the regional distribution of the eustatic (mass-related) contribution to sea level rise. The most extreme sea levels in this region are generated by tropical cyclones. The intensity of the strongest tropical cyclones is likely to increase, but many climate models project a substantial decrease in tropical cyclone numbers in this region, which may lead to an overall decrease in the total number of intense tropical cyclones. This projection, however, needs to be better quantified using improved high-resolution climate model simulations of tropical cyclones. Future changes in ENSO may lead to large regional variations in tropical cyclone incidence and sea level rise, but these impacts are also not well constrained. While storm surges from tropical cyclones give the largest sea level extremes in the parts of this region where they occur, other more frequent high sea level events can arise from swell generated by distant storms. Changes in wave climate are projected for the tropical Pacific due to anthropogenically-forced changes in atmospheric circulation. Future changes in sea level extremes will be caused by a combination of changes in mean sea level, regional sea level trends, tropical cyclone incidence and wave climate. Recommendations are given for research to increase understanding of the response of these factors to climate change. Implications of the results for adaptation research are also discussed.

Contents

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1. Introduction

There can be few locations in the world that are more vulnerable to the impacts of climate change than the low-lying atoll island nations of the Pacific (Fig. 1). Even at current mean sea levels, vulnerability to extreme sea levels is large. For instance, in 1972, Cyclone Bebe caused great damage to Funafuti, leaving behind a large rampart of coral debris (Maragos et al., 1973). In 1990, Cyclone Ofa struck Samoa, with a high storm tide inundating many low-lying coastal regions. In 1997, the storm surge from Cyclone Gavin breached sea walls on the north coast of Vanua Levu island in Fiji, causing extensive flooding of Labasa town, the largest urban area on the island. In 2004, large waves accompanying Cyclone Heta caused significant damage to Niue, with much of the infrastructure on the island destroyed (Terry, 2007). Other significant impacts have occurred, highlighting the vulnerability of this region to inundation from extreme sea levels.

Predicted rising sea levels will lead to increases in inundation that put the future viability of human habitation on a number of Pacific islands at risk (Mimura et al., 2007; Nicholls and Cazenave, 2010). Increases in extreme sea levels are arguably the most significant threat that this region faces from anthropogenic climate change (Mimura et al., 2007), yet our ability to predict the future vulnerability of this region is limited. The main reason is that the climate of the tropical Pacific is already extremely variable due to the strong influence of the El Niño Southern Oscillation (ENSO) phenomenon, which has its source in this region (Sarachik and Cane, 2010). This makes it difficult to detect any trends above the existing large interannual variability. In addition, predictions of future tropical cyclone incidence in this region generally indicate substantial decreases in numbers, but current interannual variability of cyclone incidence is also very large (e.g. Chand and Walsh, 2009).

The recent publication of authoritative review papers on the effects of climate change on ENSO (Collins et al., 2010), climate change on tropical cyclones (Knutson et al., 2010a) and sea level rise and variability (Church et al., 2010b) provides an opportunity to reassess the possible impacts of climate change on extreme sea levels in the South Pacific, since in the current climate the interannual variation of both tropical cyclone behaviour and extreme sea levels is dominated by ENSO.

Extreme sea levels are the result of several coinciding processes, including astronomical tides and severe weather events such as tropical cyclones, which generate elevated coastal sea levels through storm surge and high waves (Fig. 2). Storm surges from tropical cyclones are well-known and documented events along many tropical continental shelf regions, where destructive sea levels are caused by the inverse barometer effect (IBE) and wind stress over the shelf seas (e.g. Fritz et al., 2007; Dube et al., 2009; Harper et al., 2009). Sea levels along the open coast may be further elevated by wave breaking processes. Paradoxically, the shelf conditions that favour high storm surges tend to attenuate the contribution of waves, and the shelf conditions that act to attenuate storm surges allow a larger contribution of waves. This is because wide and gently sloping continental shelves cause waves to steepen, break and lose energy and height further offshore, thereby reducing the wave heights at the coast. Steep shelf margins such as those that surround many islands and atolls in the Pacific, on the other hand, are less conducive to high storm surges but may instead support larger wave-induced contributions to sea level anomalies, which have been reported at Midway Atoll in the northern tropical Pacific by Hoeke (2010).

Tropical cyclone-induced storm surges tend to be localised and concentrated in the region of maximum onshore winds close to the cyclone centre. While potentially devastating, they are rare at any given location and therefore contribute to the extreme tails of the distribution of sea level anomalies. The waves generated by such systems, on the other hand, can propagate for thousands of kilometres in the deep ocean as swell with little loss of energy, potentially affecting a larger number of more distant shorelines. Therefore they may contribute to more frequent sea level anomalies, although these may be of smaller magnitude than the combined impacts of storm surge and local storm waves. Tidal extremes vary on predictable

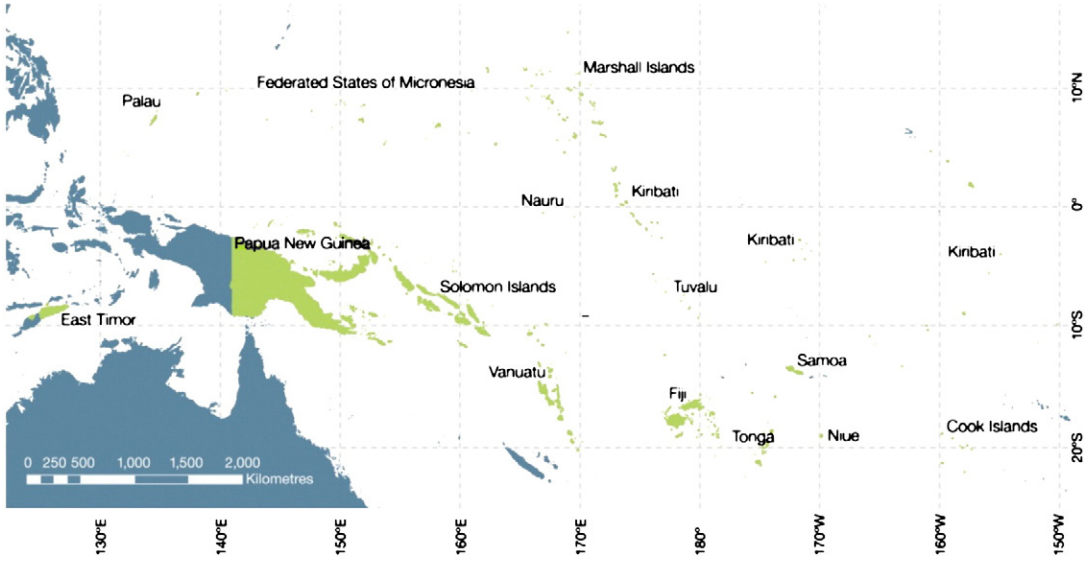

Fig. 1. Map of locations mentioned in the text.