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Annex 1

M. Wandres et al., “A National-Scale Coastal Flood Hazard Assessment for the Atoll Nation of Tuvalu”, *Earth’s Future* (forthcoming 2023) (excerpts)

A national-scale coastal flood hazard assessment for the atoll nation of Tuvalu

Authors: Moritz Wandres[1,2*], Antonio Espejo[1,2], Tomasi Sovea[1,2], Sapolu Tetoa[3], Faatasi Malologa[3], Arthur Webb[4], James Lewis[5], Gary Lee[1,2], Hervé Damlamian[1,2]

[*]**Corresponding Author:** Moritz Wandres, Pacific Community (SPC) – Private Mailbag, Suva, Fiji

Email: moritzw@spc.int

Affiliations:

[1]Geoscience, Energy and Maritime (GEM) Division, Pacific Community (SPC), Suva, Fiji

[2]Pacific Community Centre for Ocean Science (PCCOS), Pacific Community, Suva, Fiji

[3]Lands and Survey Department, Government of Tuvalu, Funafuti, Tuvalu

[4]Resilience & Sustainable Development Unit, United Nations Development Programme (UNDP), Suva, Fiji

[5]Intercoastal Consulting, Burleigh Heads, Australia

Abstract

Atoll nations such as Tuvalu are considered to be amongst those most vulnerable to the effects of climate change. Here we present a national-scale coastal flood hazard assessment for Tuvalu based on high-resolution Light Detection and Ranging (LiDAR) topography and bathymetry. We follow a fully probabilistic approach, considering sea level anomalies, tides, and extreme wave conditions from a mixed climate (i.e., from distant extra-tropical storms and local tropical cyclones). Nearshore processes such as wave setup and runup are also accounted for. Hazard maps were calculated for the present sea level, as well as for sea level rise projections corresponding to different shared socioeconomic pathways (SSP2 4.5 and SSP5 8.5) and time horizons (2060 and 2100).

With a mean elevation of 1.55 m above mean sea level (1.37 m above mean high water spring) >25% of land area is inundated once every five years and >50% of land area floods once every 100 years nationally. Results indicate that present day 1-in-50 year floods (>45% of land area flooded) will occur more than once every five years by 2060 (annual exceedance probability >20%), even under the moderate SSP2 4.5 sea level rise projections. Results of this study highlight the pressing need for ambitious and large-scale adaptation solutions which are commensurate with projected sea level rise and marine hazard impacts. The methodologies presented in this paper can easily be applied to other low-lying islands in the tropical Pacific, where mixed climates (i.e., regular and TC conditions) and non-linear nearshore processes dominate extreme water levels and flooding.

Plain language summary

Low-lying atoll nations such as Tuvalu are widely recognised to be amongst those most impacted by the effects of climate change. To make informed adaptation decisions, accurate baseline data (i.e., topography and bathymetry) and marine hazard information are fundamental. In this paper we present a national-scale coastal flood hazard assessment for Tuvalu based on state-of-the art high-resolution baseline data and statistical and numerical models. We considered the present-day sea levels and sea level rise projections corresponding to different climate change scenarios. Under present-day sea levels >25% of Tuvalu’s land area floods once every five years and >50% of land area floods once every 100 years. Our results indicate a significant increase in severity and frequency of extreme coastal flooding due to climate change with present-day 1-in-50-year floods occurring more than once every five years by 2060. This study highlights the pressing need for ambitious and large-scale adaptation solutions. The methodology presented here is suitable to be used in other Pacific Island locations.

Key points

- We present a probabilistic flood hazard assessment of Tuvalu considering tides, sea level anomalies, storm surges, and waves from a mixed climate (i.e., generated by tropical and extratropical storms)
- A mean elevation of 1.55m above MSL makes Tuvalu highly vulnerable to wave driven flooding with >25% of land area inundated once every 5 years
- Present day 1-in-50 year floods (>45% of land area flooded) will occur more than once every five years by 2060 due to sea level rise

1. Introduction

Small Island States are widely recognised to be amongst those most impacted by the effects of climate change (Mycoo et al., 2022). Recent studies project a significant increase in the frequency and extent of coastal flooding in the tropical Pacific (Shope et al., 2016; Vitousek et al., 2017), posing a strong risk to the habitability of many atolls and low-lying reef islands over the coming decades (Storlazzi et al., 2018). This is particularly the case when considering other risk factors such as freshwater or land-based food supply (Duvat et al., 2021). A detailed localised understanding of the coastal inundation hazard of atolls is therefore critical for targeted adaptation and resource prioritisation. The island nation of Tuvalu is one of the few countries in the world that consists exclusively of low-lying atolls and reef islands. As such, the country and Tuvaluan People are particularly vulnerable to coastal flooding (Duvat et al., 2021; Taupo et al., 2018). For example, in 2015 most of Tuvalu's islands were severely impacted by large waves, generated by distant-source tropical cyclone (TC) Pam (Hoeke et al., 2021). In 2018, a large swell generated by an extra-tropical low-pressure system in the Southern Ocean and Tasman Sea caused extensive flooding in some of Tuvalu's southern islands (Tuvalu Meteorological Service, 2018). Additionally, to large waves generated by distant storms, Tuvalu also experiences direct hits from TCs (such as TC Bebe in 1972) and associated extreme wave and water level conditions (e.g., Maragos et al., 1973). Apart from relatively frequent wave-driven inundation events, many low-lying areas in Tuvalu regularly flood during spring tides as marine water percolates through the porous limestone and temporarily fills depressions at the surface (Patel, 2006; Yamano et al., 2007).

Coastal inundation in fringing-reef environments often occurs as a compound event, where waves, tides, and sea level anomalies all interact non-linearly to generate extreme total water levels (TWLs) and flooding (e.g., Becker et al., 2014; Ford et al., 2018; Hoeke et al., 2013; Wandres et al., 2020).

There are two important wave-driven mechanisms that contribute to nearshore water levels on reef-mediated shores such as the islands of Tuvalu (e.g., Beetham et al., 2016). Waves dissipate as they break on the reef edge and the excess momentum flux in the water column causes a steady elevation of the mean still water surface (e.g., Becker et al., 2014). On reef-fronted islands, this effect (called wave setup) has been found to reach up to one third of the incident offshore wave heights (Munk & Sargent, 1948; Tait, 1972; Vetter et al., 2010). The dissipation of swell groups also generates infragravity (IG) waves (bore-like uprush of individual waves onto the beach), which can significantly contribute to the total runup, which can be defined as the sum of wave setup, IG waves, and waves in the sea and swell frequency bands (Baldock, 2012; Pomeroy et al., 2012; van Dongeren et al., 2013; Beetham et al., 2016). Wave setup and IG waves are strongly modulated by the offshore water level conditions (i.e., tides and sea level anomalies; Beetham et al. 2016).

The multivariate nature of wave-driven flooding makes the determination of wave driven inundation intensity and likelihood challenging. Hoeke et al. (2021) recently investigated nearshore extreme TWLs in Tuvalu over a 40-year period using an empirical equation by Merrifield et al. (2014). The methodology allowed to assign a probability to historical flood events such as the severe inundation from distant tropical cyclone (TC) Pam in 2015. While this is useful in terms of risk knowledge and community awareness, the methodology does not (and was not intended to) provide actionable hazard information such as flood depth and extent. Process-based numerical models such as XBeach (Roelvink et al., 2009) or SWASH (Zijlema et al., 2011) have been shown to accurately resolve the nonlinear processes associated with reef-fronted flooding (e.g., Buckley et al., 2014; Quataert et al., 2015; Storlazzi et al., 2018). However, these models are computationally expensive, making their usage over large areas difficult and time consuming. To address this, Pearson et al. (2017) developed a Bayesian-based system to assess wave-driven flooding on reef-fronted coasts by creating a large synthetic database of XBeach simulations. Rueda et al. (2019) expanded on the work by applying an interpolation technique to efficiently obtain runup estimations for infinite combinations of reef-morphologies and oceanographic forcings. More recently, Liu et al. (2023) developed an explicit wave-runup formula based on Pearson et al.'s (2017) database. However, the synthetic database of simulations only includes waves smaller than 5 m, making it unsuitable for areas with TCs (i.e., where wave heights are exceeding 5 m).

Other studies investigating exceedance probabilities of extreme TWLs in areas of TCs indicated some issues in estimating return intervals for rare extreme TWLs using conventional methods such as Generalized Extreme Value (GEV) distribution. Firstly, the infrequency of TCs often fails to capture TC-driven extreme TWLs of longer return periods, particularly when basing the extreme value analysis on short observation periods (e.g., Haigh et al., 2014; O'Grady et al., 2019). Secondly, in areas where TCs and distant-storms (along with tides and atmospheric variability) modulate TWLs, the mixed nature of the extreme value distributions require special consideration (O'Grady et al., 2022).

Here we present a novel, comprehensive approach to assess probabilistic inundation hazard in reef-fronted islands, accounting for all relevant drivers of coastal inundation, i.e., waves generated by tropical cyclones, extra-tropical storms, tides, and sea level anomalies. Nearshore processes such as wave setup and runup (e.g., IG wave motions) are also accounted for. The hazard assessment is based on state-of-the-art Light Detection and Ranging (LiDAR) bathymetry and topography data.

Tuvalu's National Strategy for Sustainable Development 2021-2030 ('Te Kete') sets out the nation's high-level strategic plan to achieve "a peaceful, resilient and prosperous Tuvalu" (Government of Tuvalu, 2020). National outcome 4 of Te Kete is focused on increased climate change and disaster resilience. The coastal hazard information presented in this paper are fundamental for Tuvalu to make science-informed adaptation decisions.

The paper is structured as follows: Section 2 describes the study site and the oceanographic conditions of Tuvalu. The underlying data are described in Section 3. The methodology to derive extreme offshore ocean conditions is outlined in Section 4 and the inundation modelling approach is described in Section 5. Results are presented in Section 6 and discussed in Section 7.

2. Study site

Tuvalu consists of nine atolls and low-lying reef islands (Figure 1). The country has a population of 10,645 people according to a 2017 census (Government of Tuvalu, 2017), with the majority living in the capital atoll of Funafuti and with the entire population living a few meters from the coastline (Andrew et al., 2019). Like other coral reef islands, Tuvalu’s islands consist of unconsolidated and/or poorly lithified carbonate sand and gravel deposits on top of coral reef platforms (Webb & Kench, 2010). Five of the islands are classified as true atolls (Nanumea, Nui, Nukufetau, Funafuti, and Nukulaelae), meaning they have an essentially continuous rim of reef at or near the surface of the sea which surrounds a deeper lagoon. Three of the islands are classified as table reefs (Nanumaga, Niutao, and Niulakita), meaning they have a continuous land margin that completely encircles a shallow enclosed lagoon(s) or pond(s). Vaitupu possesses both characteristics of a table reef and atoll thus does not strictly conform to either definition, in that its two small lagoons are almost completely enclosed by land (Mclean and Hosking, 1991). Tuvalu’s islands are all low-lying and while various values for land area and mean elevation can be found in the literature and online, no high-resolution country-scale topographic survey had been performed prior to this study.

Few studies have investigated Tuvalu’s wave climate (e.g., Barstow & Haug, 1994; Bosserelle et al., 2015b; Durrant et al., 2014), however, these studies were based on either relatively coarse global wave hindcasts or short term in-situ observations. More recently, Wandres et al. (2023) developed a 44-year (1979-2022) high-resolution wave hindcast of Tuvalu. The authors identified three main wave sources: mid-latitude storms in the Southern Ocean and in the North Pacific, easterly trade winds, and tropical cyclones. It was found that Tuvalu’s wave climate is closely linked to large-scale climate modes such as the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Arctic and Antarctic Oscillation (AO and AAO).

Funafuti has a maximum tidal range of 2.4 m (Ritman et al., 2022). Sea level rise trends in Tuvalu based on tide gauge records between 1993 and 2008 were estimated to be 5.9 mm/year with negligible impact from vertical land movement (Aung et al., 2009). More recently, the Guidance for Managing Sea Level Rise Infrastructure Risk in Pacific Island Countries report analysed rates of sea level rise from tide gauges across the Pacific and found a rate of 4.84 mm/year in Tuvalu (PRIF, 2021). Other recent studies investigating SLR in the South Pacific over longer time periods found similar trends. For example, a recent study deriving sea level trends from satellite altimetry estimated an increase in sea level in Tuvalu of 13±7 cm (~4.82 mm/year) between 1993 and 2020 (Marra et al., 2022).

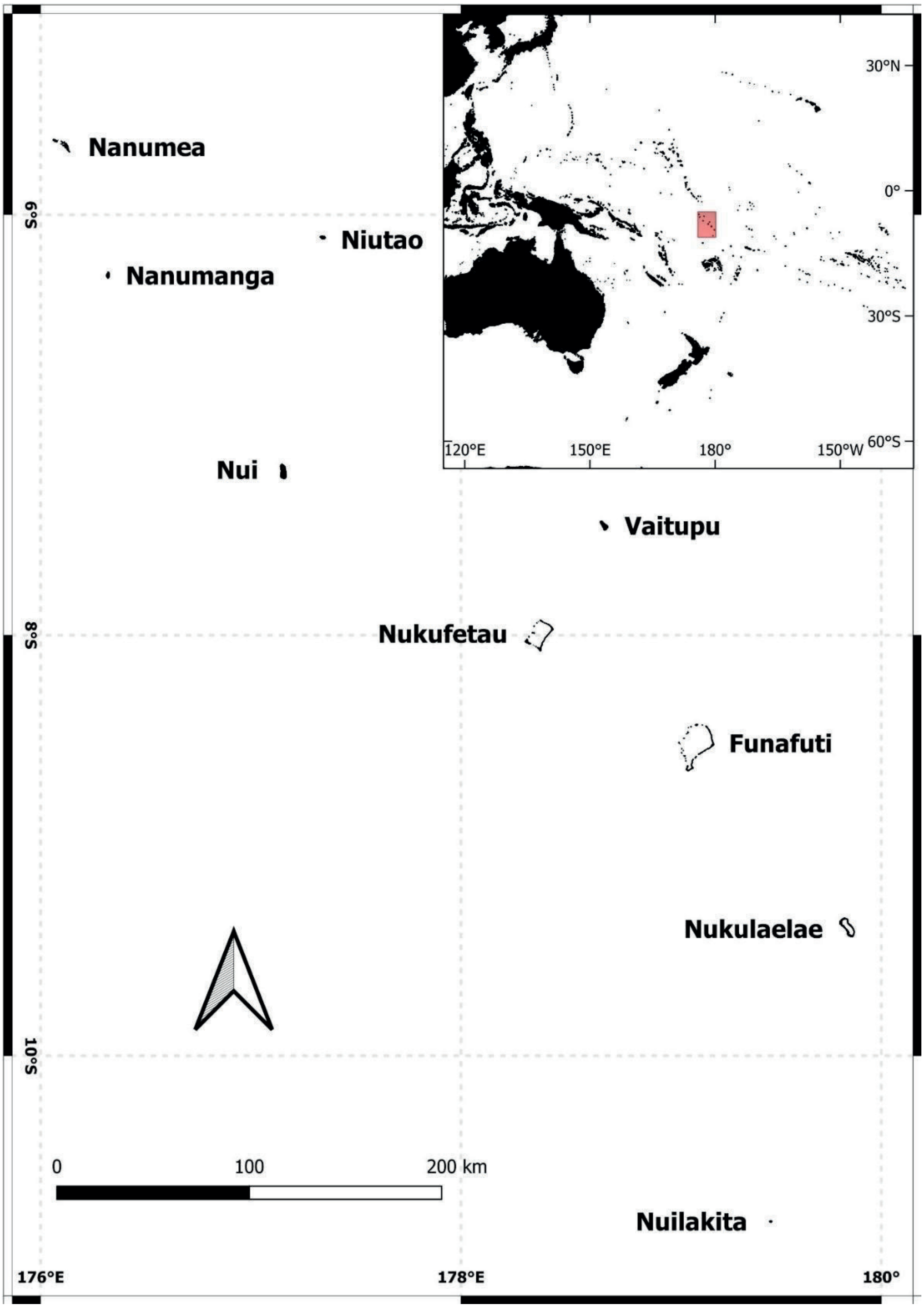

Figure 1: Map of Tuvalu and its nine atolls.

3. Data

3.1. Bathymetry and topography

Most islands in the Pacific region have no established vertical reference datum and in turn no locally referenced mean sea level. Without mapping the topography and referencing it to the sea level, accurately assessing coastal hazards and the long-term impacts of sea level rise on low-lying communities is impossible.

Light Detection and Ranging (LiDAR) is a remote sensing method that uses light in the form of a pulsed laser to measure variable distances to the Earth. LiDAR surveys provide accurate (horizontal and vertical errors < 10cm) and high-resolution point cloud data that can be interpolated onto digital elevation models (DEMs). Due to their high cost, LiDAR surveys generally only focus on densely populated or otherwise high-priority areas. Through the Tuvalu Coastal Adaptation Project (TCAP), the United Nations Development Programme (UNDP) contracted Fugro to collect nationwide airborne LiDAR topography and bathymetry data (FUGRO, 2019).

The initial data collection was reduced to the Geodetic Reference System 1980 (GRS80) ellipsoid. Strategic benchmarks on all nine atolls were occupied and linked to temporary tide gauges by the Tuvalu Lands and Survey Department and the Pacific Community (SPC) to reduce the final data to a local reference datum (MSL).

LiDAR data were seamlessly blended with multi-beam bathymetry data previously collected by SPC (formerly SOPAC; Krüger, 2008). The multi-beam data covered water depths of ~10 m up to ~2000 m around all of Tuvalu's nine atolls. Beyond the areas of in-situ bathymetric data, the General Bathymetric Chart of the Oceans (GEBCO) was used.

Tables 1 & 2 display the maximum and mean elevation above MSL for all islands and the entire country obtained from the LiDAR DEM. Mean elevations were calculated using two different methods: 1) the average elevation of the areas above mean sea level (MSL); 2) the average elevation of all areas above mean high water spring tide (MHWS). These two methods were used as some sandbanks and reefs might be exposed at mid-tide, therefore being included in (1). The 2nd method therefore gives a better estimate of Tuvalu's inhabitable land area.

The highest points in Tuvalu are in Nanumaga and Nukulaelae (both ~10.5 m above MSL; Table 1). However, these points are results of anthropogenic activities through dredging of pulaka (swamp taro) pits. On most other atolls, the highest points were also the results of human intervention. The highest natural points in Tuvalu are in Niulakita and Nanumaga (both approximately 6.5 m above MSL) and in both cases these elevations are associated with the ocean-side storm berm landforms of the islands. Across all nine islands, the most elevated naturally occurring land is consistently associated with these oceanside nearshore storm berm features, which accreted due to the deposition of carbonate sediment during inundation events (Mclean and Hosking, 1991).

Table 1: Maximum elevation of Tuvalu's islands derived from the LiDAR DEM. Description of the points were obtained from the Government of Tuvalu Lands and Survey Department.

Island Name	**Max. elevation**	**Point description**
Funafuti	6.93 m	The highest point is located near Queen Elisabeth Park which is a pile of sand that was used for leveling the surface of the reclaimed land on the main islet before Pacific Island Forum meeting 2019.
Nanumea	6.71 m	The highest point is located on Lakena islet, a pulaka pit (swamp taro) farming area for locals, thus the point is likely man-made.
Nanumaga	10.48 m	The three highest points are all situated near pulaka pits. They are related to spoil mounds from pulaka pit excavations.
Nukulaelae	10.48 m	The highest point is located on Fagaua islet near a pulaka pit. Thus, it is most likely a result of human activity.
Vaitupu	7.68 m	The two highest points to the north side of the island are situated in the densest area of pulaka pits. They both are likely man-made. Another similarly high point to the south of the island is part of the village, thus it could be a natural or man-made point.
Nukufetau	5.81 m	The highest point in Nukufetau is on Fale Islet. The islet is the farming area for locals with pulaka pits and a piggery farm. Thus, the highest point of the island is man-made.
Niulakita	6.54 m	The highest point in Niulakita seems to be the natural storm berm with no apparent structures or pulaka pits nearby.
Nui	8.37 m	The highest points on Fenuatapu (Mainland) and Meang islet are the results of

		human intervention. Both are located near pulaka pits.
Niutao	8.67 m	The highest point in Niutao is a result of human intervention (pulaka pit).

Overall, Tuvalu has a land area of 38.69 km^2 above MSL and a mean elevation of 1.55 m above MSL (Table 2). Keeping in mind the tidal range is approximately 2 m this means large areas of Tuvalu are exposed to high tides. A better estimate of the habitable area is therefore to use MHWS as a reference datum. Across all of Tuvalu, 25.33 km^2 of land area are above MHWS. Funafuti, the most populous atoll of Tuvalu, has a maximum elevation of 6.93 m above MSL and a mean elevation of 1.48 m above MSL (1.12 m above MHWS). The atolls of Nukulaelae, Nukufetau, and Nui also have mean elevations <1.2 m above MHWS with median elevations <1.1 m. We compared the statistics obtained from the LiDAR survey to another commonly used topographic dataset, i.e., the Shuttle Radar Topography Mission (SRTM; Farr et al., 2007) dataset. In the SRTM dataset, the mean elevation above MSL in Tuvalu is overestimated by 7.65 m (>590%) while the maximum elevation is overestimated by 16.52 m (>250%). This highlights the inadequacy of coarse global datasets for coastal hazard assessments in low-lying small island nations and the need to invest in accurate baseline data.

Table 2: Mean and median elevation and land area of Tuvalu's islands calculated from LiDAR topography data. Mean and median elevations and land area are provided in reference to mean sea level (MSL) and mean high water spring (MHWS).

Island Name	**Mean elevation above MSL (m)**	**Median elevation above MSL (m)**	**Mean elevation above MHWS (m)**	**Median elevation above MHWS (m)**	**Land area above MSL (km^2)**	**Land area above MHWS (km^2)**
Funafuti	1.48	1.52	1.12	1.08	3.98	2.85
Nanumaga	2.52	2.35	1.96	1.64	2.83	2.48
Nanumea	1.96	1.98	1.33	1.22	3.94	3.46
Niulakita	3.26	3.47	2.75	2.86	0.46	0.42
Niutao	2.44	2.64	2.2	2.17	2.4	1.87
Nui	0.97	0.56	1.17	1.09	10.87	4.25

Nukufetau	1.44	1.53	1.06	1.01	4.34	3.11
Nukulaelae	1.15	1.13	1.06	1.03	3.52	1.91
Vaitupu	1.75	1.75	1.32	1.17	6.36	4.98
All	**1.55**	**1.54**	**1.37**	**1.21**	**38.69**	**25.33**

3.2. Wave hindcast

Wave data were obtained by performing a 44-year (1979-2022) hindcast of the wave conditions in Tuvalu using the unstructured version of the third-generation wave model Simulating Waves Nearshore (UnSWAN; Booji et al., 1996). The model is a Eulerian formulation of the discrete wave action balance equation (Booij et al., 1999). The computational mesh was generated using OceanMesh2D, a MATLAB based software package for two-dimensional unstructured mesh generation (Roberts et al., 2019). The spatial resolution of the flexible mesh ranged from 20 km offshore to 300 m around the atolls and in shallow waters. The grid domain covered the area between 11.5˚S and 4.5˚S and between 175.5˚E and 178.5˚W (12949 nodes/25269 elements).

The model was forced with 1-hourly 10 m surface winds and 1-hourly 2D wave spectra from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) (Copernicus Climate Change Service (C3S), 2017). A more detailed description of the model setup and validation is provided in Wandres et al. (2023).

3.3. Offshore water levels

3.3.1. Astronomical tides

Tides around Tuvalu's nine islands were obtained from the well-established global tide model TPXO8 (Egbert & Erofeeva, 2002). Tidal elevations were extracted using the Tide Model Driver (TMD) MATLAB software package (https://github.com/EarthAndSpaceResearch/TMD_Matlab_Toolbox_v2.5) for the time period corresponding to that of the wave hindcast (1979 to 2022). A previous study by

7. Discussion and Conclusion

This paper presents a novel and comprehensive methodology to address coastal inundation hazard in reef-fronted islands in the tropical Pacific across a wide range of scales. Here, we apply the methodology to the atoll nation of Tuvalu, leveraging on recently collected LiDAR topography and bathymetry data. Our methodology accounts for tides, mean sea level anomalies, and storm surges, along with a mixed climate (e.g., cyclone and non-cyclone wave conditions). Shallow water processes such as wave breaking and wave transformation across the reef flats are also considered. Hazard maps (inundation extent and depths) for different return periods were calculated for the present sea level and future SLR scenarios according to the latest IPCC Assessment Report (AR6). Results indicate that Tuvalu is highly susceptible to coastal inundation, with >25% of the nation flooded once every 5 years. Present day 1-in-50 year floods (>45% of the nation flooded) will occur more than once every five years by 2060, even under the moderate SSP2 4.5 sea level rise projections thus threatening the habitability of Tuvalu.

Previous studies on coastal hazards in the tropical Pacific have often focussed on a single hazard such as waves generated by distant storms (Hoeke et al., 2013; Wandres et al., 2020), local tropical cyclones (Maragos et al., 1973), or storm surges (McInnes et al., 2014) and over small areas like a single beach or island (e.g., Storlazzi et al., 2018). Other studies have used empirical equations to estimate nearshore total water levels, and applied these regionally or globally (e.g., Vitousek et al., 2017; Vousdoukas et al., 2023 2018, 2017), potentially missing some important physical processes (e.g., wave setup and IG waves). The methodology presented here can be efficiently applied across large areas in a mixed climate (regular and TC conditions) while maintaining a high spatial resolution and while resolving all necessary physical processes.

Recently, O'Grady et al. (2022) highlighted the need for special consideration when investigating extreme water levels in areas of mixed climates (i.e., in areas where the extreme water levels are driven by both cyclone and non-cyclone ocean conditions). The authors developed a formulation to account for two distinct extreme value distributions of TWL in a single mixed climate. However, to resolve non-linear wave transformation processes and translate TWL nearshore to coastal inundation in mixed-climate environments, a different approach is required. Here we present an alternative framework to estimate extreme water levels and coastal flooding in a mixed climate environment by treating the tropical cyclone and the regular climate independently. We performed Monte-Carlo simulations based on a non-parametric kernel density function combined with the simulation of thousands of years of extreme TC ocean conditions based on the STORM database (Bloemendaal et al., 2020). This method allowed us to explicitly map the multivariate drivers (wave conditions and offshore water levels) to the extreme nearshore TWL and flooding. We demonstrate that higher return interval floods are dominated by local tropical cyclones in the southern islands of Tuvalu (Figure 9a). More frequent events in the southern islands are dominated by distant-source swell events ($T_p \geq \sim 13s$). In the northern group, most occurring inundation (i.e., ARIs ≤ 100 years) is dominated by distant-source swells.

Changes in wave climate were not considered in this study as changes in waves are expected to only have minimal effects on inundation levels compared with changes in sea levels. However, as global warming continues, the frequency of tropical cyclones is anticipated to decrease while the intensity of tropical cyclones will increase (e.g., Knutson et al., 2010; Portner et al., 2019). Whether this will significantly alter the coastal flood hazard in Tuvalu remains subject to further study. Similarly, there is some discussion about the extent to which vertical accretion of coral reefs and reef islands will be able to keep up with sea level rise. Some evidence suggests that so far islands have not experienced any net erosion despite increased sea levels over recent decades

(Duvat, 2018; Beetham et al., 2017; Kench et al., 2019; Webb & Kench, 2010). There is some doubt, however, that reef accretion rates will be able to keep up with accelerated rates of SLR, particularly if coral health degrades (Perry et al., 2018).

In general, the susceptibility of an atoll or reef island to coastal flooding largely depends on its bathymetry and topography. In extremely low-lying islands, a small increase in MSL leads to the inundation of most of the island's surface. Examples are Nukufetau, Nukulaelae, or Funafuti, where > 89% of the atoll areas are projected to be flooded once every 5 years by 2100, irrespective of the climate change projection (Figure 12). On higher islands like Niulakita on the other hand, the flooded area increases approximately linearly with SLR. This becomes important when prioritising adaptation measures for the different islands over the coming decades since higher islands are already naturally less vulnerable than lower lying atolls.

The methodology presented here can easily be upscaled to other islands in the Pacific region, where accurate baseline data are available. Unfortunately, many islands in the Pacific region have no established vertical reference datum and have never been properly surveyed. Freely available topographic data such as SRTM (Farr et al., 2007) have large uncertainties in low-lying islands making them inadequate for actionable inundation hazard assessments. The collection of high-resolution baseline data in low-lying areas should therefore be prioritised by donors and decision makers.

In line with other studies (Mycoo et al., 2022; Vitousek et al., 2017), our results indicate a significant increase in severity and frequency of extreme floods due to climate change, which will threaten the habitability of low-lying islands and atolls over the coming decades particularly, when considering the already limited access to freshwater resources or farmland (Duvat et al., 2021; Storlazzi et al., 2018; Nakada et al., 2012). In addition, a study by Taupo et al. (2018) found that poorer households in Tuvalu are more likely to reside in lower-lying areas closer to the coastline, exacerbating the risk to an already vulnerable group. The present study is therefore particularly important, allowing decision-makers to put policies and strategies into place to cope with the effect of sea level rise and coastal flooding on Tuvalu's population and key infrastructure. To that end, and to support Tuvalu's National Strategy for Sustainable Development (with regard to climate change and disaster resilience) the hazard information produced here, has already informed land reclamation and coastal adaptation initiatives that are currently underway in Tuvalu. Additionally, we created a graphical user interface that allows Tuvalu Government staff to navigate between different inundation scenarios and climate change projections and investigate the effect of various scenarios on the community and infrastructure. The system was deployed at the Tuvalu Government and is accessible through the intranet. A copy of the system is maintained by SPC (see Open Research section).

Work is currently underway to translate the hazard data into risk information for population and infrastructure. This will enhance the actionability of the hazard products and in turn optimise their use within the Government of Tuvalu's decision-making process.

Annex 2

Tuvalu: A History (H. Laracy ed. 1983) (excerpts)

TUVALU

A HISTORY

Cover note: The front cover depicts the Tuvalu coat of arms, and the back cover the flag of Tuvalu.

The official description of the coat of arms from the Royal College of Heralds is as follows:

The Arms of Tuvalu, 1976

Per fess Azure and Or in chief upon Grass issuant a representation of an Ellice Maneapa or meeting house all proper and in base four Barrulets wavy Azure a Bordure Or charged with Banana Leaves and Mitre Sea Shells placed alternately proper together with the Motto:

TUVALU MO TE ATUA

A translation of the motto is "Tuvalu is for God".

Published jointly by the
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and the Ministry of Social Services,
Government of Tuvalu.

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Cover design by Neysa Moss.

Maps by Department of Geography, University of Auckland.

No royalties are paid on this book.

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According to the evidence of linguists, who can work out how old a language is, and hence for how long people have been speaking it, the language of Tuvalu—and hence the settlement of the country—goes back about two thousand years. The traditional stories and genealogies, however, mostly go back only about 300 years. The oldest, those from Nanumea, go back 700 years. It seems, therefore, that the stories we have today came to us not from our very earliest ancestors, but from later arrivals in Tuvalu.

Where did our ancestors come from? Most of them came from Samoa, possibily by way of Tokelau, while others came from Tonga and Uvea (Wallis Island). These settlers were all Polynesians. In the northern islands, however, particularly in Nui, many people are also descendants of Micronesians from Kiribati. A likely indication of Tuvalu's links with Tokelau (and there are others) is found on Nanumea in the use there of the term *hauai* to describe the mythical beings Pai and Vau. *Hauai* is not a Tuvaluan word but was probably introduced from Tokelau, where it means 'women ogres' or 'female cannibal spirits'.

And where did the Polynesians come from? According to recent research by archaeologists, they are derived from the so-called Lapita people who came from South-East Asia and spread through Melanesia, from the eastern islands off the coast of New Guinea to New Caledonia, about 5000 years ago. Little is yet known about these people, who were but one of many groups populating Melanesia, apart from the facts that they produced pottery ornamented with distinctive tooth-shaped designs, and that they were very capable sailors. The name Lapita comes from a place in New Caledonia where a large deposit of their pottery was found. About 3,500 years ago some of the Lapita people went from Vanuatu to Fiji, and from there to Tonga and Samoa. We know this because some of their pottery has been found among the remains of the earliest settlers in those islands. Later, the people in Fiji were joined by other settlers from Vanuatu, but those in Tonga and Samoa were left alone to evolve in their own way. There they developed the particular set of physical, social and linguistic features which marked them out as Polynesians. And from there they set out to settle the islands to the north, south and east, eventually coming to Tuvalu. Linguists can trace the movements of the Polynesian people by showing the relationships between their languages. Linguistic research also supports the findings of the archaeologists by relating the Polynesian languages to the vast family of Austronesian languages spoken in Melanesia.

Exactly why our ancestors began coming to Tuvalu about 2000 years

4

LAND

Laloniu Samuelu

Tuvaluans value their land above any other of their possessions. When the *palagi* arrived they brought with them western forms of wealth: money, knives, axes, lamps, cooking pots and so on. The new tools made life in the islands easier and more comfortable—or so it seemed to the people. Consequently, our traditional implements gradually gave way to those of the *palagi*. But not all economic values changed. For instance, money, which enabled the *palagi* to put a price on anything, could not buy Tuvaluan land.

When money was introduced our people quickly learned the use of it, although they never came to equate its value with that of land. Why this was the case is easily explained. Tuvaluans viewed their pieces of land and *pulaka* pits not simply as economic assets to be bought and sold, but as the possessions which secured for them a recognised status in the community. It was status that really mattered. This is still the case, especially in the rural areas. Among people living a typically Tuvaluan way of life money is unmistakably second to land in their scale of values.

Tuvaluans may be divided into two loose economic categories. *Vakaluga* is used to describe those who own many pieces of land and *pulaka* pits. Those who possess few are called *vakalalo*. The distinction is not rigid and a *vakalalo* can become a *vakaluga*, and *vice versa*. Moreover, mere possession counts for little. No matter how much a *vakaluga* holds, his real worth is measured by the productivity of his labour. Some *vakaluga* could be very lazy, so that they produce less than a *vakalalo*. Such a person could lose his high status, and it could only be restored if his sons grew up to be industrious men.

Pulaka pits are considered differently from pieces of land. A person might be rich in both *pulaka* and coconuts or only in one of them, but

The nation claiming a 'sphere of influence' was not committed to administering the area it claimed. Nor, however, were powers who were not party to the agreement obliged to respect it. Thus, the Anglo-German agreement of 1886 could not stop American traders from coming to Kiribati in 1891 in order to recruit people for work on plantations in Guatemala. To prevent the Americans from developing their interests in the area, and possibly establishing a political presence there, thereby complicating the arrangement made between the two other great powers, Germany asked Britain to assert a firm claim to Kiribati. The alternative would have been for Germany to take the group but Britain was unwilling to allow that for fear of upsetting the Australians, who did not wish to see the extension of German rule in the Pacific.

Accordingly, in May 1892 Captain E. H. M. Davis of HMS *Royalist* declared a protectorate over Kiribati. After that, *en route* to Fiji, he visited Tuvalu to investigate affairs there, and to land two men whom he was deporting from Tarawa on the ground of being troublemakers. Their names were Tentonanibia, who was landed at Niutao, and Tentababani, who was left on Funafuti, where he promised to teach the people to grow *pulaka* the way it was done in Kiribati. Also at Funafuti, Davis took aboard the Jamaican trader Charles Bernard and his family and transported them to Nukulaelae, where he picked up and deported to his homeland a Tongan named Lutello. Lutello was a former missionary in the Pelew Islands who had caused trouble on Nukulaelae by displacing the true chief, Lapana. At each island, Davis noted in his report, the people asked him to hoist the British flag, but as he had no orders to do so he was unable to oblige them.

Even so, their wish was soon granted. Rather than leave some other power the opportunity to take Tuvalu, Britain shortly afterwards decided to tidy up the political map of the area. In September 1892, therefore, Captain Gibson of HMS *Curacao* was sent to claim Tuvalu. Everywhere, he reported, the people were still willing to accept British rule. Here is his account of what happened at Niutoa, which was much the same as what happened elsewhere:

> I arrived off this Island about 10.30 a.m. and some canoes at once came off to the ship. I landed and, with Mr Buckland, an English trader here, visited the King and the Missionary. I explained to the King that the object of my visit was to declare a British Protectorate. He expressed his willingness to the act, and summoned a meeting of the people in the official House. I there told the people that I had come to declare a British Protectorate. After a considerable

> received a salary of five dollars per annum from his subjects (that is, one tenth of what is considered necessary for the pastor), and he had a fair amount of coconut and taro land, but less than some of his subjects. Since the island has been under British protection the king is a nominal king only, an ornamental, but not very expensive, head of a nice little republic.

In contrast to the weak position of Elia was that of Opetaia who, she went on, 'is the real ruler of the island, in that he is responsible to the Commissioner and is responsible for the enforcing of all laws! His authority', she commented:

> is greatly strengthened by the vague terror that his people have of the supernatural powers of the missionary, and by the wholesome respect for law inspired by the British Commissioner and the big guns of the British warships.

Besides being the magistrate, Opetaia had been chosen as sub-chief by the people and was also a deacon of the church.

The second Resident Commissioner of the Gilbert and Ellice Islands, from 1896 to 1908, was William Telfer Campbell. A strict man, he attempted to introduce flogging as a punishment for drunkenness and for assault, but the High Commissioner refused to approve this harsh proposal. Yet Campbell made his mark on affairs in other ways. He set up land registers and introduced a land tax which remains today as an important source of income for local authorities. He encouraged the people to form large villages (as the missionaries had already done), and to adopt reef latrines and a standard house design, one feature of which was a separate kitchen. He also formed a police force composed largely of Tuvaluans but led by Fijian sergeants and *palagi* officers. This was based first at Tarawa and later at Banaba, to where the government headquarters of the then Gilbert and Ellice Islands Protectorate were shifted in 1908.

In 1917, the year after the conversion of the Gilbert and Ellice from a protectorate to a colony, the government issued a revised set of laws. In these it recognised the extent to which the position of High Chief had been eroded, and so abolished the office. The government also sought to reduce the power of the church over local administration—a cause which had been especially dear to Campbell—by restricting the number of *kaupule* and police to one or two per village and by making all appointments subject to approval of the Resident Commissioner. Island regulations were to be issued only with the approval of a District Officer, who was also empowered to review sentences of the Native noticeable and more disturbing to them with each constitutional advancement, and that such things would have a serious effect on them when Kiribati and Tuvalu were left to themselves after independence.

On the future economic development of Tuvalu, people on all the islands agreed on one point: that the British government should continue to provide the cash for it. Somehow the islanders were convinced that despite the tough conditions governing separation, Britain would be unwilling to dump them. But when asked what they would do if it did, some islanders replied that the Russians would be willing to help and, if necessary, would be invited into Tuvalu.

The UN Mission should have been convinced by the end of their visit to Tuvalu of the overwhelming support by the people for separation. Never did they encounter opposition to the separatists' crusade. The debates and discussions they listened to would have convinced them that separation was already a forgone conclusion. Even the people of Nukulaelae, who had hitherto always opposed separation, surprised the UN Mission when they announced that they had misunderstood separation and all its implications in the past, and they would now support it and vote for it.

Accounts of the referendum administrator's meetings on the islands not visited by the UN Mission mirrored those on the other six islands. People complained about the conditions of separation; and in spite of these showed unfailing support for it. The result of the referendum showed that 92% of those who voted favoured separation; 7% were against it; and 1% of the votes were declared invalid. As was required under the conditions governing separation, the GEIC government's consent was necessary to allow separation to take place. The Council of Ministers agreed to support the result of the referendum and thus allow the Tuvalu people to fulfil their wishes and aspirations. This decision was subsequently supported unanimously by the House of Assembly.

Post Referendum Changes

A number of changes occurred after the House of Assembly voted in December 1974 in favour of separation. First, the Ellice Committee was established that month; second, one of the two Tuvalu members of the Council of Ministers gave up his ministerial job to become adviser on Tuvalu affairs to the Chief Minister; third, there was the Ellice Separation Conference in March 1975; fourth came the constitutional amendments of July 1975; and last, there was the separation of the Ellice Islands from the Gilbert Islands, to form the separate British dependency of Tuvalu on 1 October 1975. The Ellice Committee was well. The civil service was taken away from the Commissioner and became the responsibility of a Public Service Commission. In other ways, too, the Chief Minister successfully strengthened his own position. Whereas previously only the Commissioner could summon and preside over meetings of the cabinet, now it was the Chief Minister; whereas previously the Commissioner was required to decide, after consultation with the Chief Minister, the business of cabinet, now the Chief Minister decided on his own. Thus, as the Chief Minister was given more constitutional powers, Her Majesty's Commissioner became more of a ceremonial head of government.

On 1 October 1978 Tuvalu gained political independence from Britain. The Independence Constitution of Tuvalu, enacted by the Tuvalu Independence Order 1978, provides for a Westminister-style parliamentary democracy with the British monarch as Head of State and represented locally by a Governor-General who must be a Tuvalu citizen. The Governor-General is appointed and removed from office by the British monarch acting in accordance with the advice of the Prime Minister, tendered after the latter has consulted the Members of Parliament. In performing his duties the Governor-General can either act in his own deliberate judgement (e.g. if the office of Prime Minister is vacant and no person has been elected to that office within such period as the Governor-General may consider reasonable, he may dissolve parliament); or, he may act in accordance with the advice of a Minister; or in accordance with the advice of, or after consultation with, the Public Service Commission.

Tuvalu has a 12 member unicameral parliament elected directly by the people. Four of the islands—Funafuti, Nanumea, Niutao and Vaitupu—are each represented by two members; the other islands—Nanumaga, Nui, Nukufetau and Nukulaelae—each have one representative. Parliament is presided over by a Speaker elected by Members of Parliament from among those of their members who are not members of the cabinet. The normal life of parliament is four years. The minimum voting age is 18 years.

The cabinet consists of the Prime Minister and up to four other ministers. The Prime Minister is elected by Members of Parliament from amongst themselves; other ministers are appointed and removed from office by the Governor-General in accordance with the advice of the Prime Minister. The Prime Minister may be removed from office by a vote of no confidence in him in Parliament. He presides over meetings of cabinet and as such also determines what business cabinet may consider at any of its meetings.

Tuvalu has not, however, taken the same progressive strides in its

Annex 3

S. Oeter, “Self-Determination”, in *The Charter of the United Nations: A Commentary*
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Annex 3

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A Commentary

THIRD EDITION

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Edited by

BRUNO SIMMA

DANIEL-ERASMUS KHAN

GEORG NOLTE

ANDREAS PAULUS

Assistant Editor

NIKOLAI WESSENDORF

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Annex 3

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oscillating between the basic purpose of the Organization and fundamental legal principle.[5] In most writings on '*ius cogens*' it is even mentioned as one of the few norms of international law of a peremptory character.[6] Article 2 (4) of the Charter corroborates such a reading when it prohibits any use of force 'inconsistent with the Purposes of the United Nations Charter'. Accordingly, it is beyond doubt that self-determination, as a purpose and principle of the UN Charter, constitutes a legally binding norm for all member States of the United Nations, as has been confirmed by a series of resolutions of the GA and SC, but also the jurisprudence of the ICJ, and State practice in the process of decolonization as well as in the cases of creation of new States in Europe after 1990.[7] Although Art. 1 (2), due to its programmatic character, cannot define in detail the content and scope of a right to self-determination, it sets forth beyond dispute that it forms part of the law of the Charter and is binding upon all members of the UN. Convincing arguments may be made also for the claim that State practice subsequent to the adoption of the Charter has transformed self-determination into a principle of customary international law, too.[8]

2 Self-determination is also explicitly mentioned in Art. 55 of the Charter. Article 55 gives some hints as to the operational measures to be taken by the UN in order to give more substance to the purpose of peaceful and friendly relations among nations 'based on respect for the principle of equal rights and self-determination of peoples'. Article 55 states that friendly relations among nations (in a normative perspective inextricably linked with self-determination) should be promoted by trying to achieve higher standards of living for peoples; solutions of international economic, social, and health problems; international cultural and educational cooperation; and universal respect for human rights and fundamental freedoms. Art. 55 is of a declaratory character concerning the principle of self-determination—it does not guarantee it, but it presupposes its existence.[9] Interestingly enough, there is no further explicit mention of self-determination in the text of the Charter, not even in Chapter XI which played a decisive role in UN practice concerning self-determination during the process of decolonization.[10]

[5] See also Doehring (n 2) 49, para 3.

[6] See only HG Espiell, 'Self-Determination and Jus Cogens' in A Cassese (ed), *UN Law/Fundamental Rights* (Sijhoff & Noorthoff 1979) 167–73; A Cassese, *Self-Determination of Peoples* (CUP 1995) 133–36; EA Laing, 'The Norm of Self-Determination' (1991) 22 Calif W Intl LJ 209, 248–52; D Turp, 'Le droit de sécession en droit international public' (1982) 20 Can YB Intl L 24, 28–29; D Raić, *Statehod and the Law of Self-Determination* (Kluwer 2002) 218–19; U Saxer, *Die internationale Steuerung der Selbstbestimmung und der Staatsentstehung* (Springer 2010) 213–15.

[7] Doehring (n 2) 49, para 1.

[8] ibid.

[9] Doehring (n 2) 49, para 2.

[10] ibid, para 4.

Annex 4

J. Crawford, *State Responsibility: The General Part* (2013) (excerpt)

State Responsibility

The General Part

James Crawford

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Annex 4

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This is not merely an issue of classification, but an issue with practical consequences. If assurances and guarantees of non-repetition are purely a form of satisfaction they would only be available to the extent an injury cannot be made good by restitution or compensation.[108] If that were the case, a state other than an injured state would also not be able to seek assurances and guarantees of non-repetition in the collective interest.[109]

14.4.3 *Appropriate assurances and guarantees*

Whether assurances and guarantees of non-repetition are required will depend on the character of the obligation and of the breach and on whether there is a real risk of repetition.[110] This calls for a case-by-case analysis. The distinction between assurances of non-repetition and guarantees of non-repetition is that assurances are normally given verbally, whereas guarantees involve something more, such as the taking of preventive measures.[111] The commentary gives examples of assurances and guarantees of non-repetition sought in diplomatic practice from the turn of the twentieth century.[112]

In *LaGrand* the Court stated that where a foreign national was not advised of their rights under Article 36 and was 'subjected to prolonged detention or sentenced to severe penalties', as occurred with the individuals in question, an apology would not be sufficient.[113] The Court considered that the programme undertaken by the United States met Germany's request for a general assurance of non-repetition. In so holding, the Court suggests that what is required is the use of 'best efforts' to avoid repetition, as opposed to an assurance or guarantee that no violation will ever occur again: the 'programme in question certainly cannot provide an assurance that there will never again be a failure by the United States to observe the obligation of notification under Article 36 of the Vienna Convention. But no State could give such a guarantee and Germany does not seek it.'[114] In *Avena*, before reaffirming its conclusion in *LaGrand*, the Court observed:

> While it is a matter of concern that, even in the wake of the *LaGrand* Judgment, there remain a substantial number of cases of failure to carry out the obligation to furnish consular information to Mexican nationals, the Court notes that the United States has been making considerable efforts to ensure that its law

[108] ARSIWA, Art. 37(1). [109] ARSIWA, Art. 48(2); Barbier (2010), 556–7.
[110] ARSIWA Commentary, Art. 30, §13. [111] ARSIWA Commentary, Art. 30, §12.
[112] ARSIWA Commentary, Art. 30, §§12–3. [113] *LaGrand*, ICJ Rep. 2001, p. 466, 512.
[114] Ibid., 513.