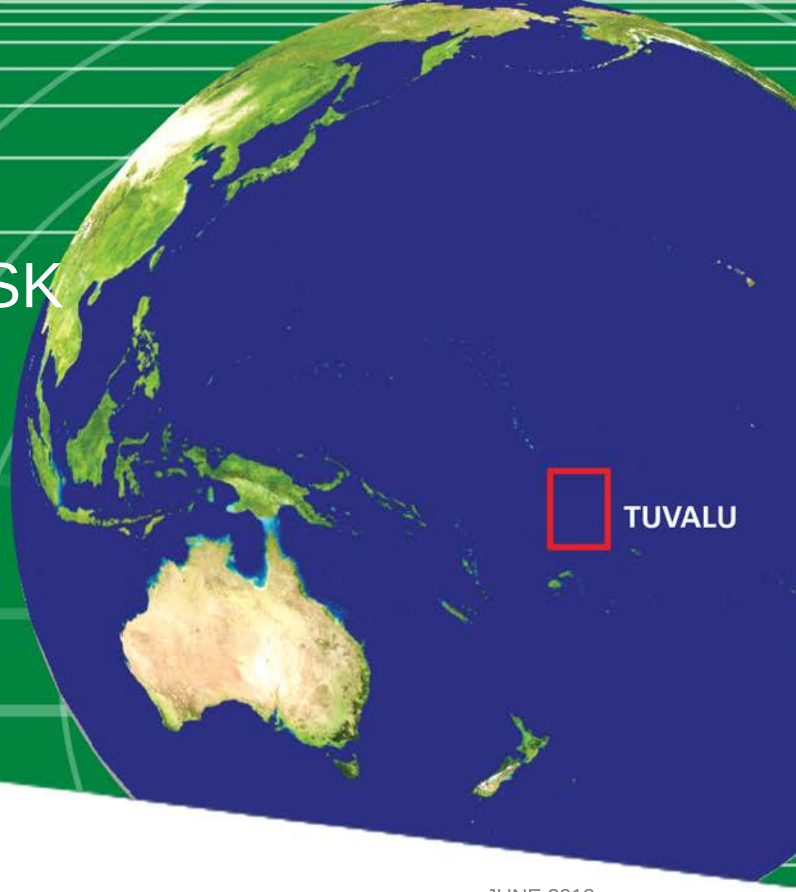
CURRENT AND FUTURE TROPICAL CYCLONE RISK IN THE SOUTH PACIFIC



COUNTRY RISK PROFILE: TUVALU

JUNE 2013

- *Tuvalu has been affected by devastating cyclones on multiple occasions, e.g. 1972 tropical cyclone Bebe, 1997 tropical cyclones Gavin, Hina and Keli. The current climate average annual loss due to tropical cyclones represents about 0.2% of the country's GDP.*
- *End-of-century climate projections suggest a small decrease in future average annual losses from tropical cyclones in Tuvalu compared to the current climate. However, for the most extreme (1-in-250 year) tropical cyclones, projections indicate an increase in losses of 5.5% for the mean estimate, and an increase of 9% in the worst case climate change scenario.*
- *The main contributors to current and future building losses are wind and storm surge, with only minor contributions from flood. The main contributor to current and future infrastructure losses is wind, with only minor contributions from storm surge and flood.*
- *Maximum wind speeds produced by tropical cyclones in Tuvalu are projected to increase slightly by end-of-century.*

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

PROJECT GOAL

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.

EXPOSURE AND POPULATION

The building assets considered in this study include residential, commercial, public and industrial buildings, while the infrastructure assets include major ports, airports, power plants, bridges and roads. The major crops in Tuvalu are coconut, banana and yam.

Table 1: Summary of Population and Exposure in Tuvalu (2010)

Total Population	9,960
GDP Per Capita (USD)	3,213
Total GDP (million USD)	32.0
Total Number of Buildings	3,018
Number of Residential Buildings	2,621
Number of Public Buildings	179
Number of Commercial, Industrial, Other Buildings	218
Hectares of Major Crops	1,914

As estimated and detailed in the previous phase of the project, the replacement value of all assets in Tuvalu is 268 million USD, of which about 85% represents buildings and 14% represents infrastructure. This study did not take into account future economic or population growth. Table 1 includes a summary of the population and exposure in the islands.

AIR TROPICAL CYCLONE MODEL

AIR has developed a South Pacific catastrophe parametric model to evaluate the tropical cyclone risk for 15 countries in the region. Historical data was used to build a stochastic catalogue of more than 400,000 simulated tropical cyclones, grouped in 10,000 potential realisations of the following year's activity in the basin. The catalogue provides a long-term view of tropical cyclone activity in the region. It was built to physically and statistically reflect the most credible view of current risk based on the historical record, including frequency, intensity and track evolution. The model estimates hazard (wind speeds and flooding levels) and damage (losses) for all events in the catalogue.

CURRENT CLIMATE

Tuvalu is located south of the equator in an area known for the frequent occurrence of tropical cyclones with damaging winds, rains and storm surge. Tuvalu has been affected by damaging tropical cyclones on multiple occasions during the past few decades. Tropical cyclone Bebe in 1972 was one of Tuvalu's worst disasters in recent history and reportedly caused six fatalities. In 1997 alone, Tuvalu was devastated by three tropical cyclones – Gavin, Hina, and Keli – which collectively produced significant damage.

The country's current tropical cyclone risk profile has been derived from an estimation of the direct losses to buildings, infrastructure and major crops, as caused by wind and flooding due to rain and storm surge. 'Losses' in this report refers to the direct costs needed to repair or replace damaged assets *plus* the emergency costs that 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).

The average expected losses per calendar year are referred to as the *Average Annual Loss* or *AAL* (see Appendix). The current climate AAL value is 0.08 million USD. The percentage distribution for the different assets considered is shown in Figure 1.

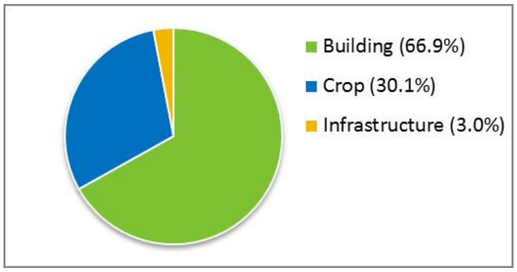


Figure 1: Contribution to total Average Annual Loss (AAL) from the three types of assets considered

The model also estimates losses from more infrequent tropical cyclones that are stronger and more damaging such as 50, 100, and 250 years - these are the 50, 100 and 250 year return period (RP) events (see Appendix). The current losses from such events are: 0.8 million USD (50 year RP), 1.4 million USD (100 year RP) and 2.6 million USD (250 year RP), respectively.

FUTURE CLIMATE

As part of the project, Geoscience Australia (GA) analysed general circulation model outputs from a total of 11 different Global Climate Models (GCMs), from two successive generations of GCM experiments referred to as CMIP3 and CMIP5. The models in the two frameworks are forced by different emission scenarios: the A2 scenario[1] for CMIP3 models and the RCP 8.5 scenario[2] for CMIP5 models. Both A2 and RCP 8.5 represent high emission scenarios.

Results from the latest generation CMIP5 models, for which no dynamical downscaling was required, indicate that these models tend to perform better at replicating the behaviour of tropical cyclones in the current climate, especially for the Southern Hemisphere. Thus, more confidence should be placed in the results from the CMIP5 framework. The below results are based on the CMIP5 models.

The Mean Estimate reflects results obtained after averaging output over all five models under the same climate framework. Figure 2 displays the relative frequencies for different storm categories, for both current and Mean Estimate future climate.

[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

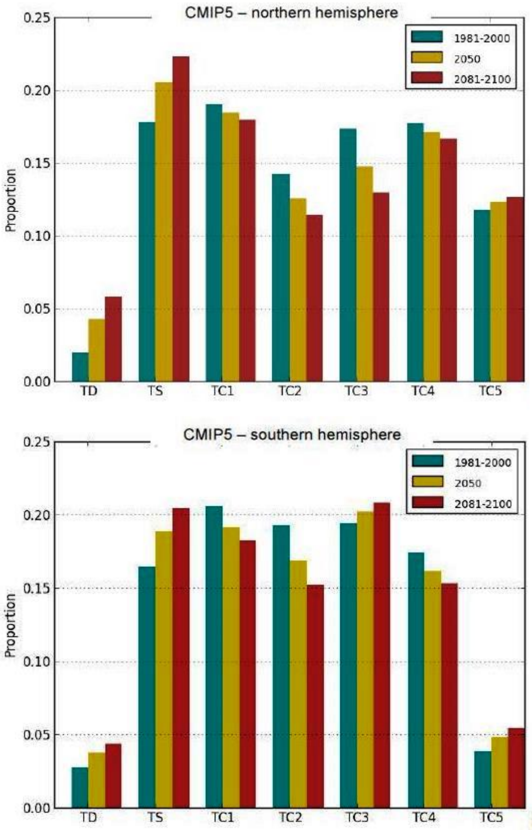


Figure 2: Mean Estimate relative proportion of TC intensity – multi model ensemble for CMIP5 models in the Northern and Southern Hemispheres. Classification is based on central pressure using a Cp-based Saffir-Simpson Hurricane Intensity Scale

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.

Future loss projections

Of the five individual models analysed, generally three models suggest large increases in losses and two models suggest decreases in losses. The significant divergence in the individual model results indicates a large range of model estimates.

Figure 3 shows end-of-century individual model projections for Exceedance Probability (EP – see Appendix) (blue) along with the current climate EP (green).

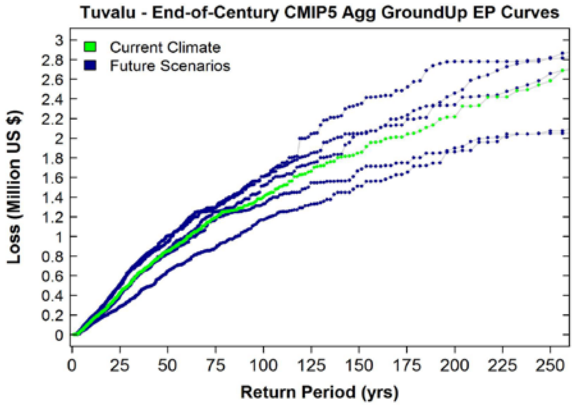


Figure 3: End-of-century EP-curves for individual CMIP5 models compared to the current climate EP-curve (green curve)

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.

There is an increase in losses projected from tropical cyclones for medium to high return periods (> 50 year RP) for the future climate. Figure 4 contrasts the end-of-century Mean Estimate projection with the current climate.

The comparison between the two EP-curves reveal increases in future losses from about the 50 year return period onward, with lower frequency events (> 90 year return period) projected to observe slightly larger increases in losses in the future climate.

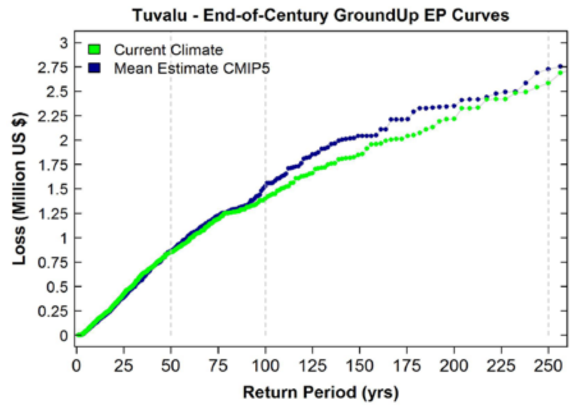


Figure 4: End-of-century EP-curve for the future Mean Estimate (blue curve) compared to the current climate EP-curve (green curve)

Mean Estimate end-of-century climate projections suggest a small decrease in future losses from tropical cyclones in Tuvalu compared to the current climate. However, for more extreme (250 year return period) events, the Mean Estimate suggests an increase in losses of 5.5% compared to the current climate, while the worst case scenario (most upper curve in Figure 3) suggests an increase in losses of around 9%.

Table 2: Loss estimates (USD) for current climate and future end-of-century Mean Estimate and worst case scenario

CMIP5 (Total Loss)	AAL	50yr RP	100yr RP	250yr RP
Current Climate	79,226	849,589	1,398,285	2,584,748
Future Mean Estimate	78,799	860,600	1,525,108	2,726,966
Future Worst Case	94,363	942,195	1,609,368	2,817,166

Table 2 contrasts current climate losses with the future Mean Estimate and worst case climate change scenario estimate across different return periods. The worst case scenario consistently projects significant loss increases when compared to the current climate across all return periods considered as well as the AAL.

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

The modelling of tropical cyclones under a future climate indicates an overall small decrease in Mean Estimate future losses compared to the current climate. The AAL decreases from 0.080 million USD to 0.077 million USD by mid-century and to 0.078

million USD by end-of-century, a decrease of 1.5% and 0.5%, respectively.

Table 3 contrasts the AAL and the 50, 100 and 250 year RP losses from current and future climates, for both 2050 and 2100 time periods, across the different assets at risk. The total loss (AAL) represents the sum of the building, infrastructure and crop AALs.

There is generally a slight increase in the losses from buildings and infrastructure, while losses from crops are expected to decline slightly. Marginally, more people are affected by future tropical cyclone risk than under the current climate for medium to high return periods (> 50 year return period).

Note that no adjustment to account for future economic or population growth was considered for any of the assets.

Table 3: Percent changes between future climate loss projections for mid-century and 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	79,226	849,589	1,398,285	2,584,748
	Future 2050 (%)	-1.5	-10.2	+1.3	+4.1
	Future 2100 (%)	-0.5	+1.3	+9.1	+5.5
Building	Current Climate	53,004	616,647	1,125,580	2,296,546
	Future 2050 (%)	-2.4	-12.3	-4.4	+0.0
	Future 2100 (%)	+0.9	+5.0	+4.3	+1.2
Infra-structure	Current Climate	2,403	16,651	43,832	117,930
	Future 2050 (%)	-0.7	-12.5	-7.1	+6.0
	Future 2100 (%)	+5.0	+2.6	+13.3	+6.9
Crop	Current Climate	23,818	225,888	285,097	342,334
	Future 2050 (%)	+0.2	-0.9	+1.3	+1.8
	Future 2100 (%)	-4.4	-2.0	+0.0	+0.3
Population Affected	Current Climate	1	10	16	29
	Future 2050 (%)	-1.7	-10.0	+0.0	+3.4
	Future 2100 (%)	-0.7	+0.0	+6.3	+3.4

Wind, flood and surge contributions to total loss estimates

The analysis captures 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 they are the main cause of damage 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 consequently also lead to significant damage to property.

The storm surge represents the sea water forced ashore due to the rise in sea level accompanying any approaching intense storm. A significant storm surge event can have devastating effects on-shore.

Both sea level and precipitation changes under future climates are not considered in this study.

The main contributors to building loss are wind and storm surge, while the main contributor to infrastructure loss is wind. The other hazards have only minor contributions to loss to buildings or infrastructure, respectively.

Figure 5 explores the *relative changes* in contributions losses split by hazard between the current and Mean Estimate future climate.

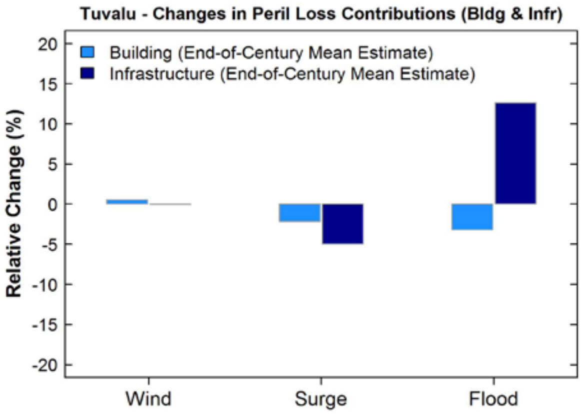


Figure 5: Percent changes between the end-of-century future climate and the current climate for Wind, Surge and Flood loss contributions to total loss, for buildings (light blue) and infrastructure (dark blue)

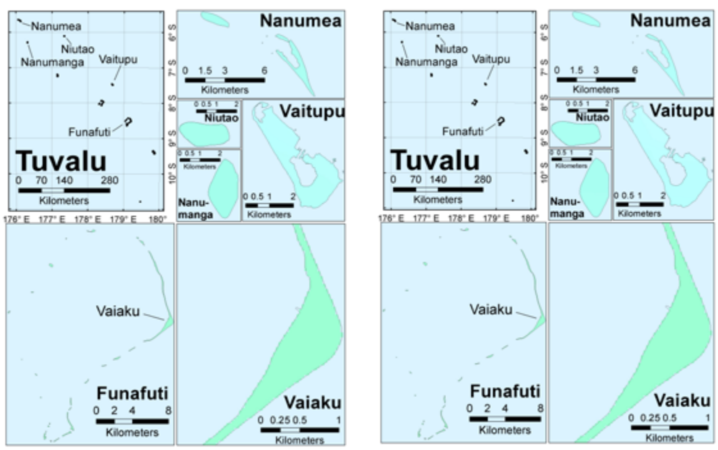
The only notable change across all hazards is the small increase in the flood contribution to infrastructure losses. However, it is important to note that the reported change is calculated between very small initial numbers and ultimately, wind remains the main contributor to loss for both assets, with a secondary contribution to building loss from storm surge.

Wind hazard maps for end-of-century climate compared to current climate

The wind hazard increases very slightly for the 100 year return period under future climate, as shown in Figure 6. The 100-year return period winds, which represent an event that has a 40% chance of being equalled or exceeded once in 50 years, are capable of generating severe damage to buildings, infrastructure, and crops with consequent large economic losses.

Figure 6 depicts the end-of-century 100 year mean RP wind speed, expressed as maximum 1-minute sustained winds in km/h, for the current climate (top panel) and future projection (bottom panel). For example, south of Vaiaku, the 100 year RP wind speed increases from 111.6 km/hr to 112.3 km/hr by the end of century.

The wind level changes are less dramatic than the changes in total losses, because a small change in wind speed can result in significantly larger damage costs. The current climate wind patterns in Tuvalu are generally maintained under future climate projections.



Current Climate *Future Climate*

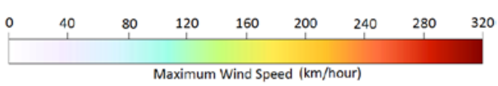


Figure 6: 100 year mean return period winds (maximum 1-minute sustained winds in km/h) for the current climate (top panel) and the CMIP5 future projection (bottom panel)

SUMMARY

The evaluation of the current and future climate tropical cyclone risk in the South Pacific region was carried out using Geoscience Australia's analysis of tropical cyclone activity along with AIR's catastrophe model developed specifically for the region. The risk model allows for the translation of the climate change induced effects observed in the frequency, intensity and path of tropical cyclones into direct loss results for the region and individual countries.

For both hemispheres, numerical models predict a 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 (Figure 2). Most notable is the regional increase in category 5 storms.

The financial impacts are measured using metrics such as the Average Annual Loss (AAL) or the 100 year return period loss. For planning purposes, it is useful to understand both average annual losses as well as possible losses from extreme events.

The Mean Estimate (Table 3) suggests increases in future losses compared to the current climate for more extreme tropical cyclones (> 50 year RP), while an overall small decrease is noted for the AAL. Slightly larger increases in losses are projected for lower frequency events (> 90 year RPs - Figure 4).

For extreme events (250 RP) the Mean Estimate by end-of-century suggests an increase in losses of 5.5% compared to the current climate, while the worst case climate change scenario suggests an increase in loss of 9% (Table 2).

The largest end-of-century changes in loss for different assets are observed for buildings and infrastructure, while crops exhibit smaller mixed changes in losses (Table 3). A slightly higher proportion of the population is projected to be affected by end-of-century tropical cyclone risk compared to the current climate, for medium to lower frequency events.

The main contributors to losses to buildings are wind and, to a lesser degree, storm surge. For infrastructure, the main contributor to losses is wind. Flood has a minor contribution to both assets. There are minimal future changes in the flood and surge contributions to total loss (Figure 5) for future climate. Similar to the current climate, the wind hazard remains the main contributor to loss for both assets.

The end-of-century Mean Estimate projects slightly stronger winds compared to the current climate, though differences are difficult to discern (Figure 6). The current climate general wind hazard patterns are maintained across the country.

Models from both the CMIP3 and CMIP5 global climate model runs were analysed in this project. The CMIP5 models demonstrated greater skill and performance in replicating current climate conditions, and reporting of damage and loss has therefore focused on results from the CMIP5 framework.

There is consistent divergence, in the resulting EP-curves for individual models under the same framework (Figure 3) indicative of significant model uncertainty. The mean changes in future losses compared to the baseline are too small to be considered statistically significant when measured against the range of model estimates.

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 estimated EP-curve reveals that generally the separation between the baseline and the future projection is not large enough to be considered statistically significant.

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 key 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.

Australian Government

With financial support from the European Union
In the framework of the ACP-EU Natural Disaster Risk Reduction Program managed by the GFDRR

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