Original Article

Mitigating proximate impacts of tropical cyclone landfalls in the Southwest Indian Ocean

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Abstract

The occurrence and impacts of tropical cyclones in the Southwest (SW) Indian Ocean were investigated over five cyclone seasons (November to April) between 2018/19 and 2022/23. Data describing cyclone characteristics, affected populations and economic losses from cyclone landfalls in Madagascar and Mozambique were extracted from the African Risk Capacity (ARC)'s Tropical Cyclone Explorer (TCE) software. Of 56 cyclones that formed in the region, 27 landfalls occurred with an average of 2.8 per season in Madagascar and 2.6 in Mozambique, mainly in January and February of each year. Most cyclone landfalls in Madagascar were categorized as moderate tropical storms (MTS, 43 %) and intense tropical cyclones (ITC, 22 %). In Mozambique, landfalls were mostly ITC (31 %) followed by MTS (23 %). Landfalls of very intense tropical cyclones (VITC) were more common in Mozambique (15 %) than Madagascar (7 %). An average of 1.8 million and 775,000 people per season were exposed to strong cyclone winds in Madagascar and Mozambique, respectively, with economic losses from cyclones per season averaging $544 million in Madagascar and $170 million in Mozambique. The African Risk Capacity (ARC), a specialized agency of the African Union, has implemented a parametric insurance solution to mitigate the proximate effects of cyclones damage on vulnerable populations. Four modules to estimate losses caused by cyclone events are described; the hazard-, vulnerability / damage-, - exposure- and insurance modules. Initial outcomes of the ARC's parametric cyclone insurance policy in Madagascar and Mozambique are discussed. Since its launch in 2020, the ARC's parametric cyclone insurance policy including its Replica partner allocated a total payout of $12.2 million to Madagascar following the landfalls of cyclones BATSIRAI in 2022 and FREDDY in 2023.

Keywords: cyclone, climate change, landfall, parametric insurance, Madagascar, Mozambique, African Risk Capacity (ARC)

Introduction

The Southwest Indian Ocean (SWIO) region is one of the most active areas in the world in terms of tropical cyclone development (Malan *et al.*, 2013). On average, 11-12 cyclones with wind speeds greater than 63 km/h and often exceeding 200 km/h occur yearly in the region (Mavume *et al.*, 2009). Several studies show that climate change is making cyclones stronger (rapid intensification, higher maximum wind speeds and more intense and very intense cyclones), wetter (strong storm surges, excessive rainfall, and risk of high coastal and inland flooding), and slower moving after making landfall on inhabited lands (Kossin *et al.*, 2020; Knutson *et al.*, 2019). In addition to huge economic losses, tropical cyclones have caused a trail of death and destruction, and physical losses across countries. Cyclone disasters significantly contribute to the high levels of poverty and food insecurity in the affected countries and exacerbate the existing conditions caused by previous disasters (World Bank, 2015;

Clayton, 2012). The strong winds, excessive rains and flooding associated with cyclones have a devastating impact on national economies and on the livelihoods of local people (Nash *et al.*, 2015; Harvey *et al.*, 2014). Moreover, they weaken people's resilience, plunge communities into indescribable poverty, and expose them to increased risks of water-related diseases such as cholera, and trauma, as recently occurred in Mozambique and Malawi during cyclone FREDDY (IOM, 2023; UNICEF, 2023).

Although most modelling studies predict a decrease in the overall frequency of tropical cyclones, several authors also predict an increase in the global average intensity of these cyclones (Knutson *et al.*, 2020). Data from international disaster databases shows that the risk of cyclones making landfall in the SWIO region over Madagascar was four times higher between 2000 and 2023 than between 1950 and 1999, and two and a half times higher for Mozambique for the same periods (EM-DAT, 2023). This implies a higher risk for Madagascar which is among the ten most exposed countries to cyclonic disasters in the world due to its geographical position in the SWIO region (Rakotoarimanana *et al.*, 2022). Despite the damage caused to Madagascar, Mozambique and many other cyclone-prone countries already struggling to recover from previous climate-induced disasters, measures taken to reduce or mitigate the effects of cyclones are still unsustainable, making local populations even more vulnerable to natural disasters. Furthermore, these countries have relatively weak disaster warning, preparedness, and adaptation strategies, and need more financial support to respond quickly and effectively to cyclone disasters. In addition, most developing countries generally lack the financial capacity to intervene quickly before, during and after disasters, often forcing them to reallocate funds from the national budgets to respond to a crisis and save vulnerable populations (Ndlovu, 2020). In most instances, humanitarian aid funds are insufficient to cover all the immediate needs of vulnerable populations (OCHA, 2012).

As an African Union Specialized Agency, the African Risk Capacity Group (ARC Agency and ARC Ltd), here referred to as ARC, was established to help African governments improve their capabilities to better plan, prepare for and respond promptly to natural disasters triggered by extreme weather events. Furthermore, through ARC Ltd, the financial affiliate of the Group, ARC offers risk pooling and transfer services. Its members are African governments comprising countries that have adopted a policy each year, as well as capital contributors such as, among others, the British Foreign, Commonwealth and Development Office (FCDO) and the German Development Cooperation (BMZ/KfW). By shifting the burden of natural disaster risks away from governments, ARC facilitates a more deliberate approach to disaster response. It disburses funds to finance pre-approved contingency plans to respond quickly to disasters. In November 2020, ARC launched its sovereign tropical cyclone parametric insurance policy for the Indian Ocean region to provide rapid financing and early response to countries affected by tropical cyclones (African Risk Capacity, 2020a). Unlike traditional insurance, which pays compensation based on the actual damage observed, parametric insurance (also known as index-based insurance) relies on the measurement of a specific index (parametric index) to establish the amount of compensation (Sengupta and Kousky, 2020). The risk transfer parameters are defined according to each country's risk profile, and the parametric insurance policy is structured accordingly. The country receives an insurance payout within a two-week period when the level of damages caused by a tropical cyclone triggers the insurance policy. The ARC cyclone parametric insurance policy is also extended to humanitarian partners under the ARC Replica programme, which allows humanitarian actors (called Replica partners) to replicate the conditions of the cyclone insurance policy of selected countries.

At the start of the season, each country participating in the cyclone risk pool pays a premium directly linked to the amount of risk it transfers to the Insurers. Several donors help countries finance premiums through a premium support facility based on agreed upon criteria. Donors often cover a bigger portion of the premium especially for new countries while encouraging a gradual increase of premium budget allocation from countries' national budget as a way of strengthening the disaster risk management and financing culture within the government system. This study aims to investigate the occurrence of cyclones in the SWIO region (Fig. 1), and their impacts on Madagascar and Mozambique. It also highlights the importance of ARC's parametric insurance policy in mitigating the risks of tropical cyclones in the Indian Ocean region.

Materials and methods

Tropical Cyclone Insurance Product

Since the fifteen tropical cyclone events that formed during the 2018-2019 cyclone season in the SWIO region, including the devastating cyclones IDAI and

KENNETH which led to the death of over a thousand people and caused extensive destruction to property, agricultural lands, and infrastructure in Mozambique (Hope, 2019), countries in the SWIO region have shown renewed interest in parametric insurances to facilitate timely response to tropical cyclone-related disasters. To respond to the needs of its member states, the ARC developed a tropical cyclone model capable of accurately estimating the risk and losses due to cyclone events, and this model underpins the insurance transaction to provide rapid financing and early response to countries affected by cyclones (African Risk Capacity, 2020b).The ARC tropical cyclone model uses cyclone track information produced by the US Joint Typhoon Warning Center (JTWC) and the Regional Specialized Meteorological Centre (RSMC)/La Reunion, based on the Automated Tropical Cyclone Forecast (ATCF) system, a global reporting system that replicates reports from WMO-mandated agencies in cyclone-affected regions. The ATCF file (resolution of 30 arcseconds ≈ 1 km x 1 km) includes near real-time data (A-deck) and archive data (B-deck) with the following characteristics for each cyclone: location of the eye (latitude and longitude), maximum wind speed (Vmax), maximum wind radius (Rmax), radius of the environment (Renv).

The tropical cyclone model, which is at the heart of the ARC parametric insurance product covers hazards related to winds and storm surges. It combines characteristics of cyclone hazards with exposure and vulnerability data to model the populations affected and the economic losses for six countries, namely, Madagascar, Mozambique, Comoros, Tanzania, Mauritius, and Seychelles. The cyclone parametric insurance product is implemented through four modules, logically sequenced to offer a reliable estimate of losses caused by cyclone events (Fig. 2):

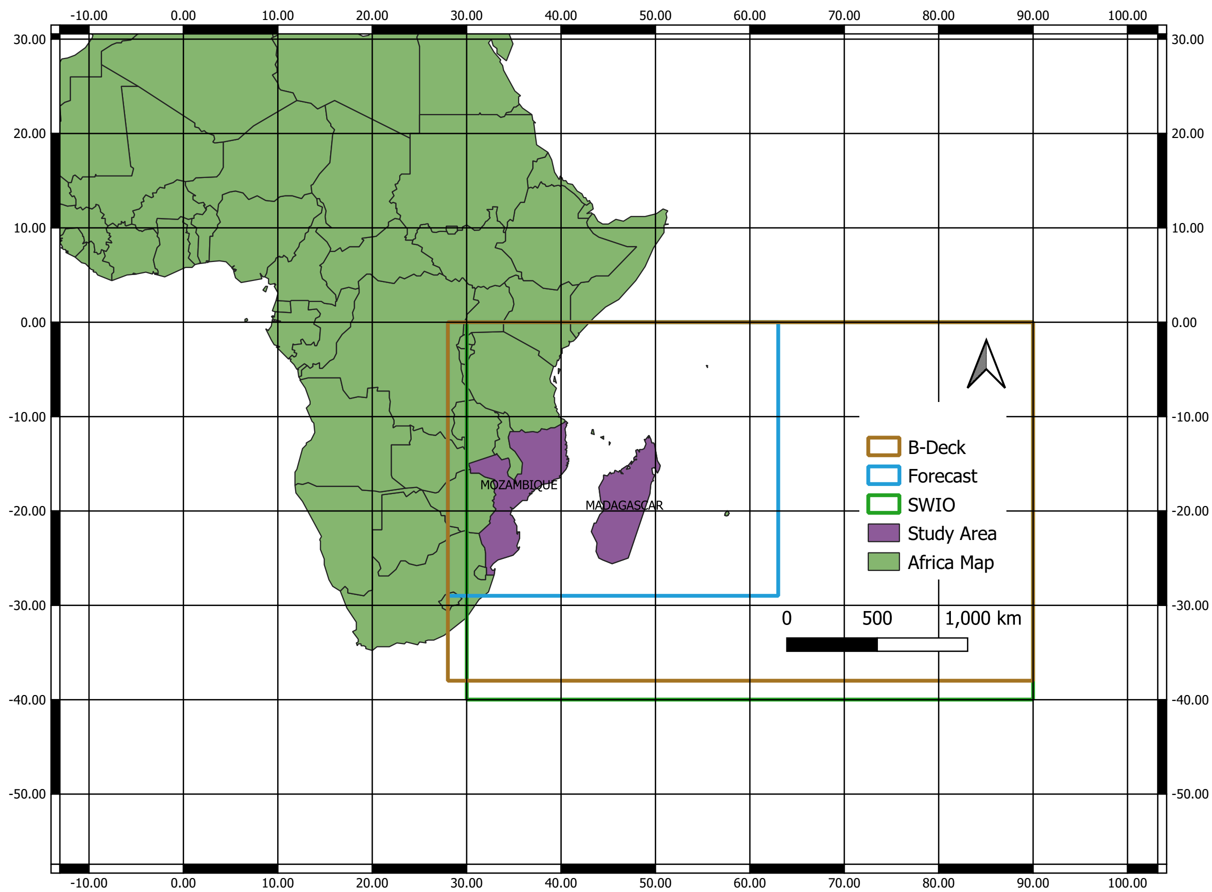

Figure 1. Study area and geographic coverage of the ARC Tropical Cyclone Explorer (TCE).

a) Hazard module:

This module uses the A-deck system files as a source of cyclone characteristics data for the modelling of cyclones wind field and storm surge height. However, to be consistent with tropical cyclone dynamics in the SWIO region, simulated events are generated using the best available historical event information for the region. Indeed, historical cyclone records since 1983

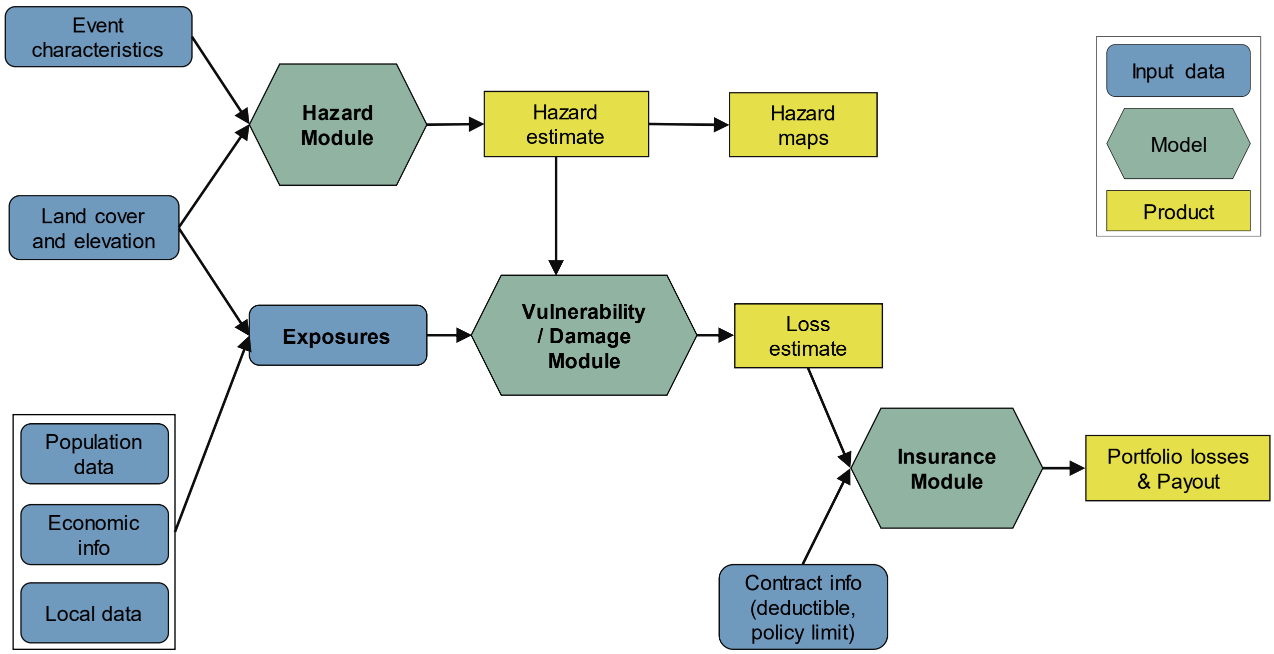

Figure 2. Generic framework of the ARC tropical cyclone insurance product.

contain only a small subset of the potential range of cyclones likely to occur. Risk modelling deploys statistical techniques to generate stochastic databases of cyclones that share the fundamental characteristics of the historical dataset but provides a solid basis for probabilistic risk assessment. Several synthetic tropical cyclone events are therefore generated for the SWIO region using the tropical cyclone tracks known as STORM (Synthetic Tropical cyclone geneRation Model) (Bloemendaal *et al.*, 2020). This methodology uses a combination of all best-track data available from the International Best Track Archive for Climate Stewardship (IBTrACS) (Knapp *et al.*, 2010). However, as the best-track data from the JTWC are more complete than those from RSMC/La Réunion, they were used to develop stochastic tracks on 1,500-years (≈10,000 cyclones) over the period of 1983 to 2013. This stochastic catalog generated from STORM presents all the characteristics of historical data and provides a solid basis for estimating risk probabilities. For the wind field parametrisation, the ARC tropical cyclone model is based on the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) approach (Jelesnianski *et al.*, 1992) which uses the relationship developed by Quiring *et al.* (2011) and Nederhoff *et al.* (2019) to estimate the radius of maximum winds for historical storms, the radius of tropical storm force winds and the radius to environment. It includes basin specific relationships more applicable to the SWIO region, which significantly improves wind depictions for historical storms and estimation of real-time events. The hydrodynamic model used to simulate the storm surge is the three-dimensional modified Princeton Ocean Model (Blumberg, 1992), which considers wave configuration and tidal dynamics. It can carry out simulations of intrinsically satisfactory quality in post-event mode when the trajectory of the cyclone is known with the best possible estimate of the relevant characteristics associated with cyclone event. During an active cyclone event in the SWIO region, upon receipt of warnings from JTWC and RSMC, the hazard module runs a simulation of the new forecast to produce near-real time detailed, geographically distributed hazard layers of maximum winds and storm surge height induced by the tropical cyclone. Based on these hazard layers, hazard estimates are generated by applying sector-specific damage and impact models to those hazard results, and later ingested into the vulnerability/damage module.

b) Vulnerability/Damage module:

The structural vulnerability approach that relies on engineering models and information on local building characteristics to determine vulnerability curves has been considered (Pita *et al.*, 2013). This approach uses local data, including details on building composition, to model vulnerability under specific tropical cyclone conditions (Wilson *et al.*, 2022). Impact algorithms corresponding to four generic exposure classes have been developed to translate hazard estimates into economic impact estimates at exposure locations. These impact algorithms account for damage due to key event perils produced by cyclones (e.g., winds and storm surges) and accommodate the range of vulnerabilities within the composite exposure categories. The wind damage curves are derived from a third power function based on cyclone winds and the type of exposures, while the storm surge damage curves are linear, starting at 0.2 meters inundation, with maximum damage occurring with inundation of 3 meters for agricultural and low-density exposures, 6 meters for medium-density, and 10 meters for high-density exposures. The loss functions are specific to each asset class and the data for the historical database events are produced using the updated exposure data, custom damage functions for each asset class, and winds and storm surge data associated with each historical data. Loss estimation focuses exclusively on direct, physical damage to exposed assets and building contents. It is designed to estimate the replacement value of affected assets. The loss at each grid point is the sum of damage to the structure and contents, while the total loss for an administrative region is the total losses for each grid point in the region. The total loss for the country is the sum of the administrative regions. The result of calculating the modelled loss for every cyclone is an exceedance probability curve showing the value of loss which is likely to be incurred at given levels of probability.

c) Insurance module:
Using specific contract terms, this module translates exposure loss estimates into loss estimates for a portfolio of assets. Payout estimates are determined when the actual economic losses caused by a cyclone exceeds the trigger point also called the attachment point (defined by the policyholder). The maximum payout (coverage limit) is paid at the exit level (exhaustion point), which represents the value of the loss at which the full payout is due to the policyholder.

d) Exposure module:
The exposures which are inputs of the vulnerability/damage module correspond to human, structural or agricultural assets located in the risk zone; exposures to cyclones generally increase as populations continue to move and expand near coasts (UN, 2017; Crowell *et al.*, 2010). The resolution of the exposure data is consistent with the data in the stochastic database and post-event hazard footprints, and it was estimated at 30 arcseconds (≈1 km^2 grid cells) using a combination of satellite remote sensing, population estimates and GDP data. Population data is from WorldPop (www.worldpop.org), while GDP data is updated to 2017 using country-level GDP from the World Bank and CIA World Factbook databases and is used to estimate the replacement value of different asset classes (World Bank, 2023; CIA, 2023). Each 1 km^2 grid cell is classified into four classes based on MODIS land-use classification and population density: rural, mixed (rural/urban), medium-density urbanized and high-density urbanised. Each individual exposure record consists of the geographic and administrative area location, and three elements are used to estimate the loss from the hazard at that exposure location: exposure of four classes, number of units of exposure, and value per unit of exposure. In addition to the above, each administrative area is assigned weather construction variables which are applied to all exposures within that area. The construction quality variables apply as adjustments to the loss curves in loss evaluation. Construction quality is estimated based on past damaging events, or experts' judgement based on available data. This global exposure database includes an estimate of the physical assets, designed to provide reasonable estimates for losses (replacement value) from cyclone hazards.

Extraction of Cyclone Impacts Data

The tropical cyclone insurance product is integrated into the Tropical Cyclone Explorer (TCE) software, a dedicated online platform developed by ARC which allows users to visualise cyclone characteristics, calculate the affected population and economic losses caused by cyclones, and the payout amount which insured countries are entitled to receive in the event of a cyclone disaster (African Risk Capacity, 2020c). To investigate the occurrence of cyclones in the Indian Ocean region, as well as their impacts on Madagascar and Mozambique, the TCE was used to extract data on cyclone characteristics and impacts from the 2018/19 to 2022/23 seasons (a cyclone season runs from November to April in the Indian Ocean region). Indeed, when a cyclone system is active in this region, JTWC and the RSMC/La Reunion issue a warning bulletin every six hours detailing the characteristics of the cyclone. Data from these bulletins are used to forecast the track of the cyclone and this information is ingested into TCE to produce estimates of the populations affected and economic losses caused by this cyclone. TCE begins to monitor the characteristics of any cyclone when its maximum sustained wind (MSW) reaches the minimum threshold of 63 km/h based on the 10-minute average sustained winds unit at 10 meters above terrain. All named cyclones considered in this study were

Table 1. Classification of cyclones based on the maximum sustained winds (MSW)*.

Classification of cyclones	Maximum sustained winds(km/h)
Moderate Tropical Storm (MTS)	63 <= MSW <= 88
Severe Tropical Storm (STS)	89 <= MSW <= 117
Tropical Cyclone (TC)	118 <= MSW <= 165
Intense Tropical Cyclone (ITC)	166 <= MSW <= 212
Very Intense Tropical Cyclone (VITC)	> 212

*10-minute sustained wind

grouped into five categories according to the RSMC/La Reunion's cyclone intensity scale as indicated in Table 1. Thus, in this paper, the word "cyclones" refers to all types of tropical cyclone events; and the windspeed considered for the categorisation is the maximum speed reached throughout the cyclone course. Although the TCE loss calculations are available for six countries in the SWIO region, only Madagascar and Mozambique, which experienced cyclone landfalls during these five seasons, were considered in this study.

Results and Discussion

Occurrence of tropical cyclones in the SWIO

Monitoring of tropical cyclones using TCE has shown that fifty-six cyclones of different categories have formed over the past five seasons from 2018/19 to 2022/23 in the SWIO region (Fig. 3). The most frequent cyclone categories occurring in the SWIO are Intense Tropical Cyclone (ITC) accounting for 32 % of all events, followed by Moderate Tropical Storm (MTS) (30 %), Tropical Cyclone (TC) (22 %) and Severe Tropical Storm (STS) (9 %) (Fig. 4). On the other hand, the most severe category of cyclones, namely, the Very Intense Tropical Cyclone (VITC), represents 7 %. It is worth mentioning that cyclones of moderate intensity, namely MTS, appear every season. On average, 11.2 tropical cyclones formed per season in the SWIO region. The 2018/19 was an above-average cyclone season for Mozambique, while Madagascar faced no cyclones. Indeed, the season was very active with fifteen cyclones formed, 60 % of which were ITC (Fig. 4). Three cyclones, DESMOND (MTS) in 2019, IDAI (ITC) and KENNETH (ITC) in 2019 made landfall over Mozambique. The Mozambique cyclone season was dominated by nine ITCs, including the two most devastating cyclones IDAI and KENNETH which caused significant loss of life, damage, and destruction in their paths. IDAI made landfall in the port city of Beira with winds exceeding 175 km/h on March 14, and continued inland affecting Mozambique, Zimbabwe, and Malawi. Cyclone IDAI has since been labelled the deadliest cyclone in southern Africa, and six weeks later the follow up landfall of KENNETH (195 km/h) in northern Mozambique made a record as the first time Mozambique had experienced two severe cyclones in the same season (IFRC, 2019; MISAU, 2019). Tropical cyclones IDAI and KENNETH caused significant destruction and damage in the provinces of Cabo Delgado, Sofala, Manica, Zambezia and Tete, killing at least 648 people (45 deaths from KENNETH and at least 603 deaths from IDAI), injuring nearly 1,700 people and leaving around 2.2 million people in need of urgent humanitarian assistance and protection (OCHA, 2019).

The 2019/20 season was slightly below-average in terms of cyclones (Fig. 4). Ten cyclones including four MTS (40 %) were recorded during that season. From these ten, three cyclones hit Madagascar; BELNA

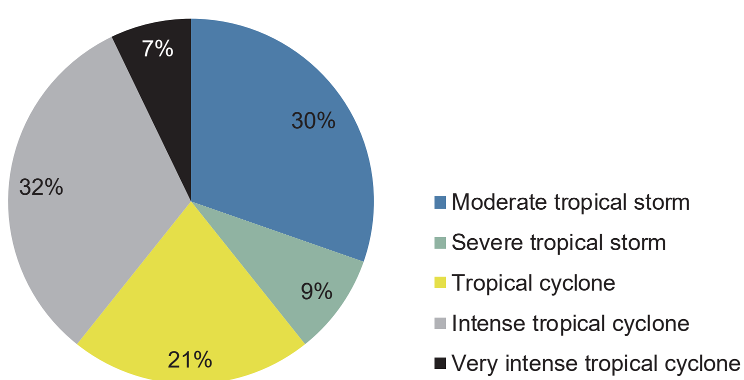

Figure 3. Proportion of cyclone occurrences (all seasons).

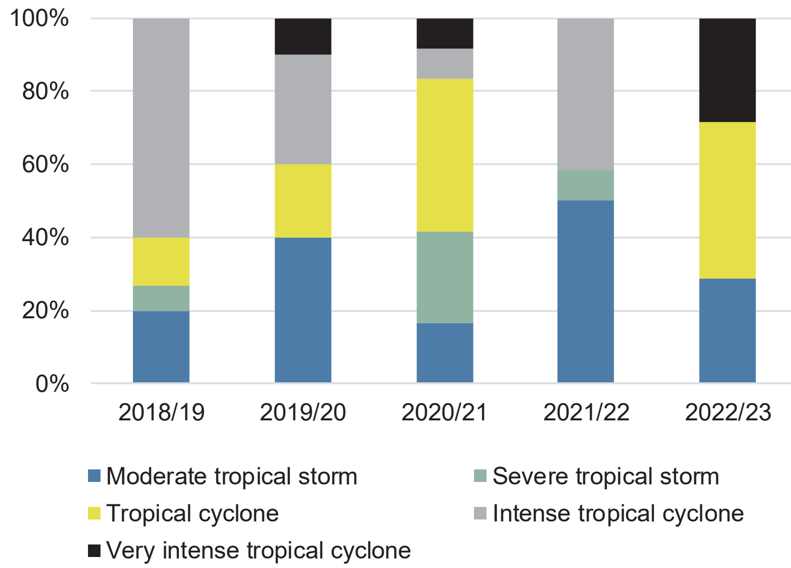

Figure 4. Category of tropical cyclones per season.

(TC) in 2019, DIANE (MTS) in 2020 and FRANCISCO (MTS) in 2020. BELNA was the season's first cyclone to hit Madagascar (Soalala, Boeny region) on December 9 at the TC stage with winds of 145 km/h. Mozambique did not experience any cyclone landfall during the 2019/20 season.

The 2020/21 season was marked by 12 cyclones, a number higher than the seasonal average. The TC category dominated the season, accounting for 42 % of all cyclones (Fig. 4). Of the 12 cyclones, three made landfall over Madagascar and Mozambique. Indeed, at the beginning of the season, both CHALANE (STS) in 2020 and ELOISE (TC) in 2021 hit Madagascar and Mozambique. ELOISE was more damaging for Mozambique which was hit on January 23 near the city of Beira with winds of 140 km/h (against 100 km/h for Madagascar). It caused widespread damage and flooding on a long swathe of coastline of Mozambique and impacted an area that was still recovering from cyclone IDAI which hit the same place in March 2019. ELOISE was followed by GUAMBE (TC) in 2021 and IMAN (MTS) in 2021 which respectively hit Mozambique and Madagascar but did not cause significant damages. Twelve named cyclones formed during the 2021/22 season, with MTS accounting for the highest occurrence (50 % of all cyclones). Among these 12 events, six made landfall over Madagascar in 2022; ANA (MTS), BATSIRAI (ITC), DUMAKO (MTS), EMNATI (ITC), GOMBE (ITC) and JASMINE (STS), and three in Mozambique ANA (MTS), GOMBE (ITC) and JASMINE (STS) during the same year. BATSIRAI was the most devastating cyclone of the 2020/21 season and the worst to hit Madagascar since ENAWO in 2017 (OCHA, 2022). It made landfall near the northern town of Mananjary (Vatovavy region) on February 5 with winds of 165 km/h and extreme gusts exceeding 230 km/h.

The 2022/23 season was a below-average cyclone season with a total of seven cyclones of which 43 % reached the stage of TC (Fig. 4). Two cyclones, CHENESO (MTS) and FREDDY (VITC) made landfall over Madagascar in 2023. From these two, FREDDY was a powerful and compact event that severely affected both Madagascar and Mozambique. After CHENESO, FREDDY was the second cyclone to hit the east coast of Madagascar on February 21 (near Mananjary) with winds of 130 km/h. It crossed Madagascar and made its first landfall on the coast of Mozambique on February 24 as a severe storm. FREDDY later re-emerged in the Mozambique Channel, and a week later made a second landfall in Mozambique near Quelimane District (Zambezia Province) on March 11 with winds of 148 km/h. FREDDY brought destructive winds and extreme rains that hit large areas in Madagascar, Mozambique, southern Malawi, northeast Zimbabwe, and southeast Zambia (OCHA, 2023). Freddy made history as the longest-lasting tropical cyclone on record.

Table 2 shows the seasonal landfalls of cyclones over Madagascar and Mozambique. With six cyclones in 2021/22, Madagascar recorded the highest number of landfalling cyclones in a single season. Madagascar and Mozambique have had at least one cyclone-free season, in 2018/19 for Madagascar and 2019/20

Table 2. Seasonal landfalls of cyclones over Madagascar and Mozambique.

Cyclone seasons	Number of occurrences	Madagascar		Mozambique	
		Number of landfalls	Ratio	Number of landfalls	Ratio
2018/19	15	0	0.0	5*	0.4
2019/20	10	3	0.2	0	0.0
2020/21	12	3	0.2	3	0.2
2021/22	12	6	0.4	3	0.2
2022/23	7	2	0.2	2*	0.2
Total	56	14	1.0	13	1.0
Average	11.2	2.8	0.2	2.6	0.2

*Take into account multiple landfalls from the same cyclone

for Mozambique. The 56 cyclones formed between 2018/19 and 2022/23 in the SWIO region caused in total 27 landfalls (48 %) in Madagascar and Mozambique. Madagascar experienced 14 landfalls (52 %), compared to 13 (48 %) for Mozambique. However, there have been three occasions when the same cyclone made multiple landfalls on the Mozambican coasts. This happened in 2018/19 with cyclones DESMOND and IDAI, and in 2022/23 with FREDDY. On average, 2.8 and 2.6 cyclones per season have made landfall in Madagascar and Mozambique respectively (Table 2). The same highest landfall ratio (0.4) recorded for Mozambique in 2018/19, and Madagascar in 2021/22 could be explained by warmer than usual sea surface temperatures produced by the propagation of ocean waves in the SWIO region (Vitart *et al.*, 2003; Mann and Emanuel, 2006; Fitchett *et al.*, 2014). As underlined by Shultz *et al.*, (2020), most storms that form over unusually warm waters tend to intensify rapidly, and many end up on inhabited lands, factors that may be linked to climate change. Figure 5 shows that most cyclones (65 %) made landfalls in Madagascar during January and February with a preponderance of cyclones in January (36 %). Rakotoarimanana *et al.* (2022) also found similar results when analysing cyclone landfalls over Madagascar from 2000 to 2022. In Mozambique, 54 % of the landfalls also occurred in January and February, with the highest number of landfalls (31 %) occurring in January. However, based on the observations from these five seasons, for Mozambique, there is as much chance of a cyclone making landfall in February as in April. For both countries, cyclone landfalls can be expected mainly in January and in February, and to a lesser extent in April for Mozambique.

Analysis of the proportion of the categories of cyclones that made landfall in Madagascar shows that they have not been regularly distributed over the past five seasons (Fig. 6a). The cyclones that most often make landfall are mainly of moderate intensity (MTS) representing 43 %, followed by intense tropical cyclones (ITC) with 22 %. Very intense tropical cyclones (VITC) seem rarer (7 %) in Madagascar. In Mozambique, the distribution of cyclones seems

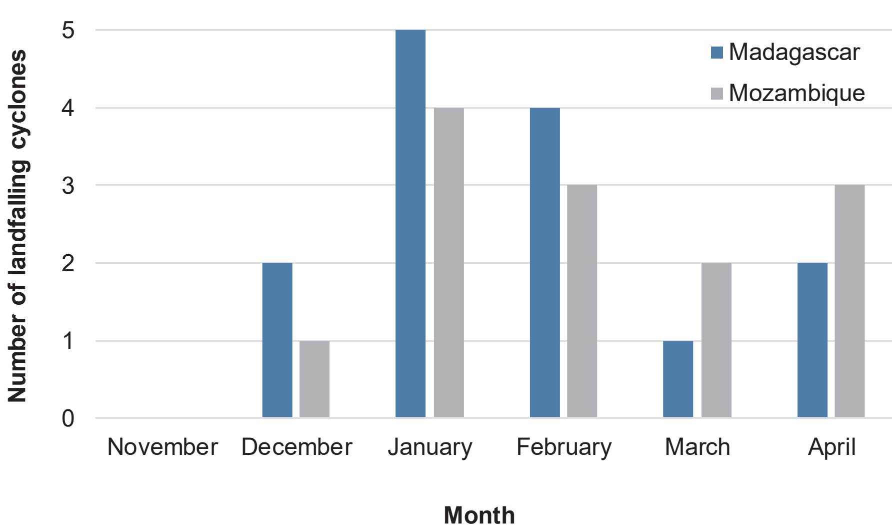

Figure 5. Monthly landfalling of tropical cyclones.

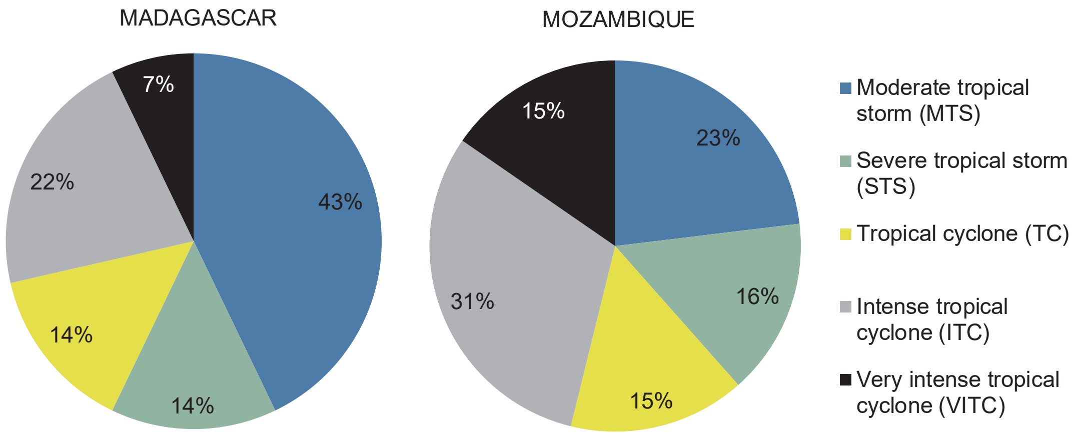

Figure 6. Proportion of the category of landfalling cyclones in Madagascar and Mozambique.

more balanced compared to Madagascar (Fig. 6b). However, unlike Madagascar, the cyclones that made landfall in Mozambique are mostly of high intensity (ITC) and represent 31 %, followed by moderate intensity cyclones (MTS), which are 23 %. On the other hand, very intense tropical cyclones (VITC) represent a more significant proportion (15 %) in Mozambique than in Madagascar. Furthermore, it is worth mentioning that in Madagascar and Mozambique, when the first cyclone that makes landfall is of high intensity, the second has been known to be of low intensity and vice versa.

Impacts of tropical cyclones as estimated by TCE

The consequences of tropical cyclones over the past five seasons have been devastating for Madagascar and Mozambique. The impacts of these cyclones on populations exposed to strong winds (≥ 118 km/h, minimum of a TC stage) and economic losses as estimated by the TCE are presented in Figures 7, 8, Table 3a and Table 3b. From 2018/19 to 2022/23, an average of 1.8 million people per season were exposed to high-intensity cyclones with winds exceeding 118 km/h in Madagascar. Although Madagascar experienced 14 landfalling cyclones, TCE estimated that in the first three seasons (2018/19, 2019/20, and 2020/21), only 32,000 people were exposed to strong winds. The number of people exposed to strong winds increased significantly with the landfall of the devastating cyclones BATSIRAI in 2021/22 and FREDDY in 2022/23, which impacted 6.8 million and 2.2 million people, respectively as

Table 3a. TCE estimated population and economic losses for Madagascar.

Cyclone seasons	Cyclone names	Populations exposed (≥ 118 km/h)	Direct economic losses (USD)	Total economic losses (USD)
2018/19	DESMOND	-	-	721,000
	IDAI	-	720,000	
	KENNETH	-	-	
2019/20	BELNA	32,261	9 million	9 million
	DIANE	0	0	
	FRANCISCO	0	0	
2020/21	CHALANE	0	5,000	270,000
	ELOISE	0	265,000	
	IMAN	0	0	
	GUAMBE	-	-	
2021/22	ANA	0	0	2,256 million
	BATSIRAI	6,868,285	2,200 million	
	DUMAKO	0	86,000	
	EMNATI	25,765	54 million	
	GOMBE	0	12,000	
	JASMINE	0	2 million	
2022/23	CHENESO	0	5 million	487 million
	FREDDY	2,202,461	482 million	

Table 3b. TCE estimated population and economic losses for Mozambique.

Cyclone seasons	Cyclone names	Populations exposed (≥ 118 km/h)	Direct economic losses (USD)	Total economic losses (USD)
2018/19	DESMOND	0	0	422 million
	IDAI	810,205	328 million	
	KENNETH	425,949	94 million	
2019/20	BELNA	-	-	-
	DIANE	-	-	
	FRANCISCO	-	-	
2020/21	CHALANE	0	1 million	227 million
	ELOISE	964,386	226 million	
	IMAN	-	-	
	GUAMBE		10,000	
2021/22	ANA	0	250,000	84 million
	BATSIRAI	-	-	
	DUMAKO	-	-	
	EMNATI	-	-	
	GOMBE	693,525	84 million	
	JASMINE	0	0	
2022/23	CHENESO	-	-	123 million
	FREDDY	980,000	123 million	

estimated by TCE. In Mozambique, the average seasonal number of people exposed to strong winds was 775,000; however, unlike Madagascar, the number of people exposed in Mozambique was almost evenly distributed over the past five seasons (Fig. 7). Mozambique has experienced five major cyclones, including IDAI and KENNETH, both of which occurred in 2018/19 and exposed 1.2 million people to winds exceeding 118 km/h. The other three devastating cyclones, ELOISE in 2020/21, GOMBE in 2021/22, and FREDDY in 2022/23, brought strong winds that severely affected 2.6 million people in Mozambique.

In addition to the populations exposed, TCE estimates direct economic losses due to cyclone winds and storm surges. Still, this does not consider indirect economic losses or losses due to flooding covered by another ARC parametric insurance product dedicated to river flooding. Tables 3a and 3b and Figure 8 clearly show that the cyclone BATSIRAI, which hit Madagascar in 2021/22, set the record as the costliest cyclone in the SWIO region over the past five seasons, with total economic losses of $2.2 billion. Indeed, TCE estimated that the Top 5 list of the costliest cyclones affecting both Madagascar and Mozambique over the

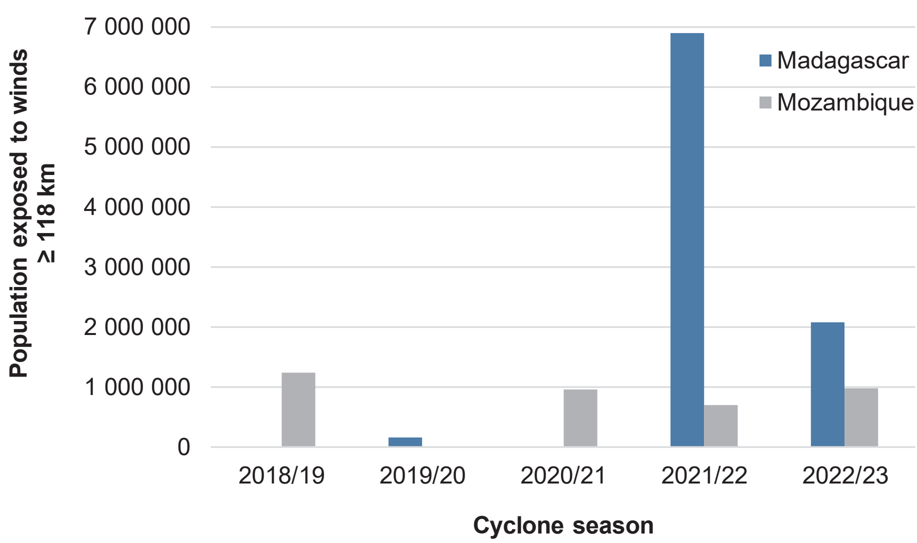

Figure 7. Population exposed to high winds (*Source: TCE*).

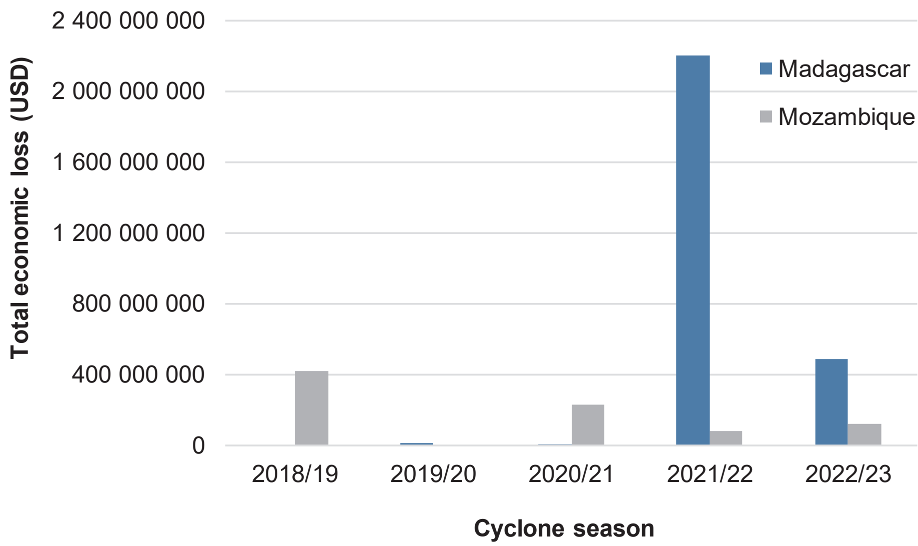

Figure 8. Total direct economic losses (*Source: TCE*).

past five seasons is dominated by BATSIRAI ($2.2 billion), followed by FREDDY ($605 million), IDAI ($329 million), ELOISE ($226 million) and KENNETH ($94 million). Furthermore, for Madagascar, the three costliest cyclones (BATSIRAI, EMNATI and FREDDY) occurred in 2022 and 2023, while for Mozambique, the three costliest cyclones (IDAI, ELOISE, and FREDDY) occurred with a two-year interval (2019, 2021 and 2023). As a result, the total direct economic losses caused by cyclones over the past five seasons is estimated at $2.72 billion for Madagascar compared to $855 million for Mozambique.

Tropical cyclone parametric insurance policy

Triggering of the cyclone policy

Under the ARC tropical cyclone insurance policy, real-time monitoring and post-event reports are issued for any cyclone affecting countries with winds exceeding 63 km/h. The TCE enabled the monitoring of the characteristics of cyclones over the past seasons. As shown in the previous section, about one-third (32 %) of cyclones forming in the SWIO region have affected mainly Madagascar and Mozambique, and the heavy rains associated with those cyclones also affected countries such as Malawi, Zimbabwe, Zambia, Mauritius, Comoros, and La Reunion. Due to its high exposure to cyclones, Madagascar was the first country to subscribe to the ARC parametric insurance policy in the 2020/21 season.

Since the launch of the ARC cyclone parametric insurance policy in 2020, Madagascar has experienced landfalls of eleven cyclones of different categories ranging from MTS to VITC.

During the occurrence of these cyclones, ARC provided countries with daily early warning information on the severity and geographic location of cyclones, areas at risk and expected impacts (number of populations at risk and economic losses) to help countries and humanitarian organisations put in place pro-active measures such as the preventive evacuation of vulnerable populations and the prepositioning of logistics necessary for emergency responses. For example, based on early warning information provided by the ARC before the landfall of the cyclone FREDDY in February 2023, the government of Madagascar evacuated 7,000 people in the coastal region who were in the path of the cyclone, while school and public transportation were suspended (African Risk Capacity, 2023). Three business days after the end of a cyclone event, ARC sent the policyholder a post-event loss report showing the total economic losses due to the cyclone and the amount of the payout the insured country was entitled to under the insurance policy. The policy is triggered when the total economic losses exceed the attachment point (or trigger point) pre-defined in the policyholder's contract.

Of the 11 cyclones that have made landfall in Madagascar since 2020, only two of high intensity, namely BATSIRAI and FREDDY, triggered the ARC cyclone parametric insurance policy. Indeed, BATSIRAI a devastating cyclone that hit Madagascar in February 2022, near the northern town of Mananjary (Vatovavy region) triggered the insurance policy for the first time. The economic losses associated which BATSIRAI were estimated at $2.2 billion by TCE. These losses are direct losses solely due to wind and storm

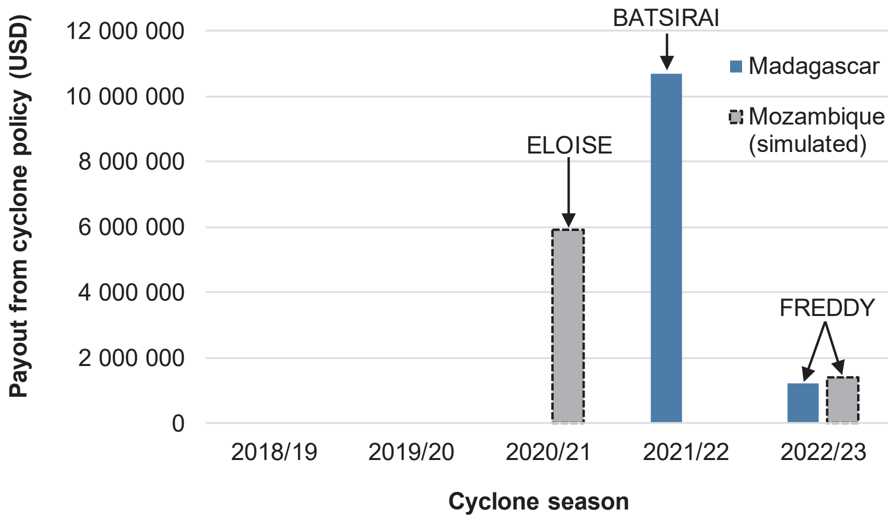

Figure 9. Payouts from ARC's cyclone parametric insurance coverage (*Source: TCE*).

surge hazards, and do not consider damages due to flooding, nor indirect economic costs (Table 3a). The calculation of the payout as per the ARC parametric insurance policy showed that these economic losses had exceeded the attachment point of $155 million pre-defined in Madagascar's cyclone policy. As a result, a payout of $10.7 million was paid by ARC to the Government of Madagascar under the 2021/22 parametric insurance policy against the risks of tropical cyclones (Fig. 9). In February 2023, FREDDY, a powerful and long-lasting cyclone, made landfall in Madagascar, near Mananjary, an area already affected by BATSIRAI in 2022. FREDDY has caused economic losses estimated at $482 million (Table 3a), thus exceeding the attachment point of $165 million indicated in Madagascar's cyclone policy. Therefore, in the aftermath of FREDDY, the government of Madagascar received a $1.2 million payout from ARC (Fig. 9). In both cases of cyclones BATSIRAI and FREDDY, the transfer of the payouts to the Government of Madagascar was processed within two weeks after the publication of the post-event loss report. These payouts enabled the government of Madagascar to quickly implement response activities to protect the vulnerable populations and save lives.

Response activities implemented to mitigate cyclone risks

Under the tropical cyclone insurance policy, ARC works in tandem with countries to develop contingency plans where a list of intervention activities is agreed upon beforehand, which may include the provision of health and nutrition support, food assistance to the affected populations, educational materials, reconstruction of schools, etc. These pre-approved plans ensure there is a strategy for a rapid use of the insurance payout (if any) for response activities, in the event the country is hit by a cyclone. For example, following the landfall of BATSIRAI, the government of Madagascar has managed to intervene for immediate assistance and early recovery in the eastern regions of Vatovavy, Fitovinany, and Atsimo Atsinanana by assisting over 85,000 beneficiaries. The main intervention activities consisted of food assistance to 26,500 households, nutritional and health support for children and pregnant/ breastfeeding women for about 6,500 households, reconstruction of 850 traditional huts and provision of household kits, supplying construction materials to health and education centres for 315 classrooms, etc. (African Risk Capacity, 2022). With the payout received following FREDDY's landfall in Madagascar, interventions were conducted in the six most affected towns, namely, Benenitra, Morombe, Sakaraha, Morondava, Manja, and Mahabo (African Risk Capacity, 2023). The intervention activities included food distribution to 13,300 households, seeds, and fertilizers to 6,000 households and cash transfer to 4,300 households. The Replica cyclone policy for Madagascar, backed by ARC's cyclone parametric insurance, also triggered a payout of $301,000 due to damages caused by the cyclone FREDDY. Therefore, the World Food Programme (WFP), the Replica partner for Madagascar, provided food assistance in the form of food distribution to over 33,000 beneficiaries at high risk of acute food insecurity, mainly in the district of Mananjary in the Vatovavy region (African Risk Capacity, 2023). Through WFP, beneficiaries received more than two months of assistance to meet their immediate needs.

Since its launch in 2020, the ARC's cyclone parametric insurance policy and its Replica partner have allocated a total payout of $12.2 million to the government of Madagascar to provide a rapid and effective response following the landfalls of cyclones BATSIRAI and FREDDY, thereby protecting its vulnerable population and saving countless lives and livelihoods. This participation of Madagascar in the ARC parametric insurance policy and the Replica programme complemented the government efforts towards reducing the impacts of cyclone disasters on their most vulnerable populations. This is very important because, the faster the response, the more lives and livelihoods are protected after a natural disaster such as a cyclone.

As seen above in Table 2, over the past five seasons, Mozambique has experienced thirteen landfalls of cyclones that have caused devastating damage. These cyclones have caused an average economic loss of $170 million per season as estimated by TCE. Table 4 indicates the TCE simulated payouts that Mozambique would have benefitted if the country had subscribed to the ARC's cyclone parametric insurance policy. The results of the simulations showed that the economic losses caused by cyclones during the 2020/21 and 2022/23 seasons, would have exceeded the attachment point. As a result, a total amount of $7.3 million would have been paid to the government of Mozambique for damages caused by the cyclones ELOISE in 2021 and FREDDY in 2023 (Table 4). These funds would have enabled the government of Mozambique to quickly assist the affected population by evacuating populations at risk, provision of health and nutritional supplies, food distribution, school materials, or reconstruction of schools and health centers.

Conclusions

Although the analysis of five cyclone seasons and a total of 27 cyclones that made landfall may not allow for statistically significant comparisons, it provides valuable information on the frequency, intensity and impacts of cyclones in the SWIO region, particularly in Madagascar and Mozambique, as well as highlights the relevance of the payouts generated by the ARC parametric insurance policy. This study showed that the ARC's parametric insurance policy and its cyclone monitoring engine, the TCE, successfully captured the occurrence and impacts of tropical cyclones in the SWIO region, especially in Madagascar and Mozambique.

As shown for Madagascar, the innovative parametric insurance solution offers by ARC works well as demonstrated by the two successive payouts that the country received following the landfalls of BATSIRAI and FREDDY which enabled the government's timely response to protect its vulnerable populations. The ARC's cyclone parametric insurance policy is an integral part of countries' disaster risk management and climate resilience strategies. Not only does it helps reduce the financial burden on countries, but it also gives incentives to take prevention and preparedness measures. This is especially critical given how the landfall of tropical cyclones has endangered the lives and livelihoods of millions of people in Madagascar and Mozambique. As post-cyclone recovery efforts are limited by financial constraints due to the significant investments required to assist vulnerable populations, ARC will continue to work with all cyclone-prone countries in the SWIO region to encourage them to join the cyclone risk pool. Their participation in the cyclone insurance policy will help build their climate resilience, strengthen their disaster response and recovery capacities, and reduce their vulnerability to climate threats. Comoros has followed Madagascar's example by subscribing to the ARC's cyclone parametric insurance policy. Discussions are underway with other countries in the SWIO region for their future participation in the coming cyclone risk pool. Modelling studies have suggested that there will be a global increase in cyclone intensity in the 21st century (Bengtsson, 2007; Knutson *et al.*, 2010). Given this vulnerability of populations in southern African regions, the need for parametric insurance coverage

Table 4. Payouts simulated by TCE for Mozambique.

Cyclone seasons	Cyclones names	Direct economic losses (USD)	Simulated insurance payouts (USD)*
2020/21	ELOISE	326 million	5.9 million
2021/22	GOMBE	84 million	0 million
2022/23	FREDDY	123 million	1.4 million

*Risk Transfer Parameters: Exhaustion point = $502 million, Attachment point = $91 million, Coverage limit = $18 million, Ceding percentage = 4.38% and Premium = $1.7 million must be a high priority for all cyclone-prone countries. It is indeed an effective way to provide faster and more flexible funds to victims of cyclones that would otherwise be difficult to ensure. Furthermore, since tropical cyclones are typically accompanied by heavy rains that cause widespread flooding and considerable damage, ARC is considering upgrading its parametric insurance product to account for the effect of excessive precipitation associated with cyclones.

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