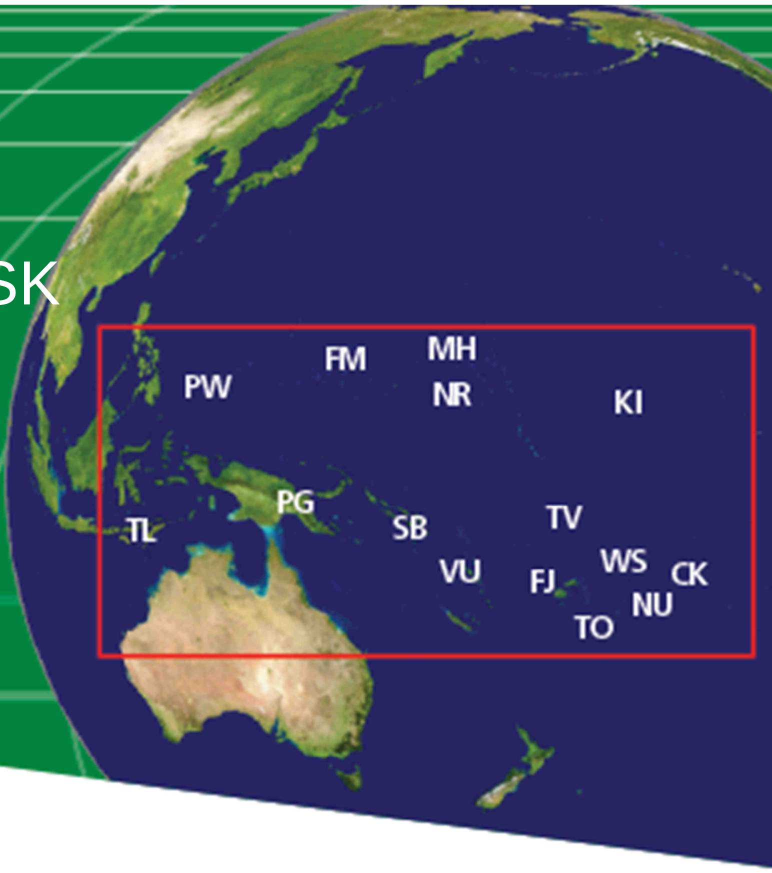
CURRENT AND FUTURE TROPICAL CYCLONE RISK IN THE SOUTH PACIFIC



SOUTH PACIFIC REGIONAL RISK ASSESSMENT

JUNE 2013

- *The South Pacific region is prone to significant tropical cyclone risk. This project compared both current and future tropical cyclone risk under climate change for 14 Pacific island countries and Timor-Leste. Outputs from 11 different Global Climate Models (GCMs) from two generations of model experiments, CMIP3 and CMIP5, were analysed to calculate projected financial losses from cyclone damages to buildings, infrastructure, and crops in each country, for mid-century and end of century. More confidence is placed on CMIP5 projections due to model performance and skill.*
- *The proportion of category 5 cyclones and tropical storms are projected to increase compared to the current climate, with increased losses for the region. Average annual losses (AAL) increase for the region from $178 million USD to $180 million USD by mid-century and to $185 million USD by end-of-century (1.0% and 3.9%, respectively, 2010 dollars).*
- *Many countries are projected to experience increased losses from tropical cyclones in the future. By 2100, the countries with the largest projected AAL increases are Samoa (+25.4%), Niue (+14.75%) and Vanuatu (+7.6%). In contrast, decreased losses are projected for Kiribati (-50%), Palau (-10.6%) and Solomon Islands (-8%).*
- *Increases in losses are more pronounced for buildings than for infrastructure and crops. Wind is the main contributor to building loss, while flood mainly contributes to infrastructure loss. Future projections indicate a slight increase in losses from wind and a slight decrease in losses from flooding for both buildings and infrastructure.*

Pacific Catastrophe Risk Assessment and Financing Initiative
in collaboration with
Pacific-Australia Climate Change Science and Adaptation Planning Program

Australian AID

BETTER RISK INFORMATION FOR SMARTER INVESTMENTS

GENERAL OVERVIEW

Contributing to the third phase of the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI), this project is supported by the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program with co-financing from the Global Fund for Disaster Risk Reduction. The primary goal of the project is to improve understanding of the risks posed by tropical cyclone hazards (winds, floods, and storm surge) to key assets in the Pacific region, under current and future climate scenarios. A clearer understanding of the current level of risk in financial terms – and the way that risk will change in the future – will aid decision makers in prioritising adaptation measures for issues such as land-use zoning, urban infrastructure planning, and ex-ante disaster planning.

The tropical cyclone risk assessment was carried out for 14 Pacific island countries and Timor-Leste (Figure 1): Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Republic of the Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, and Vanuatu.

The project was a collaboration between the Australian Government, Geoscience Australia (GA), and AIR Worldwide (AIR).

GA evaluated datasets derived from 11 General Circulation Models (GCMs) under two different model frameworks (CMIP3 and CMIP5) representing two distinct future climate scenarios. GA reported on the changes in the tropical cyclone risk from the current climate to the future climate via a number of tables called perils-matrices. This information was used by AIR to modify its South Pacific tropical cyclone stochastic catalogue in order to create new 'climate-conditioned' catalogues. These catalogues were then run through AIR's South Pacific risk model to provide an estimate of the financial impacts to the region from future tropical cyclones.

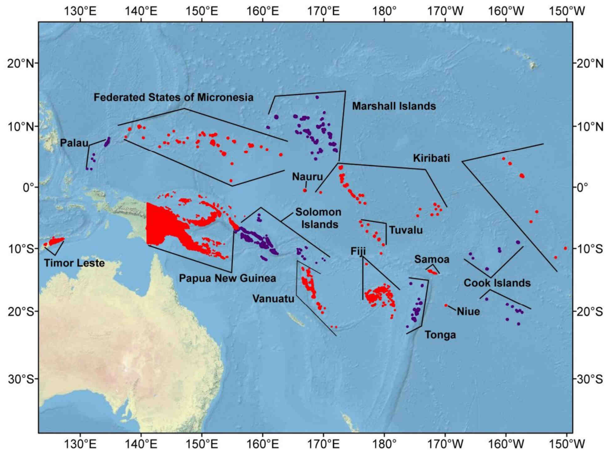


Figure 1: The region of interest with red/purple highlight for the 15 countries included in the analysis

EXPOSURE AND POPULATION

The previous phase of the PCRAFI project focused on developing a geo-referenced exposure database which included characteristics and locations for millions of building and infrastructure assets, as well as hundreds of thousands of hectares of cash crops. This database is one of the most comprehensive exposure datasets ever created for the South Pacific Region.

The exposure database includes a comprehensive inventory of residential, commercial, public, and industrial buildings in 15 countries. The buildings' location, number of stories, replacement cost, and structural characteristics are all part of the database. The infrastructure data comprises a detailed and extensive inventory of major assets, such as airports, ports, power plants, dams, major roads, and bridges. The infrastructure information includes location and estimates of the replacement costs of each asset. The exposure database also includes the spatial distribution of major crops in each country, along with the replacement cost of the crops derived from crop production budgets issued by local governments. Table 1 shows a summary of the population and exposure in all countries considered based on 2010 data. The estimated total replacement cost of all assets in the 15 countries is approximately 113 billion USD, an amount that comprises 94 billion USD in buildings, 15 billion USD in infrastructure assets, and 4 billion USD in major crops.

Table 1: Summary of Population and Exposure in the 15 countries considered (2010)

Country	Population (2010)	All Buildings	Major Crops (hectares)
Papua New Guinea	6,405,600	2,393,279	1,350,990
Timor-Leste	1,066,600	398,685	66,883
Fiji	846,800	266,140	169,733
Solomon Islands	547,500	169,112	83,955
Vanuatu	245,900	100,746	78,434
Samoa	182,900	48,831	35,553
Micronesia	111,600	31,988	7,729
Tonga	103,400	34,751	36,010
Kiribati	101,400	27,589	18,633
Marshall Islands	54,800	12,894	8,601
Palau	20,500	5,719	3,622
Cook Islands	19,800	10,602	6,390
Nauru	10,800	2,755	86
Tuvalu	10,000	3,018	1,914
Niue	1,480	1,108	1,618

AIR TROPICAL CYCLONE MODEL FOR THE SOUTH PACIFIC

AIR's South Pacific risk model is a catastrophe parametric model that evaluates tropical cyclone risk for 15 countries in the South Pacific region (25°N-35°S, 120°E-120°W). At the core of the model is a 10,000 year tropical cyclone stochastic catalogue that includes more than 400,000 simulated tropical cyclones. The catalogue was developed based on the observed historical record in the region. A validation process was carried out to ensure that the simulated storms physically and statistically reflect the observed storms, from frequency and intensity to track evolution. The catalogue represents the current climate long-term view of tropical cyclone activity in the region.

The AIR tropical cyclone hazard model was peer reviewed by scientists at GA, who determined it to be scientifically sound. A sample validation exhibit is included in Figure 2, which shows a firm agreement between observed and modelled tropical cyclone annual frequencies in each of the 15 countries considered. Islands located very close to the equator (e.g. Nauru and Kiribati) show little to no historical frequency and corresponding simulated frequency.

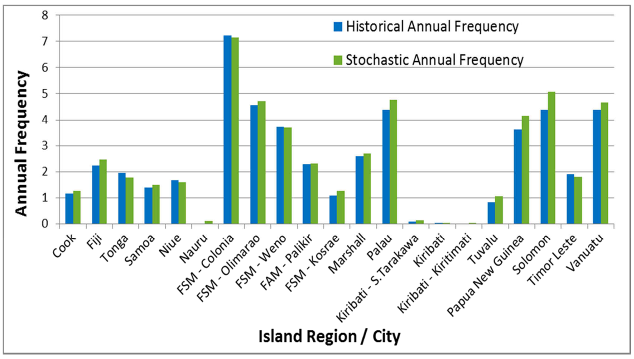


Figure 2: Historical and simulated annual frequency of storms by country/island in the South Pacific region

Once the hazard associated with a storm is estimated, the damage is calculated based on the specific vulnerability of structures and crops as derived from damage and loss data from past events in the region and corroborated by engineering analyses. The vulnerability is measured by a relationship that provides expected loss when an asset is subject to different levels of wind speeds or water heights. In this study, the calculated losses reflect both the cost needed to repair or replace the damaged assets and the emergency losses that local governments may sustain as a result of providing necessary relief and recovery efforts (e.g. debris removal, setting up shelters for those made homeless, or supplying medicine and food).

NUMERICAL MODEL SIMULATIONS AND THE PERILS MATRIX

GA provided general circulation model output from a total of 11 different Global Climate Models (GCMs) from two generations of GCM experiments, referred to as CMIP3 and CMIP5. The CMIP5 models are the next generation of GCMs and therefore represent the most up-to-date understanding of the climate system.

In addition, GA provided two *Mean Estimates* representing the ensemble average of all models under the same framework. The models in the two frameworks are forced by two different high emission scenarios: the CMIP3 models represent an A2 scenario[1] while the CMIP5 models represent a RCP 8.5 scenario[2]. Numerical model outputs are provided for the current climate (1981-2000) as well as for two future time periods – 2050 and 2100.

Given the distinct climate scenarios considered for the two generations of model experiments, the results provided by CMIP3 and CMIP5 are not directly comparable.

Tropical cyclones (TCs) are detected and tracked from the model output using a complex procedure based on several strict meteorological criteria. Upon identifying all TCs in the model output, relative frequencies for all storm categories are considered (see Appendix for storm category definitions), and a series of parameters are computed for each model and for two subdomains within the South Pacific region. These statistics are incorporated into a series of tables called ‘perils-matrices’ and were provided by GA to AIR for analysis. A visual representation of the information included in a sample perils-matrix is shown in Figure 3, which displays CMIP5 Mean Estimate relative frequencies for different storm categories for both current and future climate.

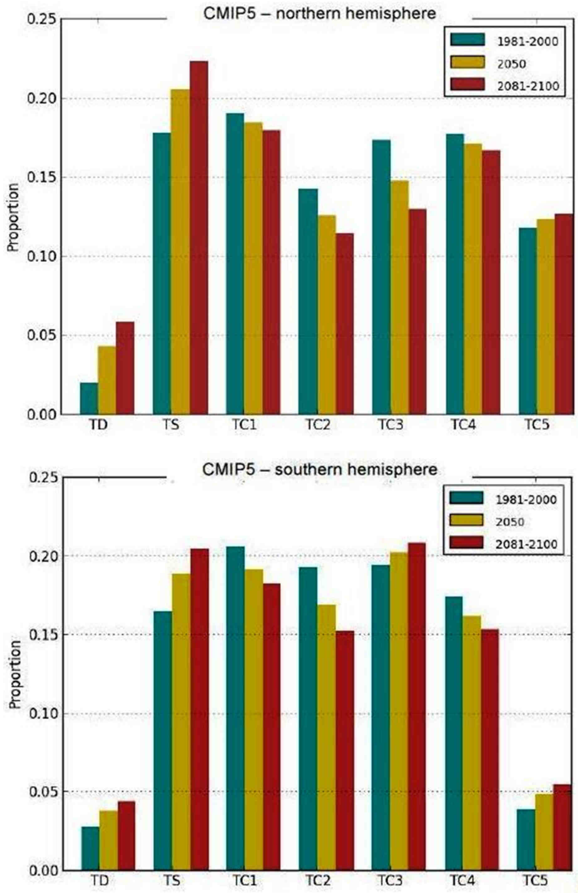


Figure 3: Mean Estimate relative proportion of TC intensity – multi model ensemble for CMIP5 models in the Northern and Southern Hemisphere. Classification is based on central pressure using former Saffir-Simpson Hurricane Intensity Scale

For both hemispheres, there is an expected future increase in the relative frequency of tropical depressions, tropical storms, and category 5 storms and a general decrease in the number of storms in the other categories. Most notable is the increase in category 5 storms (and category 3 storms in the southern hemisphere) which may have a measurable impact on observed losses in the region. There is also a slight equatorward movement of tropical cyclone tracks in the northern hemisphere and poleward movement of tropical cyclone tracks in the southern hemisphere.

[1]http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=98
[2]http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0148-z.pdf

CLIMATE CONDITIONING AND EVALUATION METRICS

Before analyses of future climate scenarios could take place, a careful comparison and adjustment of the current climate was carried out to ensure that the GCMs' output and AIR's South Pacific model catalogue shared a similar baseline.

Future climate scenarios were simulated by forcing changes in the tropical cyclone catalogue in accordance with changes to the frequency and central pressure projected by the various future climate models.

Several metrics are used in order to evaluate the change in losses and risk between the current and future climate: *Average Annual Loss (AAL)*, *Return Period (RP) Loss*, and *Exceedance Probability (EP) Curve*. (See the Appendix for a comprehensive definition of these terms.) While the AAL represents the long-term expected loss, the RP losses refer to more infrequent but stronger and more damaging events.

FUTURE RISK COMPARED TO CURRENT RISK

Mean Estimate end-of-century model projection compared to current climate

Figure 4 contrasts the end-of-century CMIP5 Mean Estimate projection with the current climate. The future projection indicates higher losses compared to the current climate, especially for more extreme (higher return period) events.

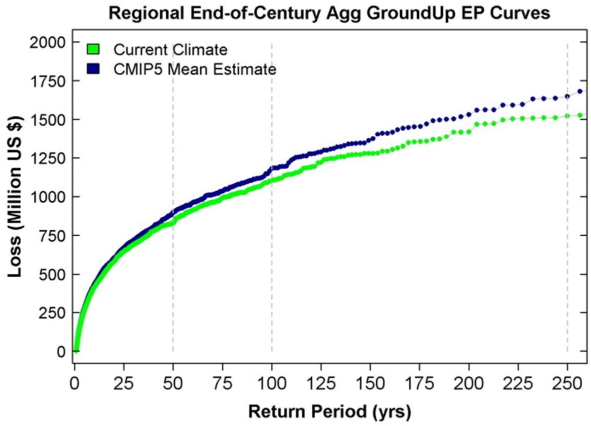


Figure 4: Regional end-of-century EP-curve for the CMIP5 Mean Estimate (blue curve) compared to the current climate EP-curve (green curve)

Aside from the model range uncertainty (see Figure 7), there is also the uncertainty associated with the risk model itself that needs to be accounted for. A statistical quantification of the uncertainty around each model reveals that the separation between the baseline and the future projection is not large enough to be considered statistically significant.

Mid-century v End-of-century future loss projections by different assets

Table 2 contrasts the AAL, 50 year RP, 100 year RP, and 250 year RP losses between the current climate and the CMIP5 Mean Estimate future climate scenario. The AAL represents the sum of the AALs for buildings, infrastructure, and crops.

Total AAL increases from 178 million USD to 180 million USD by mid-century and to 185 million USD by end-of-century, an increase of 1.0% and 3.9%, respectively. The largest change in losses is projected for 1-in-250 year tropical cyclones, which could increase by 8.2% by 2100.

Figure 5 displays current AAL as a percentage of GDP by country across the Pacific. Vanuatu and Niue display the largest percentages.

Table 2: Regional percent changes between the CMIP5 Mean Estimate future loss projections for mid-century, end-of-century, and the baseline, for different return periods, by different assets. Baseline loss numbers are expressed in USD.

Mean Estimate		AAL	50yr RP	100yr RP	250yr RP
Total Loss	Current Climate	178,198,886	829,003,877	1,099,552,080	1,523,057,384
	Future 2050 (%)	+1.0	-0.9	+1.3	+3.1
	Future 2100 (%)	+3.9	+8.1	+7.3	+8.2
Building	Current Climate	111,198,476	633,464,829	827,865,828	1,185,702,262
	Future 2050 (%)	+2.2	-2.2	+3.3	+4.4
	Future 2100 (%)	+6.3	+4.3	+5.0	+5.4
Infra-structure	Current Climate	10,436,570	67,878,189	84,470,664	105,373,954
	Future 2050 (%)	-1.9	-0.5	+2.4	-0.3
	Future 2100 (%)	+1.3	-0.3	+1.0	+0.4
Crop	Current Climate	56,563,840	216,372,784	288,390,026	489,192,742
	Future 2050 (%)	-0.7	-0.6	+11.1	+0.9
	Future 2100 (%)	-0.3	+1.8	+11.3	+0.2
Population Affected	Current Climate	533	3,001	5,123	8,432
	Future 2050 (%)	+0.6	+2.4	+0.1	-0.8
	Future 2100 (%)	+2.6	+10.5	+4.7	+9.1

By 2100, increases in losses for buildings are generally similar to the increases in total losses for the region. Infrastructure losses are projected to be an order of magnitude smaller than building losses and do not show a consistent future trend. For crops, the projected changes are mixed, with both increases and decreases at different return periods; the largest increase (11.3%) is noted for more extreme (1-in-100 year) events.

The number of people affected by future tropical cyclones increases, especially by end-of-century, with the largest increase (10.5%) observed for 1-in-50 year events. Note that no adjustment to account for future economic or population growth was considered.

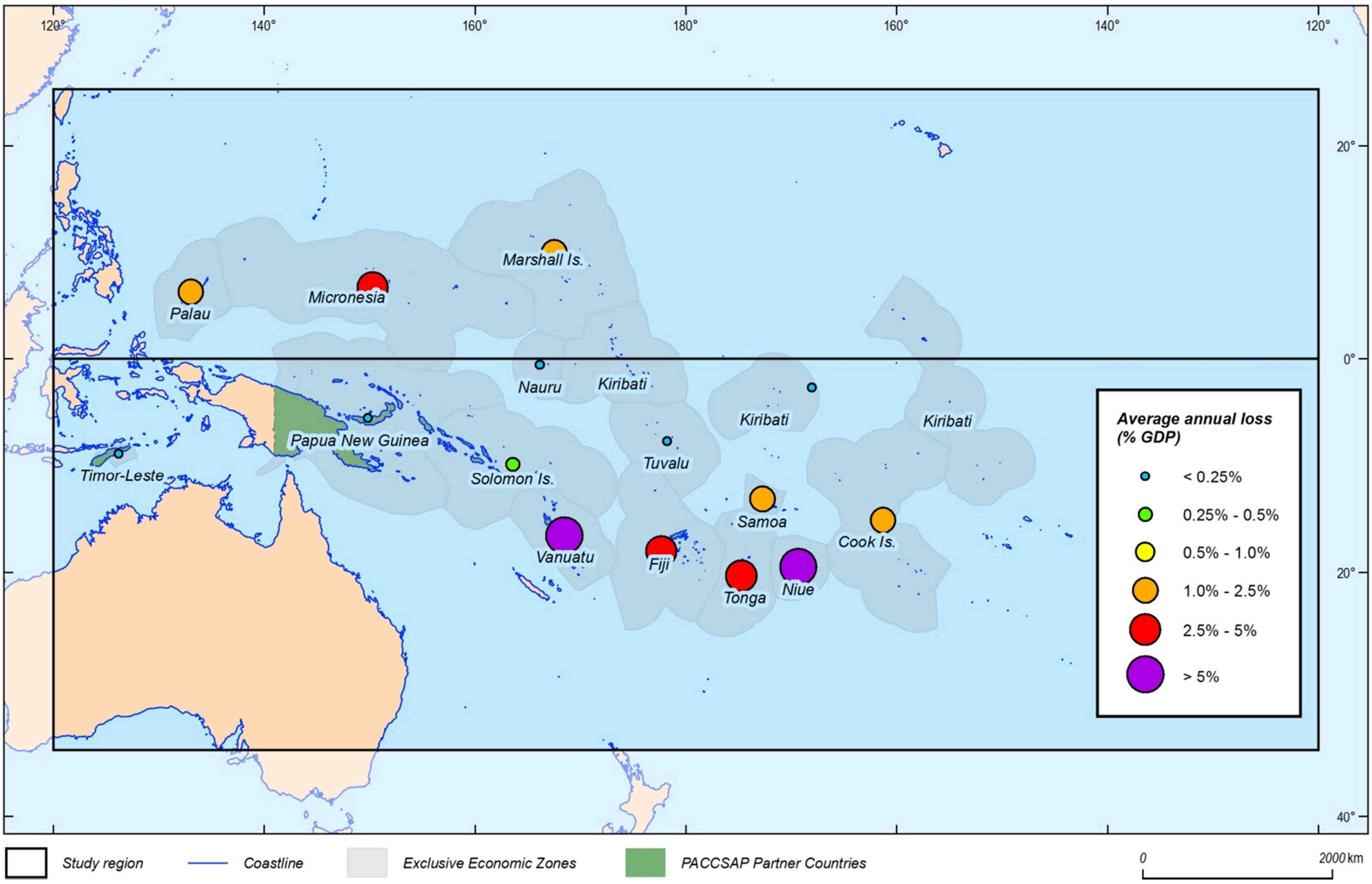


Figure 5: Current climate AAL as a percentage of GDP by country across the South Pacific

The increases in future losses from tropical cyclones may be due to increases in the relative frequency of TC5s in the Northern Hemisphere (NH) and the increase of TC3s and TC5s in the Southern Hemisphere (SH) for both mid-century and end-of-century projections (see Figure 3). The CMIP5 Mean Estimate is also characterised by a slight movement of the tropical cyclone tracks poleward in both hemispheres, which may contribute to the loss increase by displacing storms over larger exposure areas.

Figure 6 displays the end-of-century changes to AALs from tropical cyclones on a country-by-country basis. Relative changes to losses in Nauru and Kiribati are extrapolated from very low current AALs.

It should be noted that, unlike the CMIP5 framework, the CMIP3 models project consistent decreases in losses compared to the baseline. However, given the better skill and performance of the CMIP5 models, increased confidence is placed in the CMIP5 results.

End-of-century individual future model projections compared to current climate

The 11 models included for analysis (six CMIP3 and five CMIP5) operate under different assumptions and provide different views of the future climate.

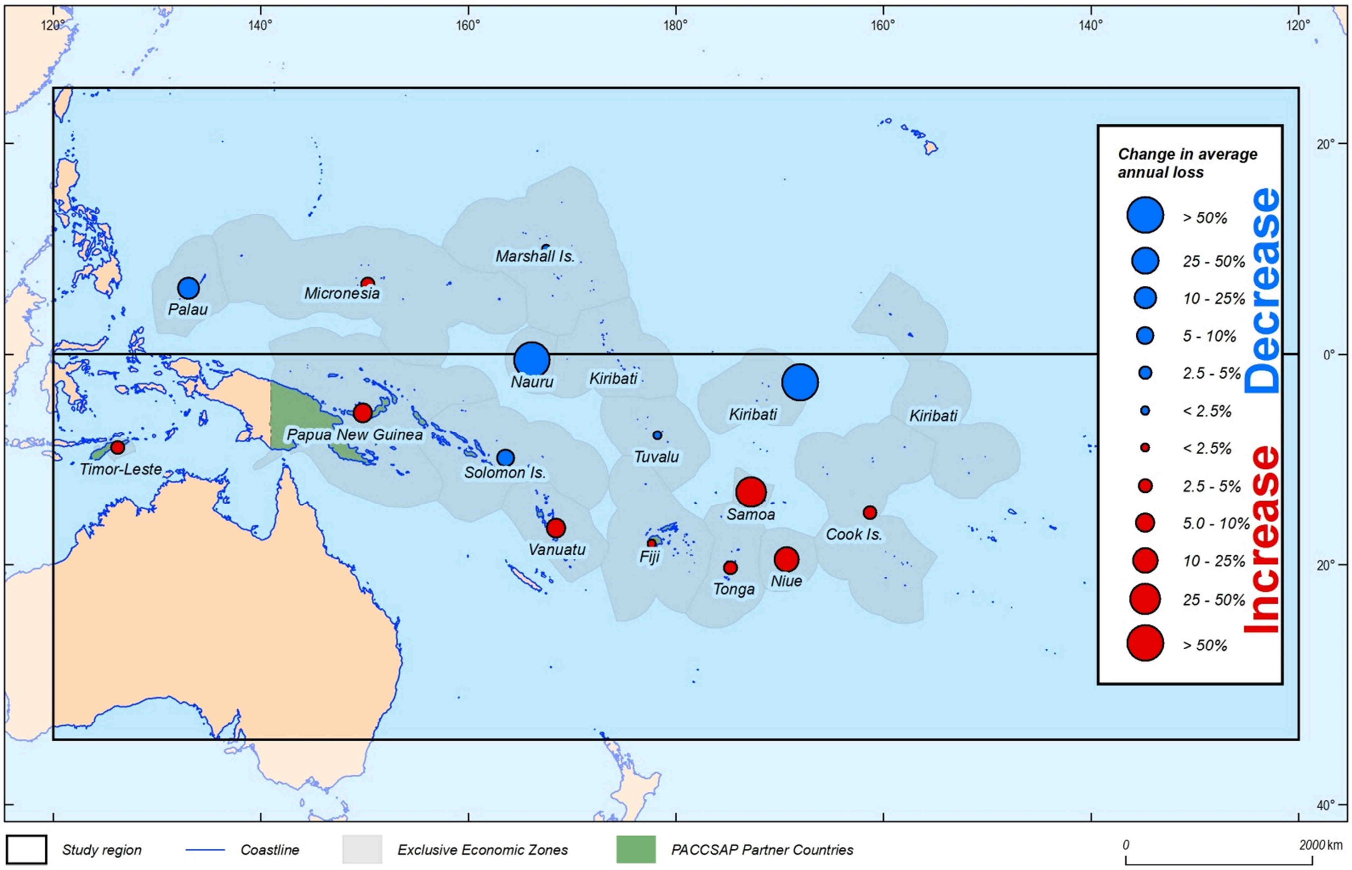


Figure 6: End-of-century changes to Average Annual Loss (AAL) for the South Pacific Region

Figure 7 shows the end-of-century individual model projections from CMIP5 for the regional EP-curve (blue) along with the current climate EP-curve (green). When progressing from small return periods (more common events) to higher return periods (more extreme events) the models' projections become more divergent.

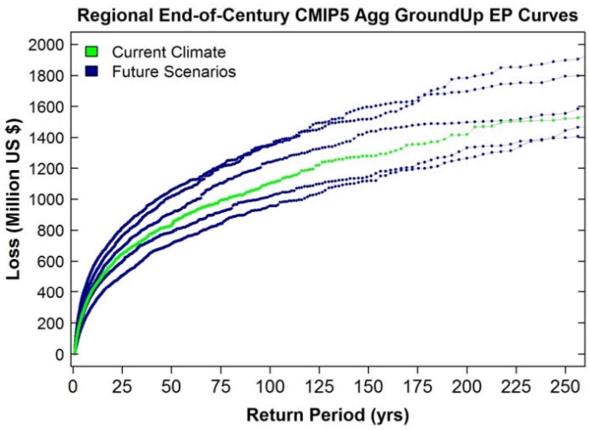


Figure 7: Regional individual end-of-century EP-curves for the CMIP5 models (blue) compared to the current climate EP-curve (green)

It is important to note that the current climate model curve falls among the individual CMIP5 model curves, meaning that there is no significant departure from the projected change compared to the current climate.

Understanding the underlying uncertainty is critical to stakeholders making use of such climate change projections. Any analysis of future model projections should consider estimates of the ensemble mean (the 'Mean Estimate' of all models), the full range of model results, and the worst case climate change scenario. The individual model that projects the greatest increase in losses as compared to the current climate defines the worst case scenario for the country.

End-of-century losses by hazard compared to current climate

The AIR South Pacific model was designed to capture the effects of three hazards associated with tropical cyclones: strong winds, precipitation induced-flooding, and coastal flooding due to storm surge. Tropical cyclone winds can be very destructive and in most cases represent the main cause of damages and subsequent losses.

Unlike the wind, which decreases in intensity as the storm moves inland, the intensity of storm-related precipitation and accumulated runoff can increase in inland regions and lead to significant damages to property.

Storm surge represents the sea water forced on-shore due to the rise in sea level accompanying any approaching storm of non-negligible intensity. A significant storm surge event can have devastating effects on-shore[3].

Figure 8 explores the changes between the current climate and the CMIP5 Mean Estimate future projection for the relative contribution of wind, storm surge, and precipitation-induced flooding to the total loss for the region. The top panel depicts losses to building assets and the bottom panel depicts the corresponding infrastructure losses.

At the regional level, wind and precipitation-induced flooding represent the two main contributors to loss for both buildings and infrastructure, while surge has a very minor contribution (<0.2%). Wind is the main contributor to loss for buildings, and flood is the main contributor to loss for infrastructure.

Projections indicate a slight increase in the contribution of wind to losses for both buildings and infrastructure. In contrast, a slightly decreased contribution from flooding is projected for losses to building and infrastructure compared to the current climate.

[3] No sea level rise was considered in the analysis of future storm surge – only the storm surge from tropical cyclone events.

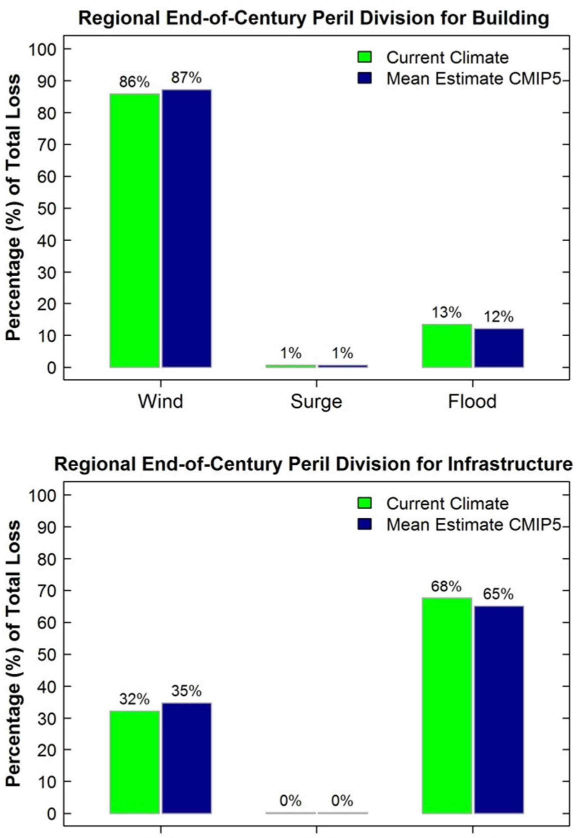


Figure 8: Regional wind, surge and flood percentage contributions to total loss for the current climate compared to the CMIP5 Mean Estimate end-of-century projections, for buildings (upper panel) and infrastructure (bottom panel)

COUNTRY SPECIFIC RESULTS

Results presented in this brochure consider the region as a whole. Results for individual countries can vary significantly from those outlined for the region. Detailed country-specific results are published separately to the Regional Risk Assessment.

Figure 9 shows the CMIP5 end-of-century AAL projections in descending order by current climate AAL for each of the 15 countries included for analysis. The bottom panel provides a zoom-in of the seven countries with the smallest AAL values.

The current climate country AAL reflects the modelled combination between the exposure level and the tropical cyclone risk for each country. For example, Papua New Guinea (PNG) has the largest exposure compared to other countries (Table 1), but due to its proximity to the equator, its tropical cyclone risk is reduced. As a result, the PNG current climate AAL is lower than the AALs for Fiji and Vanuatu, countries with smaller exposure levels than PNG but with increased tropical cyclone risk.

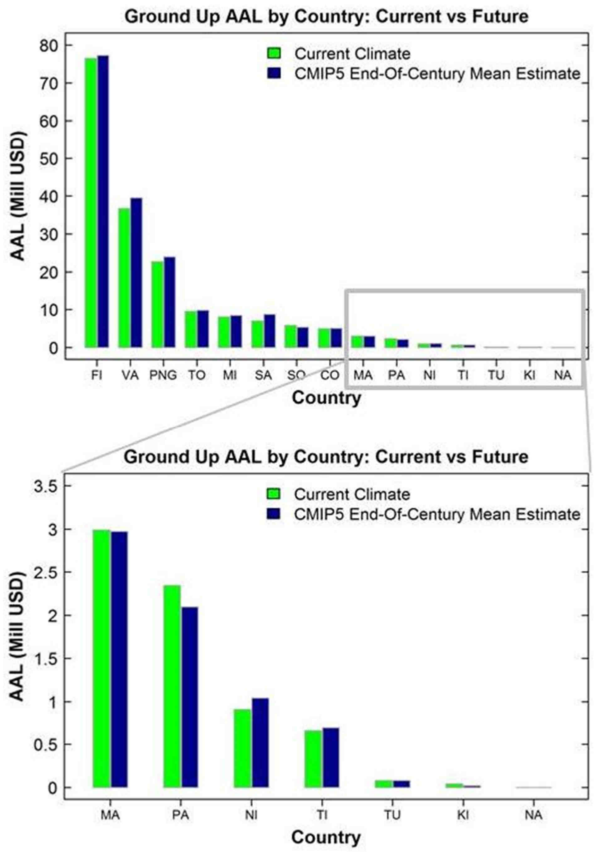


Figure 9: End-of-century AAL projections for the Mean Estimate (blue) compared to current climate (green). Bottom panel focuses on countries with the smallest current climate AAL values. Countries are labeled by the first letters in their name (see Appendix).

Projected changes at country level under different climate scenarios are in part due to each country's particular positioning (latitude and longitude) with respect to storms of different categories.

The Mean Estimate CMIP5 projections suggest a general increase in AAL for most countries. There are exceptions however, with Solomon Islands (-8%), Palau (-10.6%), Kiribati (-50%), Marshall Islands (-0.5%) and Tuvalu (-0.5%) displaying a slight decrease for end-of-century AAL. Some of the largest projected end-of-century increases in the country AALs are recorded for Samoa (+25.4%), Niue (+14.75%) and Vanuatu (+7.6%).

It is important to note that the level of change reported for individual countries' AALs may differ in sign and magnitude for more extreme (higher return period) events.

SUMMARY

The assessment of current and future climate tropical cyclone risk in the South Pacific region was carried out using AIR's catastrophe model with input on projected future tropical cyclone activity from GA's analysis of 11 future climate models for the region. The risk model allows for the estimation of losses from future tropical cyclones for individual countries and the region due to projected changes in the frequency, intensity, and path of tropical cyclones and their impact on key economic assets (buildings, infrastructure, crops and population).

Future financial impacts are estimated both annually and for more extreme events. Accounting for both annual averages, along with more extreme events, is critical to fully understanding the magnitude and likelihood of future cyclone risks.

The CMIP5 Mean Estimate indicates a general increase in losses compared to the current climate across different return periods (Table 2 and Figure 4). The loss increases may be linked primarily to the projected increase in the proportion of Category 5 cyclones in both hemispheres under this climate change scenario (Figure 3). These changes are also associated with a poleward movement of cyclone tracks in the Southern Hemisphere and equatorward movement of tracks in the Northern Hemisphere. There is a greater increase in losses projected for more extreme (higher return period) events.

When detailing changes by various assets (Table 2), the largest losses and percent changes are generally observed for buildings, while infrastructure and crops have smaller changes. The proportion of people affected by tropical cyclones increases, especially by end-of-century.

Wind and precipitation-induced flooding are the main contributors to loss at the regional level, with wind being the main contributor to loss for buildings, and flood being the main contributor to loss for infrastructure. Future projections indicate an increase in the wind contribution for both buildings and infrastructure. The opposite is true for precipitation-induced flooding, with the flood contribution to losses projected to slightly decrease

A CMIP5 country-by-country analysis reveals that most countries' AALs are projected to increase in the future. The largest increases are recorded for Samoa (+25.4%), Niue (+14.75%) and Vanuatu (+7.6%).

While models under the CMIP3 framework consistently project a decrease in loss at regional level, more confidence should be placed in the results from the CMIP5 models, which indicate an increase in losses across the region. Results from the CMIP5 models indicate that these models perform better at replicating the behaviour of tropical cyclones in the current climate (especially for the Southern Hemisphere).

Nevertheless, there is divergence in the resulting EP-curves for the CMIP5 models, indicating significant uncertainty. Evaluation of future estimated losses should always take into account the underlying model uncertainty for interpreting significance of the results. As such, none of the *regional* loss changes reported in this study are large enough to be considered statistically significant.

The findings of this study offer valuable input to stakeholders in the region. Better understanding of future risks allows for well-informed decisions about cost-effective adaptation responses. Decisions on future development, particularly in areas highly exposed to the impacts of climate change, should not increase risk.

Specific results and conclusions for individual countries may vary from those outlined for the region. For more details on individual countries' results, please refer to the country-specific brochures.

APPENDIX

Classification of tropical cyclones

A tropical cyclone represents an atmospheric low-pressure system with a spiral arrangement of thunderstorms that produce strong winds and heavy rain. The table below describes the categorisation of storms based on maximum sustained winds and minimum central pressure as used in this study.

Classification	1-minute sustained wind speed (km/h)	Minimum central pressure (hPa)
Tropical Depression (TD	<=62	>=1005
Tropical storm (TS)	63-118	1005-995
Category 1 (TC1)	119-153	995-980
Category 2 (TC2)	154-177	980-965
Category 3 (TC3)	178-208	965-945
Category 4 (TC4)	209-251	945-920
Category 5 (TC5)	>=252	<920

Definition of key metrics used to describe future risk changes

Several metrics are utilised in order to evaluate the change in losses/risk between the current climate and the future climate: Average Annual Loss (AAL), Return Period (RP) Loss, Exceedance Probability (EP) curve.

- Average Annual Loss (AAL). AAL represents the sum of all losses observed in the domain divided by all realisations of next-year activity (10,000 years); AAL thus refers to the average loss that can be expected to occur per year.
- Return period (RP) loss. The X-year return period loss is the loss that can be expected to occur or be exceeded on average once every X years. Highlighted for this analysis are the 50 year (2.0% exceedance probability), 100 year (1.0% exceedance probability) and 250 year (0.4% exceedance probability).
- Exceedance Probability curve (EP-curve). An EP-curve represents the probability curve that various levels of loss will be exceeded. By inverting the exceedance probability to obtain corresponding return periods, the EP-curve then represents the various levels of loss associated with different return period events. An EP-curve is obtained by sorting all losses largest to smallest observed over a domain, assigning a rank to all entries (1 being the largest loss, 2 being the second largest loss etc.), and then dividing the ranking by the total number of years (10,000).

Loss and damage

The 'losses' referred to in this report represent the 'damages' (i.e., the direct ground up-losses before the application of insurance (zero deductible)), plus an estimation of the emergency losses (i.e., debris removal, setting up shelters for those made homeless, or supplying medicine and food). All estimates of current and future losses in this report are in 2010 dollars.

Labeling of individual countries

Figure 9 contrasts AALs for all 15 countries considered. In the plot the countries are labeled as following: *MA = Marshall, MI = Micronesia, PA = Palau, CO = Cook, FI = Fiji, KI = Kiribati, NA = Nauru, NI = Niue, PNG = Papua New Guinea, SA = Samoa, SO = Solomon, TI = Timor-Leste, TO = Tonga, TU = Tuvalu, VA = Vanuatu.*

Australian Government

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