Vanuatu Klaemet Infomesen blong Redy, Adapt mo Protekt

Van-KIRAP

Economic Assessment of Tropical Cyclone (TC) Hazards over Vanuatu.

30 SPREP PROE

Sustainable, transformative and resilient for a Blue Pacific

By mid-century (2050), tropical cyclone associated cost over Vanuatu could increase to 21–22 % of GDP under a low emission scenario or 23 – 26 % of GDP under a high emission scenario.

Economic Assessment of Tropical Cyclone (TC) Hazards over Vanuatu

Authors: Anil Deo, Savin Chand, Kevin Henessy, Geoff Gully, Ron Hoeke, Geoff Gooley, Rebecca Greogory, and Leanne Webb

Contents

Executive Summary

This report presents information about tropical cyclone (TC) associated economic cost (hereafter referred to as "cost" or just "C")[1] over Vanuatu, including historical averages and projections as they relate to "global and local warming levels".

The report uses datasets and information from Vanuatu Government Agencies and presents the information in new and more salient ways, with more context and detail; thereby making the information more relevant to decision-makers for application at a sectoral level. The report examines historical TC related cost-intensity relationship for Vanuatu and estimates the mean cost per TC and annual total cost under a warming climate by the mid and late-century. The key findings for Vanuatu are summarised as follows:

- Considering the historical data, the mean cost per TC, when scaled to the 2022 GDP value, over the period 1987 – 2023 is VT 17.43 billion (USD 151.82 million) or 18.9 % of GDP.
- The cost is quite sensitive to the TC intensity: cost is directly related to about the fifth power of the maximum windspeed (in kilometres per hour: km hr^{-1}).
- By mid-century, climate projections indicate a slight increase in maximum windspeed.
- Estimates using the above power law show that the mean expected cost, per TC, by mid-century could increase to 21–22 % of GDP under a 0.6 °C local warming (low greenhouse gas emissions scenario) or 23-26% of GDP under a 1.2 °C warming (high emissions scenario). This translates to VT 19.29–20.42 billion (an increase of VT 1.86–3.00 billion) and 21.31–23.81 billion (an increase of 3.88–6.38 billion) respectively.
- By late-century, climate projections indicate a larger increase in maximum windspeed.
- By late-century, the mean expected cost per TC could increase to 21–22% of GDP under a 0.6 °C warming (low emissions scenario) or 29–37% of GDP under a 2.7 °C warming (high emissions scenario). This translates to roughly an impact increase of VT 1.86–3.00 and 9.65–16.83 billion respectively.
- Estimates show a 14 % decrease in the frequency of TCs by late-century: the historical period has an average of 0.85 TCs yr^{-1}, but this could decrease to 0.73 TCs yr^{-1} by late-century.
- The cost calculations above do not account for this projected decrease in cyclone frequency. Combining the projected increase in maximum windspeed with the projected decrease in the frequency of TCs, the annual total cost could increase to VT 19.8 – 25.0 billion yr^{-1} (i.e., with a mean frequency of 0.73 TCs yr^{-1}) by late-century under a 2.9 °C warming in comparison to the historical annual total cost of VT 14.82 billion yr^{-1} (which is the product of VT 17.43 billion per TC and the mean frequency of 0.85 TCs yr^{-1}).

[1] Economic cost is the combination of losses and damages. Losses includes the decline of output of the productive sectors, lower revenues, and sales, as well as the private and public increased expenditures to manage the disasters and new risks associated with them. Damage is understood as physical devastation and deterioration to capital stock such as infrastructure, buildings, and assets.

1. Introduction

Tropical cyclones (TCs) are among the costliest and deadliest natural disasters for Vanuatu as they include a number of different hazards – such as extreme winds, flooding, storm surges and tornadoes – that can act individually or interact with one another to substantially increase the potential for loss of life and property damages in impacted areas (CSIRO and SPREP, 2021). Of particular concern for various sectors of the community is the TC wind hazard, which often can have devastating effects directly through damaging winds, and secondary effects through destructive waves and storm surges in coastal regions. The risk to the Vanuatu economy to TCs highly depends in part on the frequency and intensity of TCs. The risk also depends on the exposure and vulnerability of communities, ecosystems, businesses, assets, and infrastructure.

Socio-economic assessments of loss and damage often quickly follow a TC to aid disaster management and recovery efforts in affected communities. For example, in the South Pacific Island countries, ACAPS (2023) documented impacts caused by back-to-back category 4 TCs Judy and Kevin in March 2023. Similarly, Esler (2015) produced a post-disaster assessment report for category 5 TC Pam in March 2015, which was the second most intense TC in the South Pacific (in terms of sustained wind speed) to affect Vanuatu. This event caused a widespread loss and damage exceeding VT 48.6 billion or US$449.4 million (Esler, 2015), which was approximately 64.1% of Vanuatu's gross domestic product (GDP). VT 29.3 billion was attributable to damage and VT 19.3 billion was attributable to loss. TC Harold in 2020 cost VT 51 billion, with VT 27 billion attributable to damage and VT 24 billion attributed to economic loss (Tugeta, 2020). Such socio-economic assessment reports, as well as other sources (e.g., insurance companies), form the basis of data on TC loss and damage for Vanuatu.

Moreover, under a changing climate, questions are raised on how the loss and damage is likely to be impacted by the changing characteristics of TCs. This relationship is further explored for the case of Vanuatu to better understand and quantify the effects of TCs on the country's economic loss and damage under a changing climate. Analysis includes the following:

- **Historical economic cost:** from 1987 – 2023 as data are available for this period.
- **Cost – intensity relationship:** estimate of the relationship between wind speed and TC economic cost using historical data.
- **Estimated percentage increase in average cost per TC in a warming climate (part 1):** using the relationship between windspeed and cost with projected changes in windspeed (excluding the projected decrease in TC frequency).
- **Conversion of cost into US dollars or VT:** computing the percentage increase in cost in US dollars or VT.
- **Estimated percentage increase in annual cost in a warming climate (part 2):** using the relationship between windspeed and cost with projected changes in windspeed and the projected decrease in TC frequency.

2. Data and Methods

It is clear from literature that the economic cost is dependent on the maximum TC wind speed (V_{max}, e.g., Emanuel 2005; Powell and Reinhold 2007 and others). The basic cost-intensity function (Nordhaus, 2010; Mejia, 2016) is:

$$ln\left(\frac{C_{it}}{GDP_t}\right) = \alpha + \beta \ln(V_{max,it}) + \delta Y_t + \epsilon_{it} \quad \text{Eq. 1}$$

where C_{it} is the estimated cost for TC "*i*" in year "*t*" at current prices, $V_{max,it}$ is the estimated maximum sustained wind speed (km hr^{-1}) within 50 km of the closest approach to mainland Vanuatu, GDP_t is gross domestic product in current prices, and ϵ_{it} is a residual error. The Greek letters α, β and δ are the estimated coefficients. β is also known as the elasticity coefficient of windspeed. We use here the multivariate least square analysis to estimate these coefficients.

Moreover, the relationship between TC cost and global warming is a complex function of economics, geography, and geophysics. The general relationship, as discussed by Nordhaus (2010), for storm *i* at time *t* is given as:

$$C_{it} = f\{Q_t, KQ_t, Kdensity_{it}, Kvul_{it}, storm[SST_t(T_t)]\} \quad \text{Eq. 2}$$

where C_{it} is the cost, Q_t is the GDP, KQ_t is the nominal capital–output ratio, $K_{density}$ is the spatial density of capital, $Kvul_{it}$ is the vulnerability of capital as function of geography, $storm_{it}$ is the maximum wind speed and other storm characteristics, SST_t is the sea-surface temperature in the cyclogenic region, and T_t is the global mean SST. Note that storm characteristics are a function of SST_t, which is in turn a function of T_t.

Following previous studies, e.g., Nordhaus (2006, 2010), for the central estimates, we consider only the number of TCs, the size of the economy, and the impact of warming on TC intensity. For estimation purposes, a simplified version of the cost function given in Eq. 2 is given as follows for cost per TC:

$$\ln(C_{it}) = ln(Q_t) + \beta \ln[(1 + \gamma \Delta SST_t) V_{max,it}] + \epsilon_{it} \quad \text{Eq. 3}$$

The diverse unmeasured locational and storm factors as well as stochastic factors are collected in ϵ_{it}, while $V_{max,it}$ is maximum wind speed (km hr^{-1}). The wind term contains the wind speed-cost elasticity β and the impact of increased SST on maximum wind speed is given by the coefficient γ (also known as the semi-elasticity). The semi-elasticity is the fraction by which potential intensity (or maximum wind speed) will increase for each °C rise in the SST.

From Eq. 3, it can be shown that the mean percentage change in cost (i.e., Δ*C*) in a warming climate is:

$$\Delta C = [(1 + \gamma \Delta SST)^{\beta} - 1] \times 100 \quad \text{Eq. 4}$$

To compute the percentage change in cost, the β values computed here and those available in the literature are used. With regards to γ, values of 0.035 and 0.055 are used which have been estimated by the early study of Emanual (2005) and Knutson and Tuleya (2004) respectively either using global data or modelling. For a complete discussion about the cost-intensity and cost-climate change relationship presented above please refer to studies such as by Nordhaus (2010), Zhai and Jiang (2014) and Mejia (2016).

TCs that passed Vanuatu within 50 km from the mainland have been considered in this study and the data for TC location and maximum windspeed near the closest approach were obtained from International Best Track Archive for Climate Stewardship (IBTrACS; Knapp et al., 2010) portal (*https://www.ncei.noaa.gov/products/international-best-track-archive*).

A limited number of studies have estimated the relationship between wind speed and TC cost, the majority of which are only for the US (e.g., Schmidt et al., 2009; Nordhaus, 2010; Bouwer and Botzen, 2011; Mendelsohn et al., 2012; Hsiang and Narita, 2012; and Strobl, 2012). Nordhaus (2006, 2010) was the first to estimate the wind-cost relation using rigorous statistical techniques. Using data on US TC landfalls and cost, Nordhaus (2006, 2010) established what is called the "ninth-power law of cost" because the elasticity of cost to wind speeds was estimated to be 9 (i.e., the cost is proportional to the ninth power of the V_{max}). Later, Bouwer and Botzen (2011) estimated the same specification used by Nordhaus (2010) but with a different set of data on US cost based on Pielke et al. (2008) and found that the wind-cost relation had an elasticity of between 6 and 8. Strobl (2012), using the same Pielke et al (2008) data, found that cost increase to the 3.8 power of wind speed. Schmidt et al (2009) constructed a capital stock index for each US county affected by TCs and estimated that the elasticity of cost to wind speed is about 2.8. Mendelsohn et al (2012) estimated the elasticity to be almost 5 for the US.

The only study that explores the wind-cost relationships outside the US is Hsiang and Narita (2012) which is over several countries. They use the Emergency Events Database (EM-DAT) and a wind-field model to search for indications of adaptation to TCs, and in the process they estimate that the semi-elasticity of cost to wind speed is 0.10, indicating that an increase in wind speed of 1.9 km hr^{-1} increases cost by 10 %.

3. Historical Cost

While there has been numerous TC passes close (< 100 km) to Vanuatu, there is a dearth of economic cost data available for most of the loss and damage associated with these TCs. Cost data for 11 TCs are presented in Table 1. These are cost associated with TCs that passed within 50 km of mainland Vanuatu. TC Judy affected Vanuatu from 28 Feb to 1 Mar 2023, then TC Kevin affected Vanuatu from 3-6 Mar 2023, so the available cost data is the cumulative impact of the two events. Hence, the respective cost shown in Table 1 for each of these two events is the partial computed from the cumulative cost of USD 443 million and proportional to the maximum windspeed at the closest approach to Vanuatu (which is very crude estimate, nonetheless). From Table 1, it is evident that TC Pam (2015) as a single event incurred the greatest economic cost over Vanuatu. This is followed by Uma (1987) with a cost of approximately 50 % of GDP and then Judy and Kevin (with a combined cost of 44 % of GDP). These events tend to show that TCs have tremendous effect on the economy and the livelihood of the people of Vanuatu.

Table 1: Historical TCs and associated cost

#	Year	TC Name	Vmax (km hr^{-1})	C (VT Billions)	C (USD Millions)	GDP (USD Millions)	(C/GDP)
1.	1987	UMA	156.68	7.27	70.00	139.50	0.50
2.	1992	BETSY	207.86	0.24	2.00	209.10	0.01
3.	1993	PREMA	235.02	0.61	5.00	200.50	0.02
4.	1996	BETI	120.38	0.0045	0.041	261.40	0.00
5.	1999	DANI	190.89	0.40	3.00	268.00	0.01
6.	2004	IVY	233.19	0.43	3.80	365.00	0.01
7.	2015	PAM	352.53	48.60	449.40	701.10	0.64
8.	2018	Gita	130.56	0.63	5.66	914.70	0.01
9.	2020	Harold	287.24	51.00	408	950.00	0.43
10.	2023	Judy	206.29	22.72	192.20	983.60	0.20
11.	2023	Kevin	258.52	28.48	240.80	983.60	0.24

4. The cost-intensity relationship

The relationship between normalized cost (C/GDP) and V_{max} associated with the 11 events shown in Table 1 is further investigated. Figure 1 shows a double-logarithmic scatter plot of V_{max} and normalized cost for the 11 TC events. The line is the ordinary least-squares best fit, and this plot shows that costs are directly related to V_{max}.

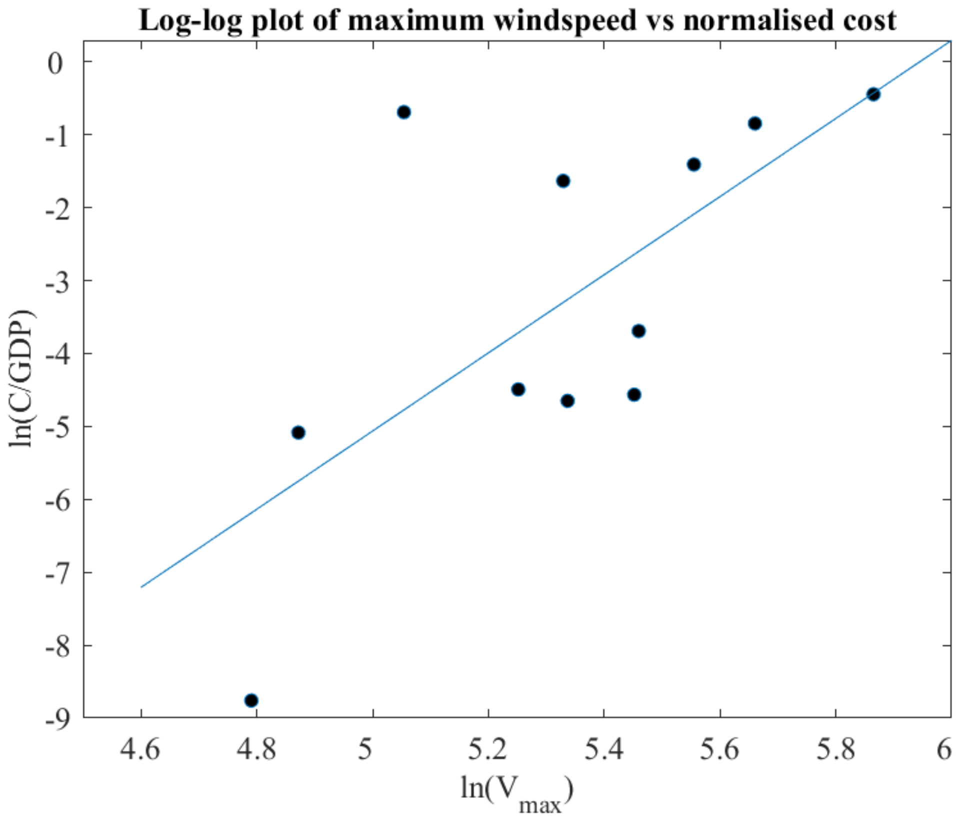

Figure 1: Log-log plot of normalised cost against maximum wind speed (V_{max}).

The basic cost-intensity function, discussed in section 2 (Data and Methods), is used in this report. The main estimated results, using the multivariate ordinary least squares method, are presented in Table 2. The regression analysis shows that the elasticity factor, β, in the windspeed is 4.88. This factor shows that the economic cost over Vanuatu is a function of maximum windspeed to almost the fifth power. The coefficient for time with a value of δ = 0.03 shows that the mean cost has been growing at a rate of 3 % percent per year.

Table 2: Estimates of coefficients for the cost-intensity function

Coefficients	Estimate	SE	t-statistic	p-value	R^2	RMSE
α	-89.68	98.55	-0.91	0.39	0.50	2.04
β	4.88	2.14	2.28	0.05		
δ	0.03	0.05	0.59	0.57		

5. Estimated Increase in Average Cost per TC in a Warming Climate

Over the 21st century, the ocean is projected to continue warming (e.g., CSIRO, SPREP and VMGD (2023). By mid-century (2040-2059), the warming near Vanuatu is projected to be 0.6 °C under low emissions (RCP2.6), or 1.2 °C under high emissions (RCP8.5). By late-century (2080-2099), the projected warming is 0.6 °C under low emissions (RCP2.6) or 2.7 °C under high emissions (RCP8.5).

Table 2 shows the estimated percentage increase in the average cost per TC over Vanuatu. Different sets of input parameters are used in Eq. 3 (see section 2) to provide a range of potential cost in the future. Firstly, elasticity (β) values computed here (i.e., 4.88) and another available in the literature, e.g., 9 (Nordhaus, 2010) are used. Secondly, semi-elasticity (γ, see Eq. 4 in section 2) values of 0.035 (Knutson and Tuleya, 2004) and 0.055 (Emanual, 2005) are used. Thirdly, the changes in sea surface temperature (SST) as reported by CSIRO, SPREP and VMGD (2023) for mid-century and end of century under RCP2.6 and RCP8.5 are used.

For the elasticity of 4.88 and semi-elasticity of 0.035, the estimated increase in average cost by mid-century is 10.7 % for a 0.6°C warming (RCP2.6) or 22.2 % for a 1.2 °C warming (RCP8.5). However, if a semi-elasticity factor of 0.055 is taken into consideration, these costs could be as high as 17.2 % under RCP2.6 or 36.6 % under RCP8.5. By late-century, the estimated increases in average cost per TC range from 10.7 – 96.5 % under the various climatic scenarios and elasticity values.

With an elasticity value of 9 and semi-elasticity of 0.035, the increase in cost under RCP8.5 could be as large as 45 % by mid-century or 125 % by late-century.

Table 3: Estimated average cost increase (%) per TC in a warming climate. The values in the brackets are the 5-95 % confidence interval. Vmax is maximum windspeed, SST is the sea surface temperature.

Case	Elasticity w.r.t V_{max}	Semi-elasticity of V_{max}	2040-2059		2080-2099	
			Change in SST (°C)	Estimated increase in average cost (%)	Change in SST (°C)	Estimated increase in average cost (%)
a.	4.88	0.035	0.6 *(0.4, 0.8)*	10.7 *(7.0, 14.4)*	0.6 *(0.4, 0.9)*	10.7 *(7.0, 16.3)*
b.	4.88	0.035	1.2 *(0.8, 1.4)*	22.2 *(14.4, 26.3)*	2.7 *(2.3, 3.4)*	55.3 *(44.2, 72.7)*
c.	4.88	0.055	0.6 *(0.4, 0.8)*	17.2 *(11.2, 23.4)*	0.6 *(0.4, 0.9)*	17.2 *(11.2, 26.6)*
d.	4.88	0.055	1.2 *(0.8, 1.4)*	36.6 *(23.4, 43.6)*	2.7 *(2.3, 3.4)*	96.5 *(78.8, 130.8)*
e.	9.00	0.035	0.6 *(0.4, 0.8)*	20.6 *(13.3, 28.2)*	0.6 *(0.4, 0.9)*	20.6 *(13.3, 32.2)*
f.	9.00	0.035	1.2 *(0.8, 1.4)*	44.8 *(28.2, 53.8)*	2.7 *(2.3, 3.4)*	125.4 *(100.7, 175.1)*

6. Estimated increase in cost in USD and VT

These percentage increases can be translated to USD and VT. Table 4, which is generated from Table 3, presents the economic impacts of intensification of TCs over Vanuatu in a warming climate. Results are shown for both the mid and late-century with the elasticity values of 4.88 and 9, both as a percentage of GDP and USD (or VT) scaled to the 2022 GDP level. The difference in TC related cost between historical and future climate is also shown.

The average cost per TC for the period 1987 – 2023 is 18.9 % of GDP which is VT 17.43 billion or USD 151.82 million. By mid-century, the average cost could be as large as 21 – 22 % of GDP under a 0.7 °C warming (cases a and c) which translates to a 2-3 % increase in the cost of GDP from the historical levels (or an impact increase of VT 1.86 – 3.00 billion). For the same period, under a 1.2 °C warming, the average cost per TC could be 23-26 % of GDP (cases b and d). This translates to a 4-7 % increase in the cost of GDP from the historical levels (or a cost increase by VT 3.88 – 6.38 billion).

By late-century and under a 0.7 °C warming, the average cost per TC could increase to 21 – 22 % of GDP (cases a and c) which translates to a 2 – 3 % increase in the cost of GDP from the historical levels (or an impact increase of VT 1.86 – 3.00 billion). For the same period, under a 2.9 °C warming, the average cost per TC could be as large as 29-37 % of GDP (cases b and d). This translates to a 10 – 18 % increase in the cost of GDP from the historical levels (or a cost increase by VT 9.65 – 16.83 billion).

Furthermore, computations using the estimates of earlier studies (i.e., cases i and j), show that the costs could be much larger than that reported above.

Table 4: Average cost per TC over Vanuatu for three time periods: 1987-2023, 2040-2059 and 2080-2099. Cases follow that shown in Table 3 and values are scaled to the 2022 GDP value.

Case	1987-2023			2040-2059						2080-2099					
				Estimated Increase			Difference			Estimated Increase			Difference		
	% of GDP	Billions of VT (2022 levels)	Millions of USD (2022 levels)	% of GDP	Billions of VT (2022 levels)	Millions of USD (2022 levels)	% of GDP	Billions of VT (2022 levels)	Millions of USD (2022 levels)	% of GDP	Billions of VT (2022 levels)	Millions of USD (2022 levels)	% of GDP	Billions of VT (2022 levels)	Millions of USD (2022 levels)
a.	18.86	17.43	151.82	20.88	19.29	168.02	2.01	1.86	16.20	20.88	19.29	168.02	2.01	1.86	16.20
b.	18.86	17.43	151.82	23.06	21.31	185.57	4.19	3.88	33.76	29.31	27.08	235.88	10.45	9.65	84.06
c.	18.86	17.43	151.82	22.10	20.42	177.88	3.24	2.99	26.06	22.10	20.42	177.88	3.24	2.99	26.06
d.	18.86	17.43	151.82	25.77	23.81	207.38	6.90	6.38	55.57	37.07	34.26	298.37	18.21	16.83	146.55
e.	18.86	17.43	151.82	22.74	21.02	183.04	3.88	3.58	31.23	22.74	21.02	183.04	3.88	3.58	31.23
f.	18.86	17.43	151.82	27.32	25.24	219.85	8.45	7.81	68.03	42.52	39.29	342.18	23.65	21.86	190.37

The frequency of TCs is projected to decrease over Vanuatu. This is shown in Figure 2a and b which presents the TC frequency in the historical (1971-2000) and future (RCP8.5; 2071-2100) climate within 50 km about Vanuatu generated using various simulations (Prasad et al., 2023). The frequency decreases from a total of 25.5 TCs over the 30-year historical period (i.e., with an average of 0.9 TCs yr^{-1}) to a total of 21.9 TCs over the 30-year future period (i.e., 0.7 TCs yr^{-1}). Considering Case b in Table 3 and 4 (i.e., for β = 4.88 and γ = 0.035), and a frequency of 0.9 TCs yr^{-1}, the historical annual total cost is VT 14.82 billion (Figure 2c), while by late-century (with 0.7 TCs yr^{-1}) annual total cost is projected to be VT 19.75 billion (Figure 2c). This is a 33.35 % increase in the annual total cost from the historical level. Note, annual total cost is the product of average cost per TC and TC frequency per year.

Considering Case d in Table 3 and 4 (i.e., for β = 4.88 and γ = 0.055), the annual average cost is projected to be VT 25.0 billion by late-century (Figure 2c). This is a 69 % increase in the annual average cost from the historical level.

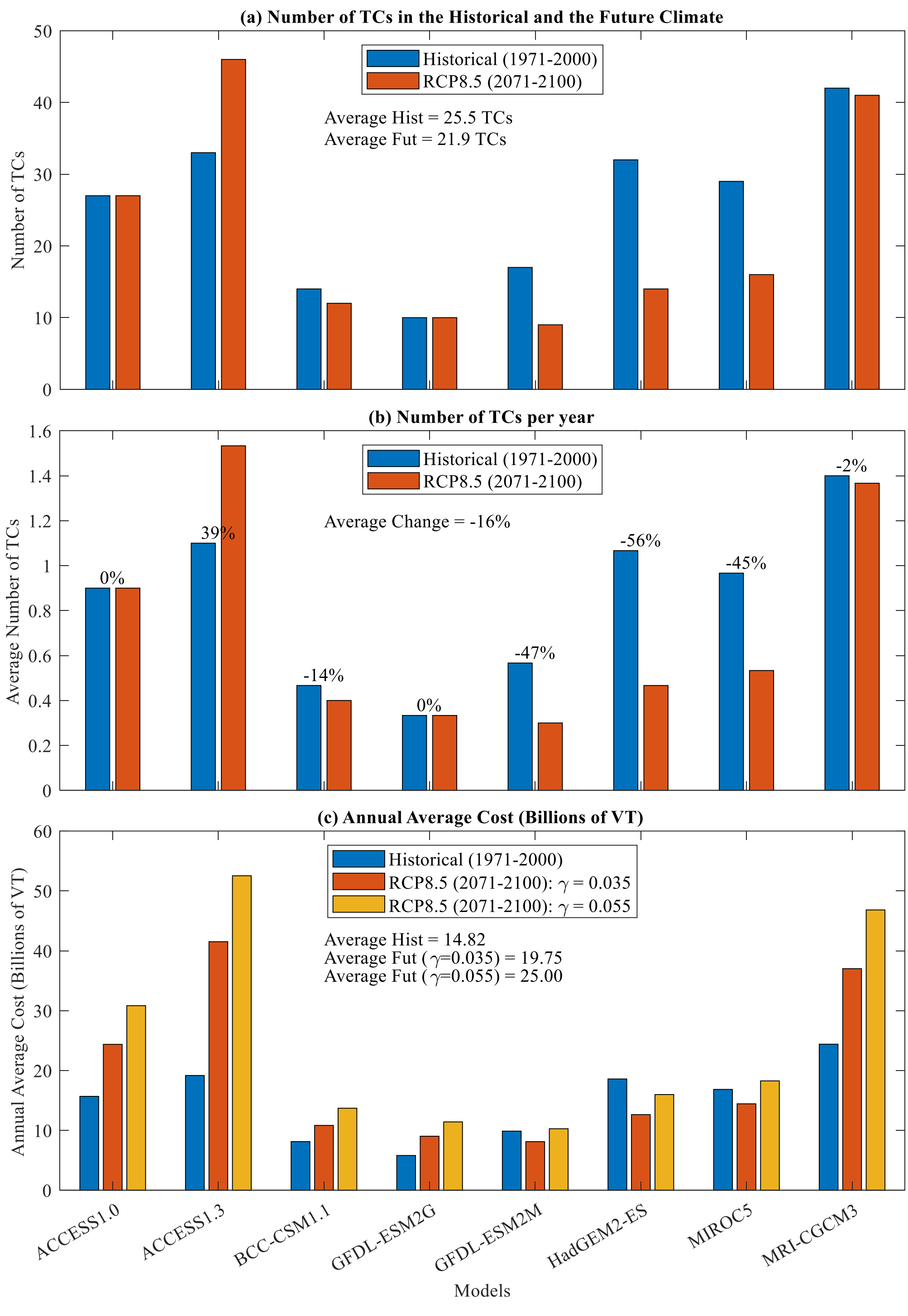

Figure 2: (a) TC frequency in the current (1971-2000) and the future (RCP8.5; 2071-2100) climate using various models within 50 km about Vanuatu. (b) Average number of TCs per year in the historical and the future climate. The percentage change in the number of TCs between the two periods for each model is shown over the bar chart. (c) The annual average cost in the historical and the future climate. The multimodal mean of the historical (i.e., Average Hist) and future cost (i.e., Average Fut, for two elasticity values) are also shown in this panel. Note, while Tables 3 and 4 show the mean increase per TC, this figure shows the

total annual increase (i.e., the product of frequency of TCs and the mean per TC) since frequency has now been taken into consideration.

7. References

ACAPS (2023). Vanuatu: the impact of cyclones Judy and Kevin. Available at: https://www.acaps.org/fileadmin/Data_Product/Main_media/acaps_20230314_briefing_note_vanuatu_the_impact_of_cyclones_judy_and_kevin_0.pdf

Bouwer, Laurens; and Botzen, Wouter (2011). "How Sensitive are US Hurricane Damages to Climate? Comment on a Paper by W. D. Nordhaus". Climate Change Economics, Vol. 2, pp. 1-7.

CSIRO and SPREP (2021). 'NextGen' Projections for the Western Tropical Pacific: Current and Future Climate for Vanuatu. Final report to the Australia-Pacific Climate Partnership for the Next Generation Climate Projections for the Western Tropical Pacific project. Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Secretariat of the Pacific Regional Environment Programme (SPREP), CSIRO Technical Report, Melbourne, Australia. https://doi.org/10.25919/hexz-1r10

CSIRO, SPREP and VMGD (2023). Vanuatu South: sub-national historical and projected climate overview. A report to the Van-KIRAP project. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Secretariat of the Pacific Regional Environment Programme (SPREP) and Vanuatu Meteorology and Geo-hazards Department (VMGD), CSIRO Technical Report, Melbourne, Australia.

Emanuel, K (2005). Increasing destructiveness of tropical cyclones over the past 30 years. Nature, 436, 686–688.

Hsiang, Solomon; and Narita, Daiju (2012). "Adaptation to Cyclone Risk: Evidence From the Global Cross-Section". Climate Change Economics, Vol. 3, pp. 1-28.

Kirono DGC, Round V, Ramsay H, Thatcher M, Nguyen K, Rafter T, Takbash A (2023) National and sub-national climate projections for Vanuatu. A report submitted to the "Climate Information Services for Resilient Development in Vanuatu (VAN-CIS-RDP)" or "*Vanuatu Klaemaet Infomesen blong Redy, Adapt mo Protekt (Van-KIRAP*)", CSIRO, Australia.

Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann, 2010: The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying tropical cyclone best track data. Bulletin of the American Meteorological Society, 91, 363-376. doi:10.1175/2009BAMS2755.1

Knutson, T. R., and R. E. Tuleya, 2004: Impact of CO2-Induced Warming on Simulated Hurricane Intensity and Precipitation: Sensitivity to the Choice of Climate Model and Convective Parameterization. J. Climate, 17, 3477–3495, https://doi.org/10.1175/1520-0442(2004)017<3477:IOCWOS>2.0.CO;2.

Prasad, K., et al, 2023:

Mejia, S.A., 2016. Gone with the Wind: Estimating Hurricane and Climate Change Costs in the Caribbean. IMF Working Paper. ISBN/ISSN:9781475544763/1018-5941.

Mendelsohn, Robert; Emanuel, Kerry; Chonabayashi, Shun; and Bakkensen, Laura (2012). "The Impact of Climate Change on Global Tropical Cyclone Damage". Nature Climate Change, Vol. 2, pp. 205-209.

Nordhaus, W (2006). Geography and macroeconomics: New data and new findings. Proceedings of the National Academy of Science (US), 103(10), 3510–3517.

Nordhaus, William (2010). "The Economics of Hurricanes and Implications of Global Warming". Climate Change Economics, Vol. 1, pp. 1-20.

Pielke, Roger; Gratz, Joel; Landsea, Christopher; Collins, Douglas; Saunders, Mark; and Musulin, Rade (2008). "Normalized Hurricane Damage in the United States: 1900–2005". Natural Hazards Review, Vol. 29, pp. 29-42.

Powell, M. D., and T. A. Reinhold, 2007: Tropical Cyclone Destructive Potential by Integrated Kinetic Energy. Bull. Amer. Meteor. Soc., 88, 513–526, https://doi.org/10.1175/BAMS-88-4-513.

Schmidt, Silvio; Kemfert, Claudia; and Höppe, Peter (2009). "The Impact of Socio- Economics and Climate Change on Tropical Cyclone Losses in the USA". Regional Environmental Change, Vol. 10, pp. 13-26.

Strobl, Eric (2012). The Economic Growth Impact of Natural Disasters in Developing Countries: Evidence from Hurricane Strikes in the Central American and Caribbean Regions. Journal of Development Economics, Vol. 97, pp.130-141.

Tugeta, Y.E. (2020). Vanuatu recovery strategy 2020-2023: TC Harold and COVID-19. Port Vila. p. 28 Available from: https://www.preventionweb.net/publication/vanuatu-recovery-strategy-2020-2023-tc-harold-covid-19