December 2019

Bermuda Monetary Authority

Catastrophe Risk in Bermuda

BSCR Stress Testing and Modelling Practice Analysis
2018 Report

Foreword

Bermuda is predominantly an insurance-based International Financial Centre specialising in the niche of catastrophe reinsurance and is host to one of the top three reinsurance markets in the world.

With such a relatively high concentration of catastrophe risk in Bermuda's market, a broad understanding of the potential adverse impacts, including identification of any concentration of risks and catastrophe modelling practices in Bermuda, is central to the Bermuda Monetary Authority's (Authority or BMA) supervisory framework. This information is also important to Bermuda insurers and other stakeholders and markets around the globe.

To maintain the significant role that Bermuda plays as a leader in the regulation of the catastrophe market, and to continue to reemphasise our commitment to high standards of transparency, the Authority produces this report annually to give a high-level overview of the catastrophe risk stress testing and modelling practice in Bermuda.

Overall, 2018 results again highlighted the industry's resilience to major but improbable catastrophe events, and the sophistication and advancement of the modelling practices in Bermuda. This underscored the reputation of Bermuda insurers as being generally well capitalised and technically proficient.

Compared to 2017, this year's gross catastrophe exposure assumed by Bermuda insurers increased by about 7.3%. However, insurers have ceded out more exposure compared to last year – thus, year-on-year, the net catastrophe exposure assumed by Bermuda insurers has decreased by about 14.8%. The global share of gross estimated potential loss assumed by Bermuda insurers on the major catastrophe perils (combined) increased by about 1.0%. The report also reviewed terrorism coverage and cyber risk stress testing - the analysis showing the impact from both standardised terrorism exposure stress testing and insurers' own defined worst impacts from cyber risk would have a minimal impact on their statutory capital.

Craig Swan
Managing Director,
Supervision

Catastrophe Risk Report

This is the fourth annual Catastrophe Risk Report published by the BMA. The content of this report is the result of the analysis carried out by BMA staff. Should you have any questions, comments or suggestions to improve this report, please contact enquiries@bma.bm.

About the BMA

The Authority was established by statute in 1969. Its role has evolved over the years to meet the changing needs in Bermuda's financial services sector. Today it supervises, regulates and inspects financial institutions operating in the jurisdiction. It also issues Bermuda's national currency, manages exchange control transactions, assists other authorities with the detection and prevention of financial crime, and advises Government on banking, and other financial and monetary matters.

The Authority develops risk-based financial regulations that it applies to the supervision of Bermuda's banks, trust companies, investment businesses, investment funds, fund administrators, money service businesses, corporate service providers, insurance companies and digital asset businesses. It also regulates the Bermuda Stock Exchange.

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This publication is available on the BMA website: www.bma.bm

Acronyms

AAL	Average Annual Loss
AIR	AIR Worldwide
AMO	Atlantic Multi-decadal Oscillation
BMA	Bermuda Monetary Authority
BSCR	Bermuda Solvency Capital Requirement
Cat	Catastrophe
Cat Return	Catastrophe Risk Return and Schedule of Risk Management
CSR	Capital and Solvency Return
EQECAT	Catastrophe Risk Management (CoreLogic)
EP	Exceedance Probability
IFC	International Financial Centre
Mph	Miles per hour
PML	Probable Maximum Loss
RMS	Risk Management Solutions
RDS	Realistic Disaster Scenarios
The Authority	Bermuda Monetary Authority
SPI	Special Purpose Insurer
SST	Sea Surface Temperatures
TVaR	Tail Value at Risk

Contents

1. Executive Summary

This report has four main objectives. First, it gives a high-level overview of the capacity of the sector to absorb shocks from various Cat risk events underwritten by Bermuda insurers[1]. Second, the report reviews various stress tests to assess if Bermuda insurers are adequately capitalised to withstand severe, but remote, underwriting losses from various possible Cat events that might adversely impact their balance sheets. Third, the report analyses the Exceedance Probability curve trends, including the level of reliance and sufficiency of the reinsurance, and pricing dynamics. Fourth, the report analyses the Cat modelling practices in Bermuda.

Overall, the 2018 Cat underwriting stress test results demonstrated that the Bermuda insurance market is resilient to potential adverse impacts from various global Cat underwriting loss scenarios and that there is a variation in reliance on reinsurance by insurers. The results also establish Bermuda insurers' ability to absorb these unlikely potential significant losses and still have capital remaining to settle policyholder obligations.

Insurers are expected to retain, on average, 71.0% on a gross basis (before reinsurance) of their statutory capital & surplus after the largest single Cat underwriting loss event, a decrease of 5 points compared to last year. On a net basis (after reinsurance), insurers are anticipated to retain approximately 92.0% of their statutory capital & surplus after the largest single Cat underwriting loss event. These results highlight the industry's overall resilience. The results also show there was no significant impact from the standardised terrorism stress scenario and cyber risk worst-case annual aggregate loss scenario carried out by insurers. Overall, the global share of gross estimated potential loss assumed by Bermuda insurers on the major catastrophe perils (combined) has increased by about 1.0%.

An analysis of the Exceedance Probability curves demonstrates that Bermuda insurers are more exposed to Atlantic Hurricane than any other peril, with gross average modelled losses over all companies stretching from US$798.4 million for the "1 in 50" year events up to US$1.4 billion for the "1 in 1,000" year events. Other perils show lower modelled losses for the "1 in 50" and the "1 in 1,000" year events, however, with significant variation between firms. The use of reinsurance[2] is widespread with the Atlantic Hurricane net average modelled losses ranging from US$289.1 million for the "1 in 50" year events up to US$720.2 million for the "1 in

[1] For the purpose of this report, insurers also include reinsurers.
[2] Net results are also net of reinstatement premiums, so not all of the differentials may arise from reinsurance.

1,000" year events. The use of reinsurance is generally more pronounced for lower frequency return periods for Atlantic Hurricane and North American Earthquake, while other named perils exhibit non-monotonic patterns between return periods such as Japanese Earthquake and Japanese Typhoon.

Average loading factors in the accumulation process rose in 2018, reaching 8.3% versus 6.7% in 2017 for Bermuda legal entities. For groups, the average loading factor stood at 8.4% in 2018 compared to 8.3% in 2017. For 2018, fewer legal entities but more groups have assumed the Atlantic multi-decadal oscillation long-term view of exposure rather than the near-term view when compared to 2017.

AIR and RMS are the most frequently used modelling software (together or standalone). In-house modelling[3] was utilised by 33.3% of legal entities and by 46.7% of groups in 2018. 43.9 % of legal entities and 46.2% of groups reported use of more than one model in their accumulation process. Legal entities mostly use their models quarterly with 44.4% of insurers doing so, while 53.3% of groups accumulate as frequently.

[3] In-house model is a proprietary model built by an insurer.

2. Introduction

Bermuda's insurance sector is regulated and supervised by the Authority. The Authority requires all Class 3B and Class 4 insurers to submit a capital and solvency return as part of their annual statutory filing, including a Catastrophe Risk Return and Schedule of Risk Management (Cat Return) detailing the insurers' catastrophe risk management practices.

Within the Cat Return, insurers report their catastrophe exposures, their Exceedance Probability (EP) curves (for various return periods), their Average Annual Loss (AALs) and their Probable Maximum Loss (PMLs), as well as stress test results designated by the Authority for their own solvency assessment. The Cat Return serves as a point of reference in the prudential filings for quantification of catastrophe risk assumed in Bermuda.

The Cat Return also determines the extent of reliance on vendor models to assess catastrophe exposures and highlights the actions insurers take to mitigate model risk, including a description of procedures and analytics in place to monitor and quantify exposure to vendor models. Additionally, the Return serves as a tool to assist the Authority in assessing the reasonableness of inputs into the catastrophe risk component of the regulatory capital requirement, and whether standards are being applied evenly.

The global insurance market and the Bermuda market in particular significantly rely upon vendor models to assess catastrophe exposures. If the vendor models underestimate potential losses arising from events, the industry as a whole may have capital levels impacted to a greater extent than expected. Not only is this a strategic and risk management issue for an insurer, it also impacts its regulatory capital requirement since the Catastrophe Risk Charge is generally a significant contributor to this requirement. Therefore, a comprehensive understanding of the modelling practices in Bermuda is a central aspect of the Authority's supervisory framework.

Drawing from the information in the Cat Returns, this report gives a high-level overview of the capacity of the Bermuda insurance sector to absorb shocks from various Cat risk events underwritten by Bermuda insurers, including identification of any concentration of risks and an analysis of the catastrophe modelling practices.

The report contributes to an improved understanding of Bermuda as an insurance-based International Financial Centre and a leader in the regulation of the catastrophe market. This ultimately demonstrates the contribution of Bermuda and emphasises the commitment of the Authority to a high standard of transparency.

3. Methodology

The report was produced using aggregated and non-aggregated data from the Bermuda Capital and Solvency Return (CSR) filings of Class 3B and Class 4 legal entities, and insurance groups for the period ended 31 December 2018[4]. Specifically, the following schedules from the CSR were used as data sources:

- Schedule V(e) - Schedule of Risk Management: Stress/Scenario Test;
- Schedule X(a) - Catastrophe Risk Return: EP Curve Total;
- Schedule X(c) - Catastrophe Risk Return: EP Curve for Regions-Perils;
- Schedule X(e) - Catastrophe Risk Return: Accumulations Overview;
- Schedule X(f) - Catastrophe Risk Return: Data Analysis; and
- Schedule X(g) - Catastrophe Risk Return: Reinsurance Disclosures

Data was aggregated only when it could be. For example, we did not use aggregated EP curve data, while we did use aggregated AAL data. EP curves were not aggregated since they represent upper quantiles of distributions and quantiles are not additive functions. AALs on the other hand, since they represent averages over distributions, can be aggregated without logical inconsistencies.

When data could not be aggregated, an augmented box plot presenting percentiles and averages was used to describe the distribution of the variable within the industry. Care has been taken not to identify individual insurers to preserve the confidentiality of the CSR filings. In total, the report was able to capture a high-level overview of the Cat risk exposure in Bermuda.

The exclusion of all other classes, such as Special Purpose Insurers (SPIs)[5], limits the conclusions that can be gleaned from the results of this survey. Therefore, one should view the results as being reflective of a segment of the industry and not the entire exposure of the Bermuda insurance market[6] which is expected to be larger than what is presented in this report. It should also be noted that, having excluded the Long-Term (life) insurers, the report does not consider mortality catastrophic risk.

The analysis of the accumulation process is based on responses from insurers in the 2018 and previous years' CSR filings. The accumulation process provides insights into the relationship

[4] Not all insurers have 31 December year-end. Therefore, the data used in the report may not fully reconcile with the BMA annual report, which will include fall-end underwriting data.
[5] The BMA publishes an annual Alternative Capital Report.
[6] Bermuda insurance market includes the Bermuda reinsurance market.

between the modelling process of insurers and the actual management of those risks from an operational point of view.

The analysis in this report was based purely from original CSR data input. No reference was made to other supporting documents separately required as part of the CSR filing. These additional documents are also reviewed by the Authority's supervisory team at the micro-level in the context of individual insurers. As such, subtle nuances provided by an insurer's full return that might otherwise impact these results are not reflected in this report.

Information Box

Class 3B and Class 4 insurers are the larger property and casualty commercial insurers in Bermuda's market and are required to maintain statutory capital and surplus of at least 99% TVaR over a one-year time horizon.

Aggregate Statistics for Classes 3B and 4, 2018. (In US$ billions)

Net Written Premiums	**37.8**
Net Earned Premiums	39.2
Net Income	3.1
Total Claims	27.2
Total Assets	216.1

Source: BMA

4. Catastrophe Risk Stress Test

As part of the annual statutory CSR filing, insurers are required to carry out rigorous and comprehensive forward-looking stress tests to measure the sensitivity of their statutory capital & surplus to various significant Cat risk underwriting loss scenarios[7].

Stress testing is a fundamental element of an insurer's overall risk management framework and capital adequacy determination[8]. The main objective of underwriting stress testing is to assess the capacity of individual insurers, and the entire sector, to absorb shocks from adverse events and to identify any concentration of risk that may emerge. Stress testing can also be used to assess the effect of tail events beyond the measured level of confidence.

The Authority assesses Cat risk stress tests at three different levels. First, using both the Lloyd's developed Realistic Disaster Scenarios (RDS) and other scenarios designed internally by the Authority, each insurer is required to estimate its loss impact for 18 standardised Cat underwriting loss scenarios (see Appendix I for details on each underwriting loss scenario's key assumptions that insurers use as a guide to estimate their market share). Second, the insurer is required to submit to the Authority three of its own highest underwriting loss scenarios if the 18 standardised RDS underwriting loss scenarios provided by the Authority do not fully align with the insurer's underwriting exposure. Third, the insurer is required to consider and provide estimates for its worst-case underwriting loss scenario based on its own independent underlying assumptions.

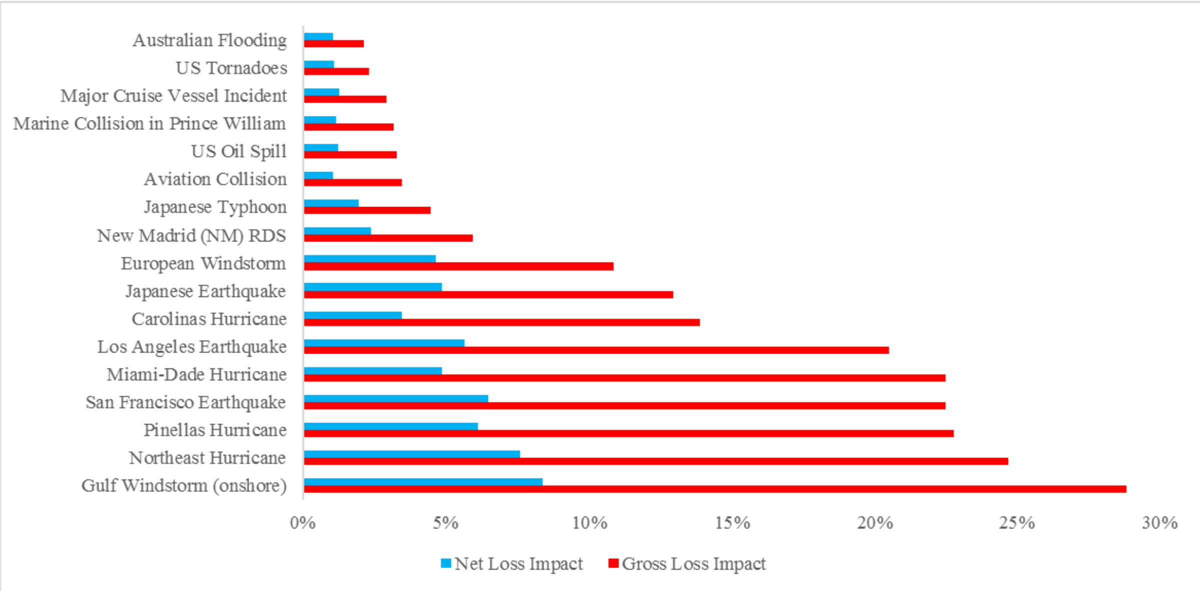
In general, the 2018 Cat underwriting loss scenario results showed that not only is the Bermuda insurance market resilient to potential Cat underwriting loss impacts arising from all major perils underwritten[9] but will still hold satisfactory capital to settle policyholders' obligations. Out of the 18 standardised underwriting loss scenarios, Gulf Windstorm (onshore) had the largest potential adverse effect with an estimated gross loss impact[10] to statutory capital & surplus of 29.0% (and 8.0% net loss impact), followed by Northeast Hurricane which had the potential to deplete 25.0% (and 8.0% net loss impact) of the market's total statutory capital &

[7]Insurers are also required to conduct stress scenarios to assess their capital adequacy under an adverse financial market and a combination of an adverse financial market scenario with an adverse underwriting scenario. However, this report only discusses the underwriting loss scenarios from Cat events.
[8]International Association of Insurance Supervisors
[9]The underwriting loss impact and associated assumptions reported by insurers are probabilistic outcomes and represent calculated estimates. Actual results may significantly differ from these estimates.
[10]Gross loss impact is before any reinsurance and/or other loss mitigation instruments.

surplus[11]. Australian Wildfires had the least impact with only 1.0% gross and net impact on the statutory capital & surplus. The gross impact from each of all the other perils ranges from 2.0% to 21.0% with the majority of the perils (nine) having gross loss impact of less than 10.0% (see Appendix II).

Figure 1. Stress Testing - Cat Loss Scenarios

(As percent of Total Capital & Surplus)

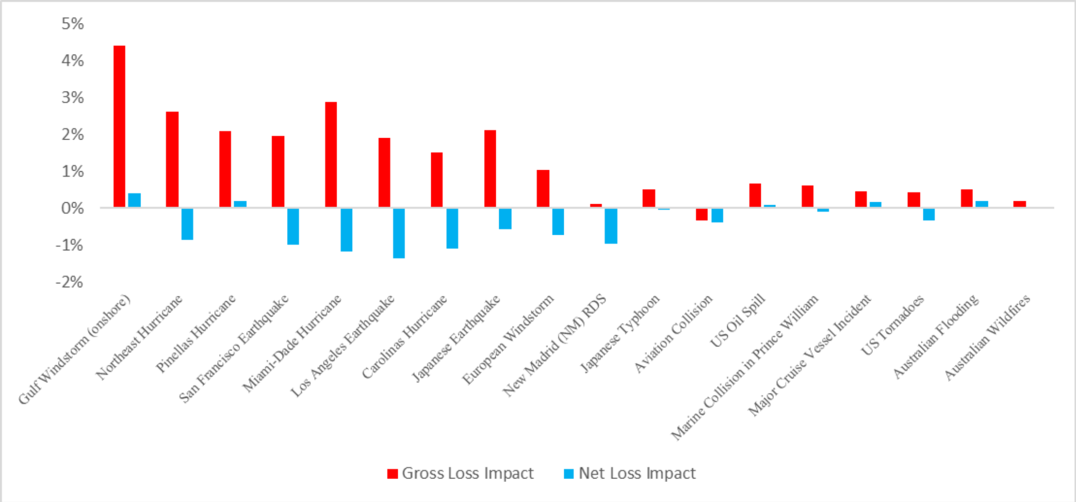


Source: BMA staff calculations.

Overall, the insurers have ceded more exposure resulting in a decrease in the net loss exposure by 14.8% compared to 2017. With regards to impact on capital & surplus, Gulf Windstorm had the highest year on year increase on gross loss impact of 4.0%, followed by Northeast Hurricane and Miami-Dade Hurricane with a 3.0% increase. Los Angeles Earthquake, Carolinas Hurricane and Japanese Earthquake gross loss impacts increased by 2%. All the other perils had either seen a slight increase in their gross loss impact or the impact had remained relatively the same (see figure 2 below).

[11]Total Capital & Surplus includes only Capital & Surplus for insurers that underwrite Cat risk, i.e. Capital & Surplus for insurers that do not underwrite Cat risk is not included.

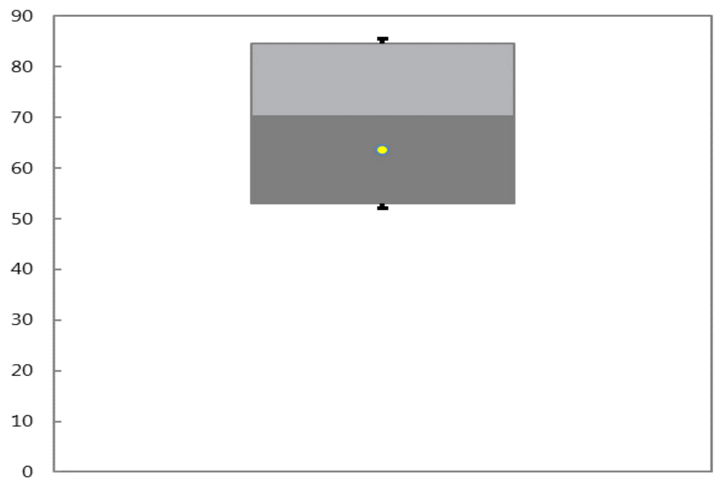
Figure 2 - Year on Year (2017 and 2018) Gross and Net Loss Impact Change



Source: BMA

At the individual entity level, the results showed that Bermuda's insurance entities are resilient to the worst-case annual aggregate underwriting loss scenario (Figure 3 below). For the worst-case annual aggregate loss scenario, insurers are required to assess the aggregate impact of three of their largest net underwriting loss impacts, assuming the underwriting loss events follow in quick successions, and there is no ability to engage in capital and other fundraising activities. Further, it is assumed there is no geographic correlation between these events. Additionally, the insurers are required to run either a series of loss simulations or other analysis performed related to extreme tail events that include all policies at the beginning of the year; or its own worst-case annual aggregate loss scenario at a level considered extreme but plausible, substantiated with the relevant underlying assumptions.

Figure 3 – Statutory Capital after Net Worst-Case Aggregate Underwriting Loss Scenario (In percent)



Source: BMA staff calculations. *Note:* Boxplots include the mean (yellow dot), the 25th and 75th percentiles (grey box, with the change of shade indicating the median), and the 10th and 90th percentiles (whiskers).

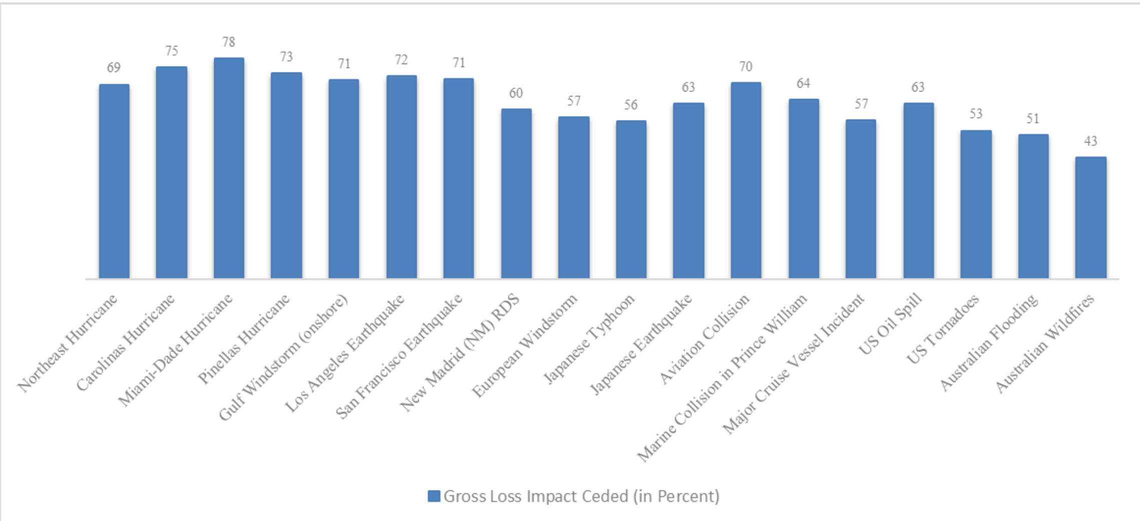
Insurers are also required to carry out a separate stress test for terrorism coverage by estimating the potential loss impact using a standardised scenario of an explosion of a two-tonne bomb. The results from the test show all entities would comfortably withstand their worst impact from this standardised scenario, retaining on average 90.0% of the statutory capital & surplus on a gross basis and 93.0% on a net basis.

Finally, insurers are required to provide cyber risk data, including their estimated aggregate exposure and their own cyber risk worst-case annual aggregate loss scenarios, and the underlying assumptions. The data shows that the insurers' own worst impacts from cyber risk would have a minor effect on their statutory capital & surplus[12].

Reliance on reinsurance

The Authority also assesses the level of insurers' reliance on reinsurance and/or other loss mitigation instruments for each peril. Overall, observing the aggregate loss impact, the results demonstrate that the level of reliance on reinsurance has increased compared to last year and varies across each peril (Figure 4). Typically, perils that have potential for the largest losses, such as Gulf Windstorm, Miami-Dade Hurricane, Pinellas Hurricane and San Francisco Earthquake, are heavily reinsured.

Figure 4. Gross Loss Impact Ceded (in percent)

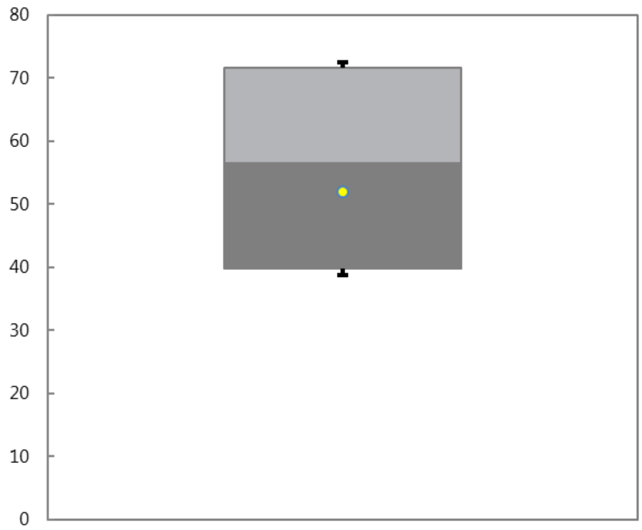


Source: BMA staff calculations.

[12] BMA publishes a separate annual report of Cyber Underwriting Risk.

On average, insurers ceded close to 52.0% of gross losses (Figure 5), which is an increase of about 2.4% compared to last year.

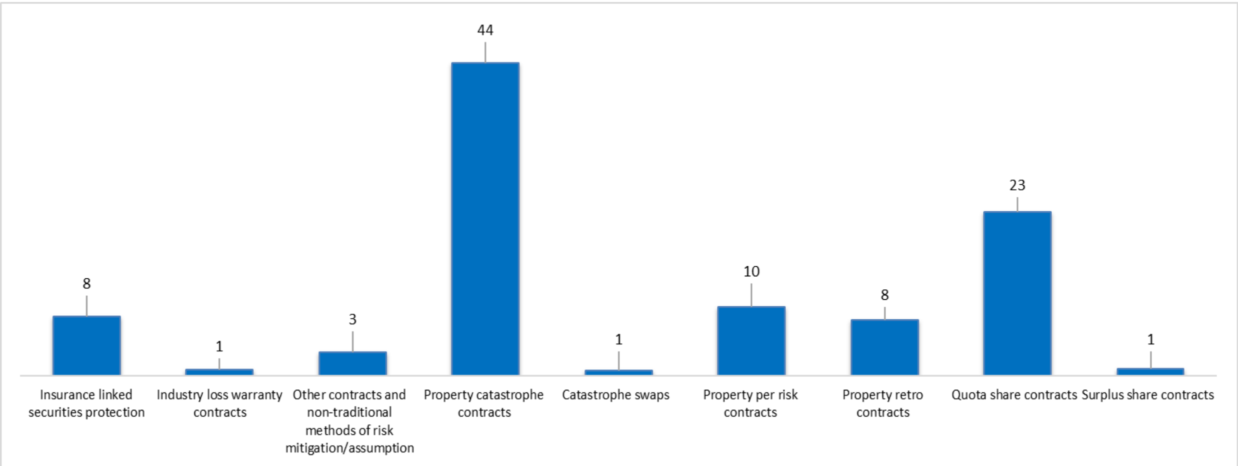
Figure 5. Loss Impact Ceded (In percent)



Source: BMA staff calculations. *Note:* Boxplots include the mean (yellow dot), the 25th and 75th percentiles (grey box, with the change of shade indicating the median), and the 10th and 90th percentiles (whiskers).

The results also showed that Bermuda insurers use a variety of reinsurance methods to cede some of their Cat exposure, which include the traditional property catastrophe contracts, quota share contracts, Insurance-Linked Securities protection and industry loss warranties contracts among others. Compared to last year, the use of property catastrophe contracts, quota share contracts and proper per risk contracts have increased.

Figure 6. Reinsurance Strategy - Aggregate Occurrence Limit (in percent)



Source: BMA staff calculations.

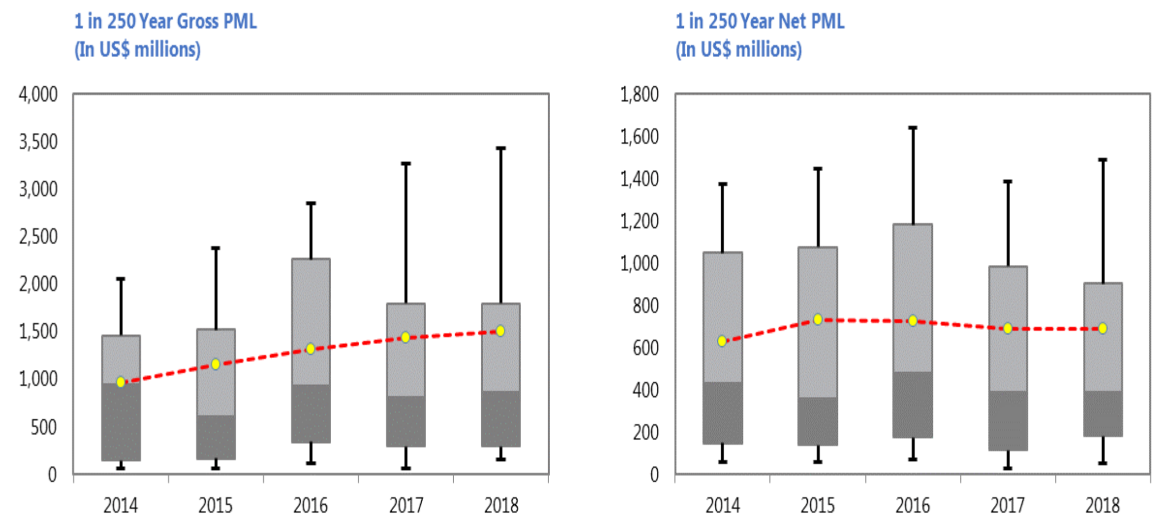
5. Exceedance Probability (EP) Curves

This section presents some outputs from the catastrophe models in Bermuda on an aggregated basis for Bermuda legal entities. Insurers are asked to produce EP curves for named perils. These perils are Atlantic hurricane, North American earthquake, European windstorm, Japanese earthquake and Japanese typhoon.

The BMA compiles the data from EP curves by drawing the distribution of EP curves in the cross-section for firms for named perils across return periods. There are plots for each peril and for each return period a box plot which includes the mean, median, 10th, 25th, 75th and 90th percentiles of the EP curves[13].

Historical trends of the gross and net "1 in 250" year Probable Maximum Loss (PML) for aggregate exposures for the past five years were evaluated. The "1 in 250" year event is the most representative of the extreme risk to which an insurer is exposed. The following panel presents the distribution of the PML for the aforementioned return period.

Panel 1. Gross and Net "1 in 250" PML



Source: BMA staff calculations. *Note:* Boxplots include the mean (yellow dot), the 25th and 75th percentiles (grey box, with the change of shade indicating the median), and the 10th and 90th percentiles (whiskers).

[13] EP curves cannot be aggregated by summing individual EP curves since an event for one firm can be completely unrelated with the event of another company even for the same peril and the same return period. For example, a 1 in 250 year event in North America earthquake means something different for a company with exposure to San Francisco versus a 1 in 250 year event for a company with exposure to Northern California outside large urban centres. Moreover, the simple addition of EP curves does not recognise diversification benefits since it assumes that all events for all perils and for all return periods can occur at the same time even if some events may be mutually exclusive.

The insurers have increased their average gross exposure between 2017 and 2018 by 4.5%. The variation within the sample in 2018 increased but not significantly with few companies having large changes in their exposures and many smaller firms with smaller exposures. The 90th percentile exposure reached $3.4 billion, up by 5.2%, since 2017.

Average net exposure increased marginally by 0.4% between 2017 and 2018, while the variation of exposures within samples dropped. The 90th percentile net exposure increased by 7.5% in 2018 and reached $1.5 billion.

The largest exposure for Bermuda insurers is Atlantic hurricane with average gross exposure between US$798.4 million for a "1 in 50" year event up to almost US$1.4 billion for a "1 in 1,000" year event. This is an average figure with significant variation within firms. For example, at the 90th percentile of losses, there are firms with "1 in 50" year exposures over US$1.5 billion, while there are firms who exceed US$2.3 billion exposures for a "1 in 1,000" year event for the same peril. The BMA calculates the net to gross exposure ratio, and we present some descriptive statistics in the next table.

Table 1. Net to Gross Exposure for Atlantic Hurricane (In percent)

Return Period	1 in 50	1 in 100	1 in 250	1 in 500	1 in 1000
Mean	47.0	49.9	54.0	57.5	60.5
Median	51.4	53.0	55.5	57.2	58.8

Source: BMA

The data show that purchase of reinsurance becomes less pronounced at higher risk layers. The median insurer retains 51.4% of the gross exposure for "1 in 50" year events, while the median insurer retains 58.8% of the gross exposure for "1 in 1,000" year events. The BMA also shows average exposure per peril, per return period both gross and net in the next tables.

Table 2. Average Gross Exposure (In US$ millions)

Return Period	1 in 50	1 in 100	1 in 250	1 in 500	1 in 1000
Atlantic Hurricane	798.4	954.9	1,155.4	1,302.9	1,446.7
NA. Earthquake	526.4	690.7	887.5	1,020.1	1,144.3
European Windstorm	274.7	348.1	434.2	490.7	544.7
Japanese Earthquake	199.1	269.5	347.6	385.5	416.1
Japanese Typhoon	154.9	196.3	233.8	257.4	281.4

Source: BMA

Table 3. Average Net Exposure (In US$ millions)

Return Period	1 in 50	1 in 100	1 in 250	1 in 500	1 in 1000
Atlantic Hurricane	289.1	371.3	502.3	609.1	720.2
NA. Earthquake	182.2	247.6	347.5	436.3	532.8
European Windstorm	126.6	157.7	197.8	228.1	259.3
Japanese Earthquake	84.2	111.1	145.5	164.9	183.6
Japanese Typhoon	65.9	81.1	97.7	110.5	124.0

Source: BMA

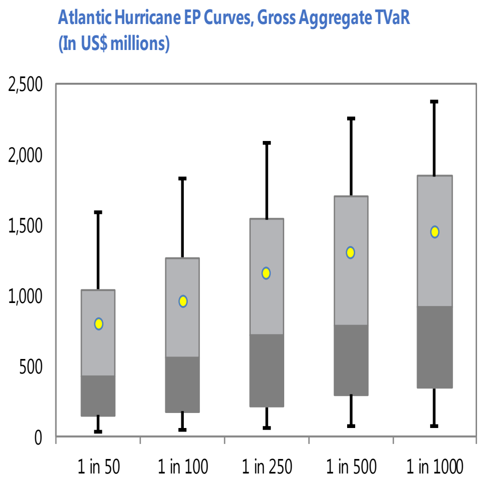
As mentioned before, the largest exposure across all return periods is Atlantic hurricane followed by North American earthquake. The BMA also plot the aggregate gross and net EP curves, which include all the catastrophic risks in an insurer's portfolio.

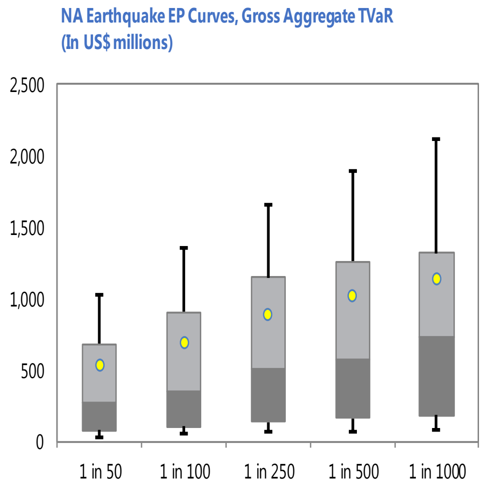
Table 4. Average Exposure for all Perils (In US$ millions)

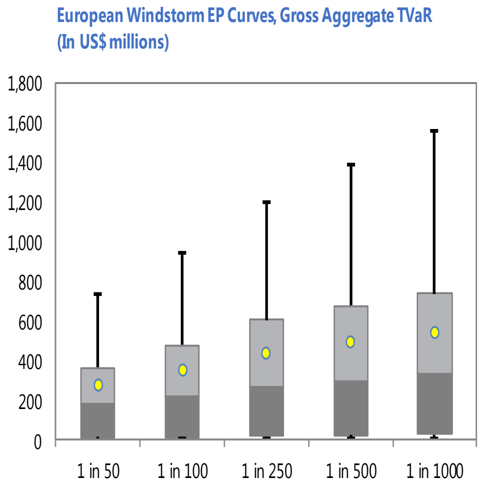
Return Period	1 in 50	1 in 100	1 in 250	1 in 500	1 in 1000
Gross	1,090.5	1,275.0	1,501.4	1,667.4	1,835.3
Net	437.3	541.5	691.2	811.5	937.5

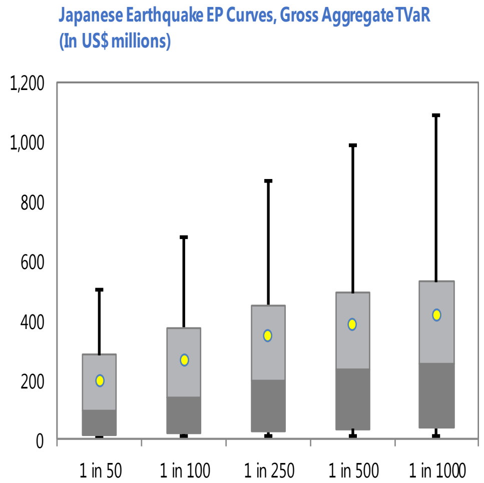
Source: BMA

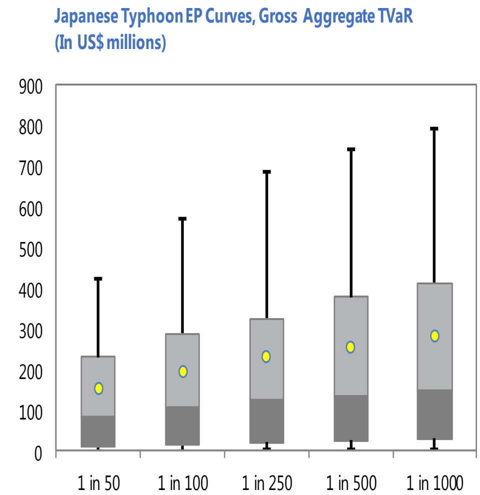
Panel 2. Gross EP Curves for Named Perils





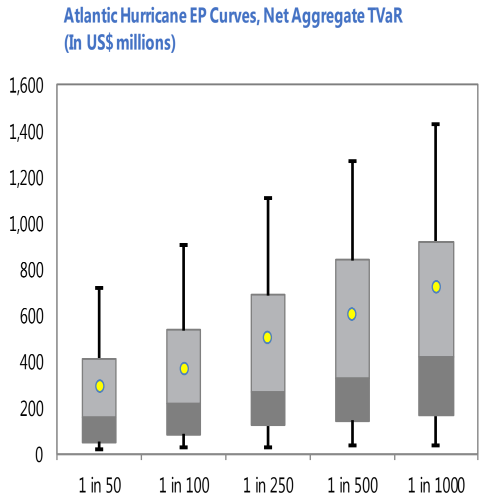


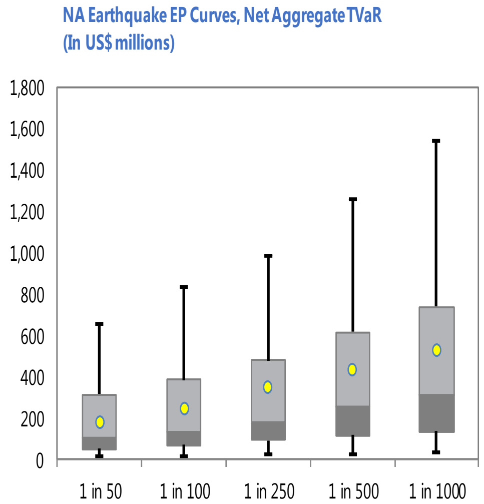


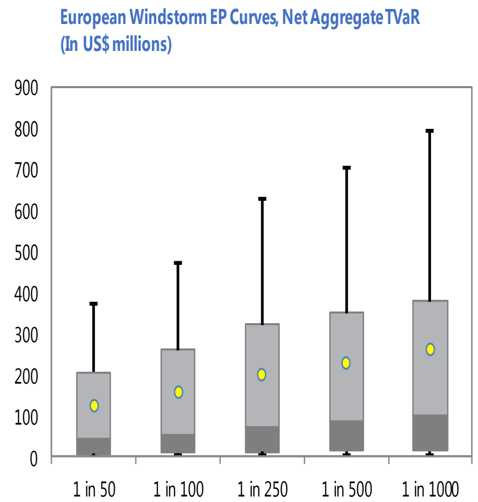


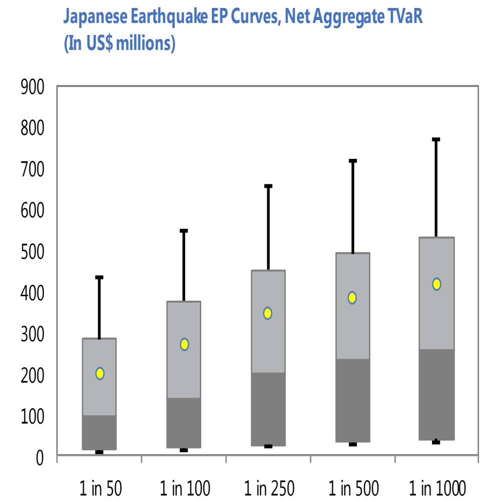
Source*:* BMA staff calculations. *Note:* Boxplots include the mean (yellow dot), the 25th and 75th percentiles (grey box, with the change of shade indicating the median), and the 10th and 90th percentiles (whiskers).

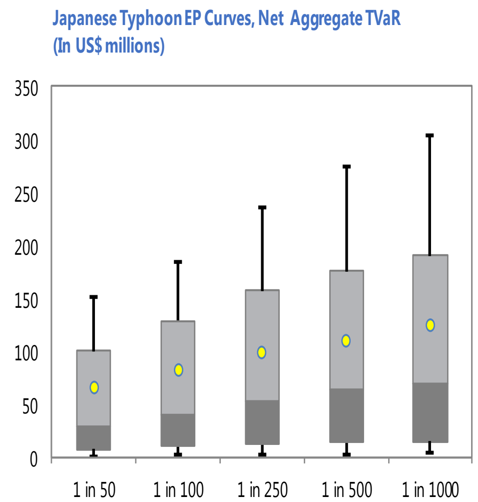
Panel 3. Net EP Curves for Named Perils





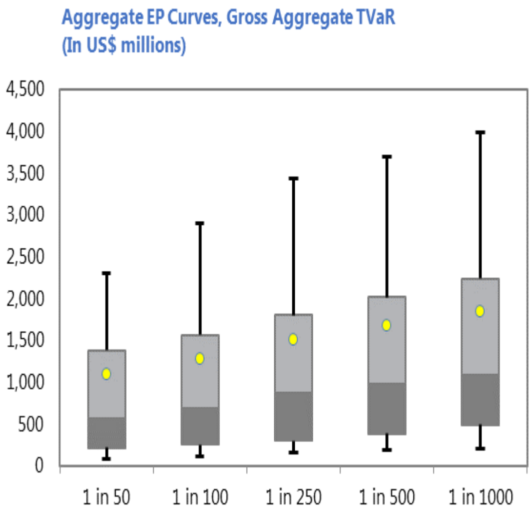


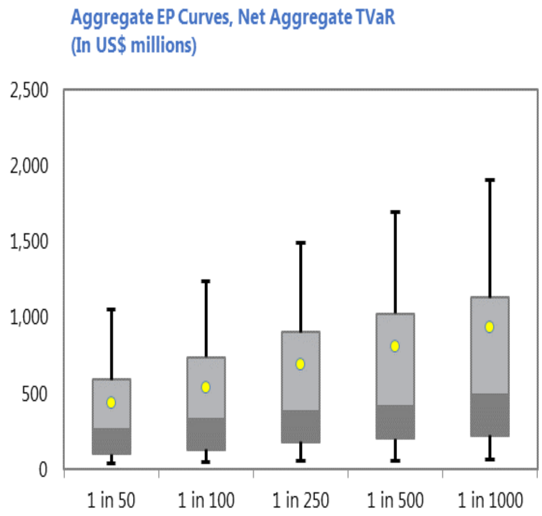




Source*:* BMA staff calculations. *Note:* Boxplots include the mean (yellow dot), the 25th and 75th percentiles (grey box, with the change of shade indicating the median), and the 10th and 90th percentiles (whiskers).

Panel 4. Gross and Net Aggregate EP Curves for all Perils

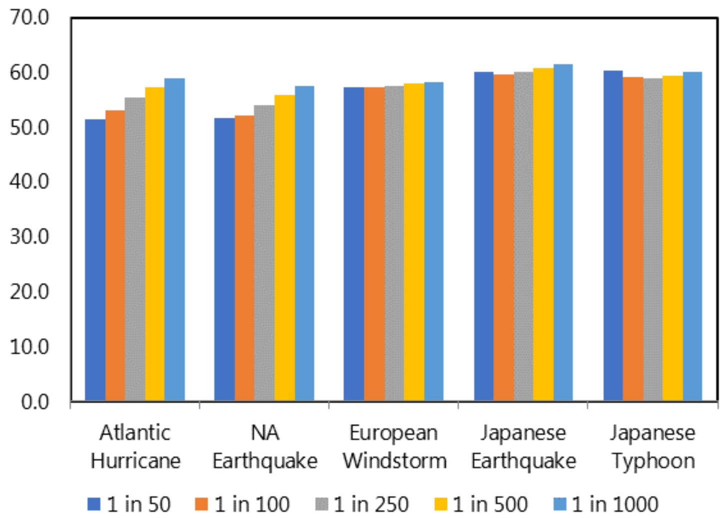




Source: BMA staff calculations. *Note:* Boxplots include the mean (yellow dot), the 25th and 75th percentiles (grey box, with the change of shade indicating the median), and the 10th and 90th percentiles (whiskers).

Figure 7. Average Net to Gross EP Exposure per Peril and Return Period

(Aggregate EP Curves, in percent)



Source: BMA staff calculations.

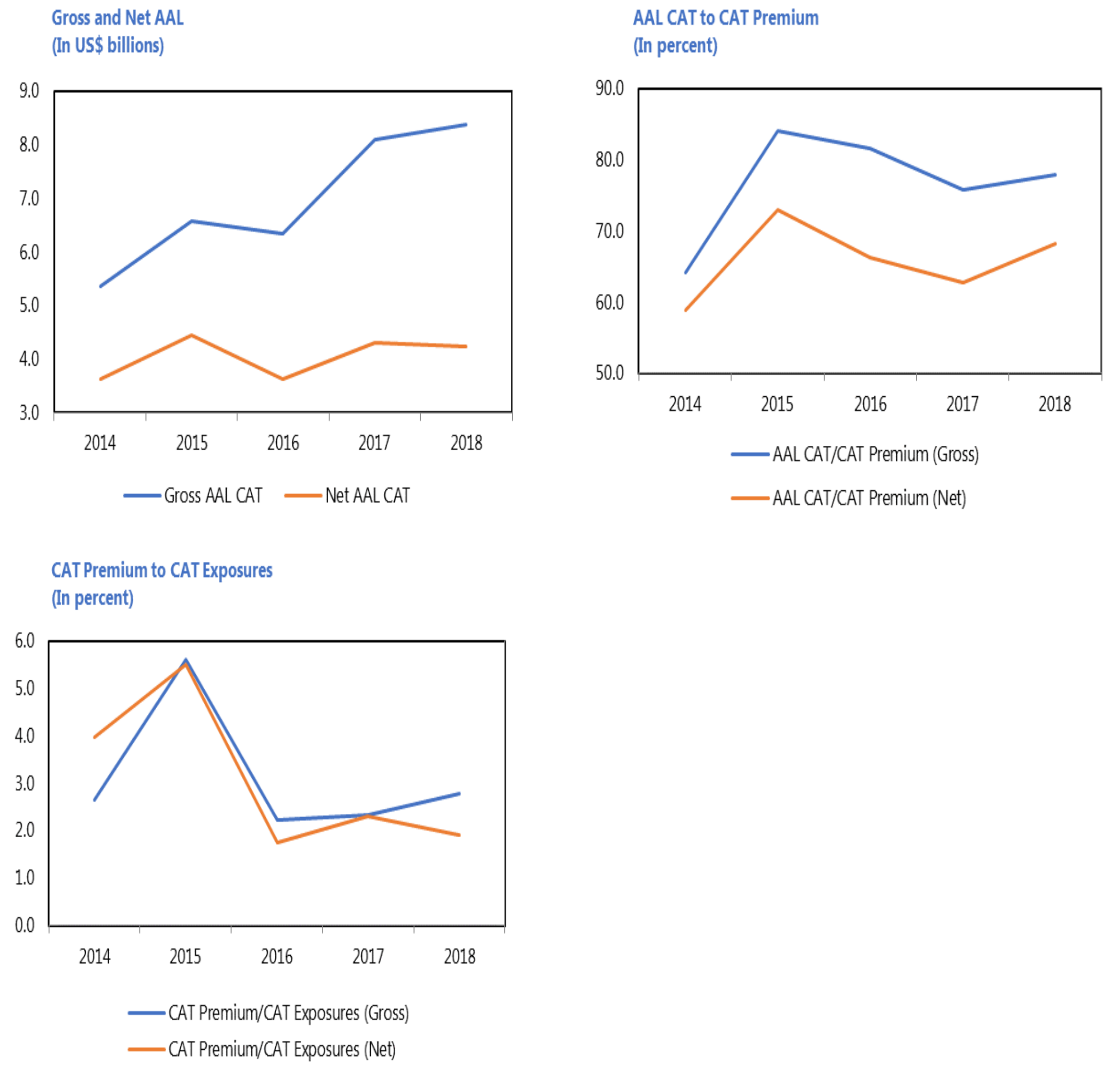
For Atlantic Hurricane, the ratio of net to gross exposure increases as the return period increases. The rarer the event, the more the insurer retains risk on average.

The observations indicate that less reinsurance is being purchased for more rare events (1 in 1,000), compared to less rare events (1 in 50). This is true for all perils except Japanese Typhoon and Earthquake (for 1 in 100 return period) where there is no monotonic relationship between retention and return periods. Nevertheless, for Japanese Typhoon, the average retention ratios are close for all return periods. European Windstorm exhibits a rather flat demand for reinsurance across return periods. However, Atlantic Hurricane and North American Earthquake are the major perils where significant variation in the use of reinsurance per return period is evident.

6. Pricing Dynamics

The following panel shows the pricing dynamics of the catastrophe market across time based on aggregated data (only) for legal entities.

Panel 5. Average Annual Loss, Risk & Pricing Ratios[14]



Source: BMA staff calculations. Note: The ratios are calculated only for modelled exposures and modelled premium.

The gross Average Annual Loss (AAL) increased between 2017 and 2018, and reached US$8.4 billion compared to US$8.1 billion in 2017. Net AAL has reached US$4.2 billion in 2018 compared to US$4.3 billion in 2017.

[14] The BMA used only modelled exposures and premium.

In Panel 5, plots of the risk and the pricing dynamics show the ratios of the Cat AAL to Cat premium on both a gross and net premium basis. The AAL largely represents the modelled estimation of the expected Cat losses, and the gross premium includes provisions for profit and expenses. The relationship between these gross and net ratios indicates the amount of expenses, profit and other loadings charged to insured entities. The BMA observes that on average, this ratio had been steadily increasing up to 2017. For 2018, the ratio stabilised for gross exposures and grew for net exposure.

The ratio of AAL to Cat premium dropped from 81.5% in 2016 to 75.8% in 2017 and has increased to 77.9% in 2018. For net exposures, the ratio has dropped–from 66.3% in 2016 to 62.8% in 2017 and 68.2% in 2018.

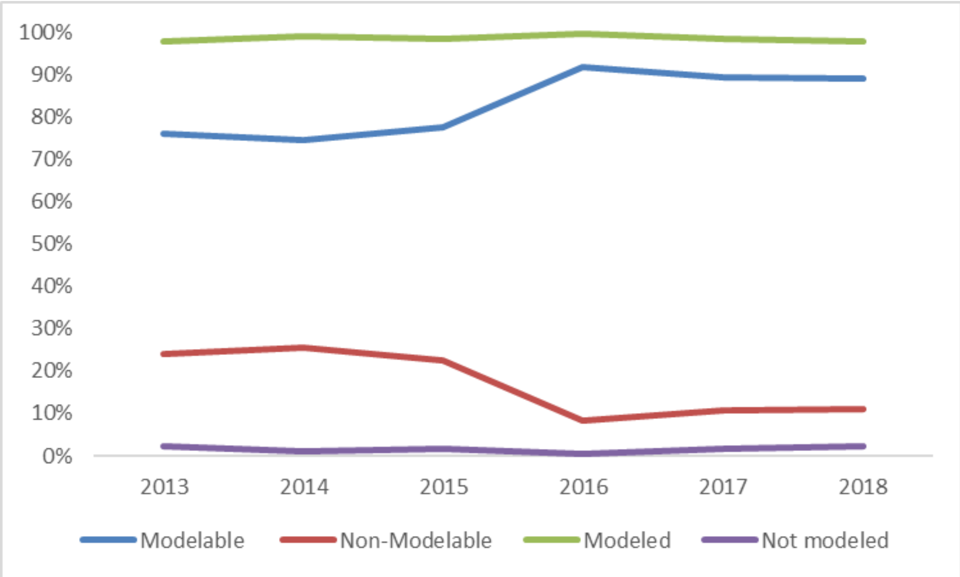
The second row of Panel 5 plots the ratio of Cat premium to Cat exposures. This ratio dropped significantly between 2015 and 2016, but it seems to have increased for gross exposures in 2017 and 2018, and declined between 2017 and 2018 for net exposures. In 2018, the ratio for gross exposures stood at 2.8%, while the ratio for net exposures was 1.9%.

7. PMLs and Accumulation Process

The accumulation process is an important component of the modelling process and is an integral part of risk management. As part of the CSR filing, the Authority collects information about the accumulation process from the prudential filings of companies on an annual basis.

The 2018 CSR filing showed that 89% of the Cat risk exposure underwritten in Bermuda is modelable using vendor CAT models and 98% of CAT risks were modelled. The percentage of both modelable[15] and modelled exposure remained the same compared to 2017[16].

Figure 8. Modelable and Modelled Exposure



Source: BMA staff calculations.

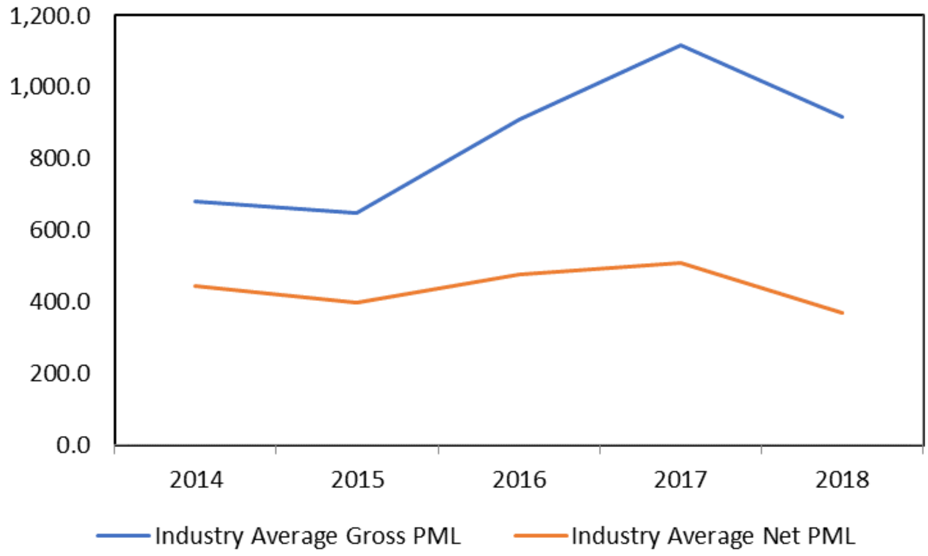
[15]**Modelable exposure** refers to the exposure that can be simulated through a vendor catastrophe model; **Non-Modelable exposure** refers exposure that cannot be simulated through a vendor catastrophe model or where there are no catastrophe models that assess the risk of the region-peril under consideration; **Modelled exposure** refers to risks that the insurer was able to model. Where exposures are not modelable through the use of vendor catastrophe models (i.e. Non-Modelable exposure), insurers often use models developed in-house to evaluate risk. As such, very few exposures are "not modelled".

[16]Reasons for non-modelled risk may include data limitations that prevent the exposure from being run through a vendor (or in-house) catastrophe model. This may be due to: 1) the resolution of the data or the completeness of the data, which for other reasons is not sufficient to produce credible modelling results; 2) Model deficiency, where there may be some modelable exposures, but the vast majority of exposures are not modelable; and or 3) there are no catastrophe models that assess the peril under consideration.

7.1 PMLs and Accumulation Process - Legal Entities

This section[17] presents aggregated results from the statutory filings of insurers for the year 2018. Bermuda Class 3B and 4 insurers are required to file the catastrophe risk schedule which is a questionnaire about modelling practices. It also includes quantitative information about catastrophe exposures. In Bermuda, the catastrophe modelling process of entire portfolios is referred to as "accumulation", which stands for the accumulation of risks. Considering quantitative factors, Bermuda insurers reported metrics on the AAL, PML and factor loadings. The latest data is provided in the following figures and tables. The PML is defined as the 99.0% Tail Value at Risk (TVaR) on an aggregate basis.

Figure 9. Gross and Net Average Industry PML (In US$ millions)



Source: BMA staff calculations.

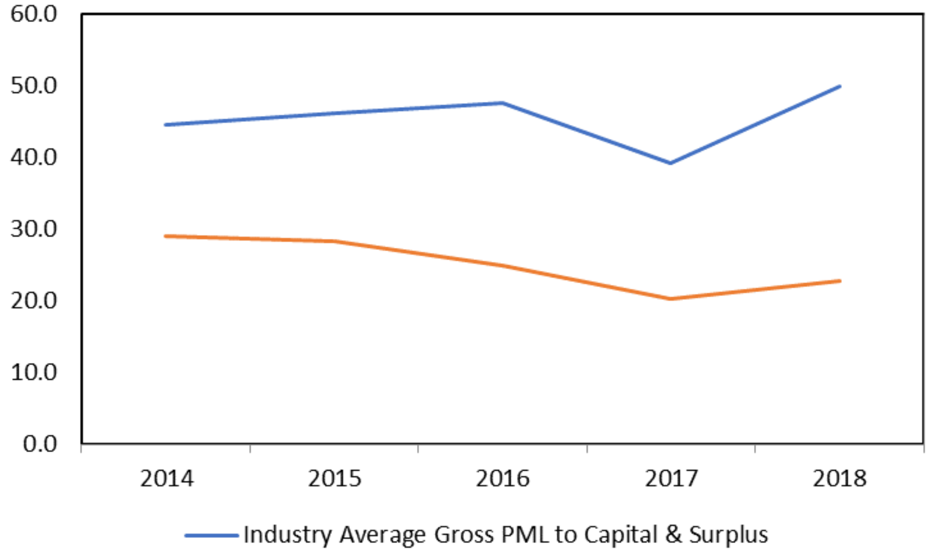
Table 5. PML (In US$ millions)

	2018	2017	2016	2015	2014
Industry Average Gross PML	918.7	1,118.0	910.0	648.9	682.0
Industry Average Net PML	369.6	509.8	476.2	398.1	445.2

Source: BMA

[17] In this section, the BMA presents catastrophe-modelling practices that were collected from Class 3B and 4 legal entities as well as Bermuda groups which are domiciled in Bermuda and have the BMA as a group-wide supervisor. In this next section, wherever the term legal entities is used, it refers to Class 3B and 4 Bermuda insurers.

Figure 10. Gross and Net Industry PML to Capital & Surplus (In percent)



Source: BMA staff calculations.

Table 6. PML Ratios (In percent)

	2018	2017	2016	2015	2014
Industry Average Gross PML to Capital & Surplus	49.9	39.3	47.7	46.1	44.6
Industry Average Net PML to Capital & Surplus	22.8	20.3	24.9	28.3	29.1

Source: BMA. Sample removes certain outliers that distort the ratios.

Table 5 represents the average PML for legal entities in dollar amounts. The PML for 2018 experienced a decrease on both a gross and a net basis.

Table 6 presents ratios of the gross and net PML to capital & surplus. This ratio expresses whether the available capital & surplus can withstand a loss equal to 99.0% TVaR. In 2017, a 99.0% TVaR aggregate loss was expected to consume 39.3% of available capital & surplus on a gross basis. After decreasing in 2017, this ratio increased in 2018. From 2016, this ratio exhibits a similar pattern with the ratio being 22.8% in 2018, up from 20.3% in 2017, on a net basis.

Table 7 presents loading factors used as add-ons for the catastrophe modelling outputs. These factors compensate for model errors, increase conservatism in the modelling process and are applied to the PML. For example, if the catastrophe model yields a PML of US$100, a 5.0% factor would raise the PML to US$105.

Table 7. Loading Factors[18] (In percent)

	2018	2017	2016	2015	2014
Average Loading Factor	8.3	6.7	5.4	5.9	8.3

Source: BMA

In light of significant catastrophe losses experienced in 2017, the average loading factor increased in 2018 to reach 8.3%. A cautious interpretation of the factor is necessary since models themselves may become more accurate and conservative, thus reducing the need for higher safety buffers.

Insurers responded to how they estimate the factor – either the factor is typically determined analytically (meaning that insurers will analyse the total output of the model and back-test the results according to the total loss experience), or insurers will take a per-risk view and blend the experience of single lines of business into the total portfolio PML. The responses can be found in Table 8.

Table 8. Loading Factor Estimation Methods (In percent of respondents)

	2018	2017	2016	2015	2014
Determined Analytically	42.1	36.4	29.6	20.4	38.7
Estimated	57.9	63.6	70.4	80.0	61.3

Source: BMA.

In 2018, 57.9% of insurers estimated the loading factor while 42.1% determined it analytically through modelling.

Another interesting modelling practice is the usage of the Atlantic Multi-decadal Oscillation (AMO). AMO refers to the alteration of Sea Surface Temperatures (SST) in the Northern Atlantic from cool to warm phases. These phases last for several years. Since the mid-1990s, a warm phase has existed. A correlation has been observed between warm SSTs and more frequent severe hurricanes, and other destructive weather phenomena. Bermuda insurers responded as to whether they consider loadings for this risk factor on near-term or long-term views.

[18] The loadings reflect the cumulative loading regardless of the level applied, i.e. within the accumulation process or post the accumulation process/applied to the PML. The same applies for legal entities and groups.

Table 9. AMO Factor Consideration (In percent of respondents)

	2018	2017	2016	2015	2014
Near-Term Frequency	65.9	61.5	74.3	89.5	89.2
Long-Term Frequency	34.1	38.5	25.7	10.5	10.8

Source: BMA.

The BMA observes that in 2018, 65.9% of insurers utilised the near-term AMO factor for their modelling of Atlantic Hurricane exposures, while 34.1% utilised the long-term factor. The AMO factor relates to trends in hurricane frequencies taken into account in modelling Atlantic Hurricane exposures and the financial losses that stem from hurricane activity. Near-term frequency and long-term frequency estimations have been converging, which explains why more insurers are using the long-term view.

Part of the questionnaire asked about the vendors that insurers use. This indicates whether insurers are forming their modelling opinions on one or multiple models, while the BMA can see which vendors are more prevalent in the market. Additionally, the BMA asked how frequently insurers perform portfolio modelling (or accumulations) and whether insurers develop their own non-vendor models. The next table summarises the responses.

Table 10. Vendor Model Usage and Licensing (In percent of respondents)

Model Usage	**2018**	**2017**	**2016**	**2015**	**2014**
AIR only	24.4	18.9	12.5	9.1	16.7
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	31.7	40.5	40.6	39.4	30.6
AIR and RMS	43.9	40.5	43.8	45.5	38.9
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	0.0	0.0	0.0	0.0	0.0
AIR, EQECAT and RMS	0.0	0.0	3.1	6.1	13.9
Model Licensing	**2018**	**2017**	**2016**	**2015**	**2014**
AIR only	20.0	17.5	13.9	7.7	15.0
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	24.4	27.5	25.0	17.9	10.0
AIR and RMS	55.6	55.0	58.3	66.7	60.0
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	0.0	0.0	0.0	0.0	0.0
AIR, EQECAT and RMS	0.0	0.0	2.8	7.7	15.0

Source: BMA

RMS seems to be the most commonly used standalone model. Moreover, the use of three models in tandem seems to be the exception, with no share of EQECAT use since 2016. It appears that no single insurer has used all three models since 2016.

Table 11. Model Frequency Usage (In percent of respondents)

	2018	2017	2016	2015	2014
Ad-hoc	2.2	0.0	0.0	0.0	0.0
Annual	2.2	2.4	0.0	0.0	0.0
Semi-annual	2.2	2.4	0.0	0.0	3.0
Quarterly	44.4	54.8	52.6	43.9	35.0
Monthly	24.4	19.0	26.3	24.4	25.0
Weekly	0.0	2.4	2.6	2.4	5.0
Daily	15.6	14.3	13.2	22.0	20.0
Real time	8.9	4.8	5.3	7.3	12.5

Source: BMA

Insurers use and update catastrophe modelling in fixed periods, usually quarterly and monthly. For each quarter, either renewals or supervisory reporting are the most common reasons to run the catastrophe models, with 44.4% of insurers reporting quarterly use in 2018 (down from 54.8% in 2017). Real-time use increased to 8.9% of insurers in 2018 compared to 4.8% in 2017. Only 2.2% of respondents used and updated their model annually, and for the first time we saw responses for ad-hoc usage.

Table 12. Model Frequency and Business Units Differences (In percent of respondents)

	2018	2017	2016	2015	2014
Yes	37.8	30.0	39.5	36.6	32.5
No	62.2	70.0	60.5	63.4	67.5

Source: BMA

Insurers were asked whether different business units use catastrophe models at different frequencies. In 2018, 62.2% of respondents said that they do not perform accumulations at different frequencies. This percentage was 70.0% in 2017.

Table 13. Internal Model Usage (In percent of respondents)

	2018	2017	2016	2015	2014
Yes	33.3	33.3	34.2	39.0	42.5
No	66.7	66.7	65.8	61.0	57.5

Source: BMA

Between 2015 and 2018, a stable percentage of insurers developed internal catastrophe models.

In 2018, 33.3% of insurers developed their own stochastic model. Insurers with very specialised lines of business outside the cover of traditional vendors are more likely to develop such in-house models to capture their unique risks.

The BMA also asked insurers how their catastrophe risk modelling reflects their reinsurance and retrocessional purchases. The responses are shown in Table 14.

Table 14. External Reinsurance Model Usage (In percent of respondents)

	2018	2017	2016	2015	2014
The company has minimal catastrophe exposure protection and as such gross is effectively net.	6.7	20.0	10.5	12.2	15.0
The accumulations are calculated on a gross basis with reinsurance protections calculated approximately outside the system.	4.4	0.0	2.6	0.0	0.0
The accumulations are calculated on a gross basis with reinsurance protections calculated explicitly outside the system.	2.2	5.0	5.3	7.3	7.5
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for some types of protection within the system.	40.0	30.0	31.6	26.8	25.0
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for each type of protection within the system.	46.7	45.0	50.0	53.7	52.5

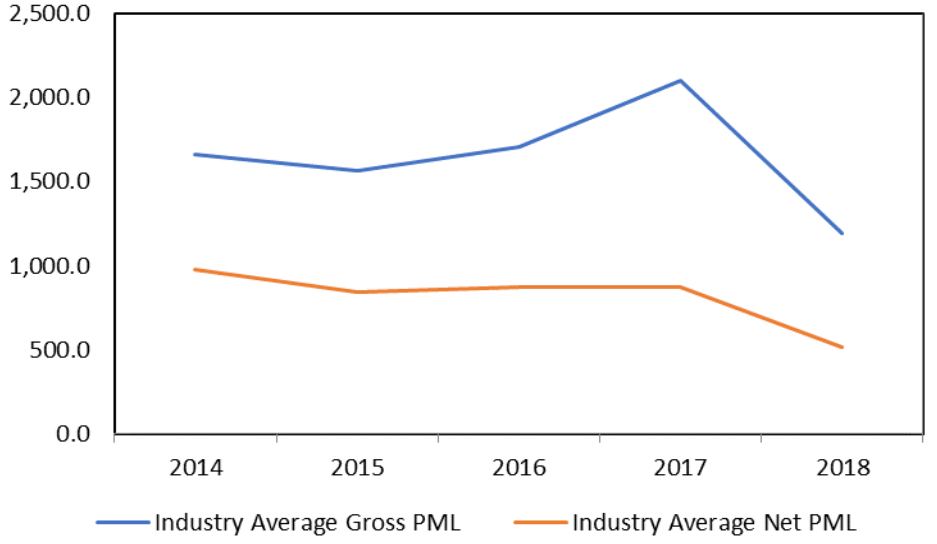
Source: BMA

The BMA observes the number of insurers purchasing little or no external catastrophe reinsurance dropped from 20.0% of respondents in 2017 to 6.7% of respondents in 2018. The vast majority of insurers model catastrophic risk by taking into account explicitly external reinsurance either for some types or for each treaty separately. In 2018, 86.7% of respondents considered either some external reinsurance or all reinsurance treaties in their catastrophe modelling. In 2018, only 6.6% of respondents did not consider directly external reinsurance in their modelling practices, compared to 5.0% in 2017.

7.2 PMLs and Accumulation Process - Insurance Groups

The same data for legal entities is also collected from insurance groups.

Figure 11. Gross and Net Average Industry PML (In US$ millions)



Source: BMA staff calculations.

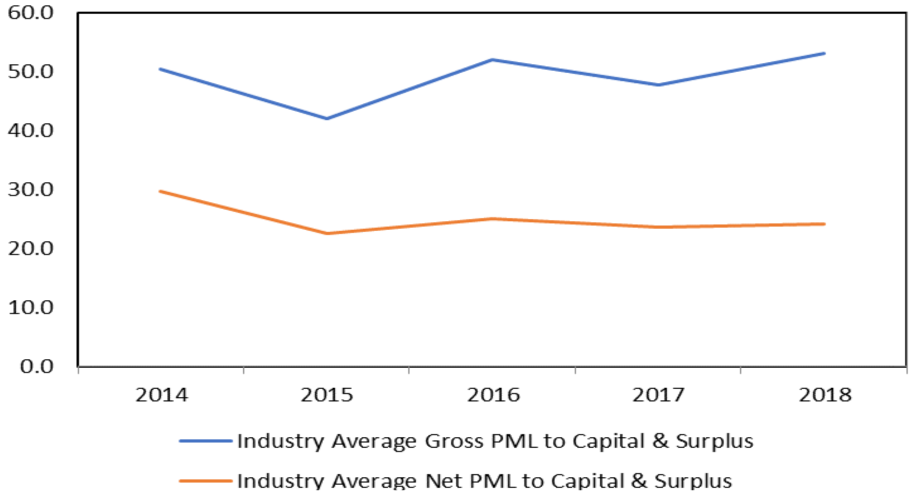
Table 15. PML (In US$ millions)

	2018	2017	2016	2015	2014
Industry Average Gross PML	1,193.9	2,105.5	1,705.7	1,563.0	1,659.0
Industry Average Net PML	513.5	873.9	870.2	842.9	979.7

Source: BMA

The BMA again observes a decrease in gross exposures attenuated by extensive reliance on reinsurance, thus decreasing the net PML.

Figure 12. Gross and Net Industry PML to Capital and Surplus (In percent)



Source: BMA staff calculations.

Table 16. PML Ratios (In percent)

	2018	2017	2016	2015	2014
Industry Average Gross PML to Capital & Surplus	53.0	47.8	52.0	42.0	50.4
Industry Average Net PML to Capital & Surplus	24.2	23.6	25.0	22.6	29.7

Source: BMA

As in the case of legal entities, the BMA reports the average loading factors for groups in Table 17.

Table 17. Loading Factors (In percent)

	2018	2017	2016	2015	2014
Average Loading Factor	8.4	8.3	6.8	7.6	5.9

Source: BMA

The loading factor for groups has increased for the period between 2014 and 2018. For 2018, the average loading factor is 8.4%. Again, a declining loading factor does not necessarily imply less conservatism but the fact that models are incorporating more additional assumptions makes the need for externally imposed assumptions less important.

Table 18 shows how groups estimate loading factors.

Table 18. Loading Factor Estimation Methods (In percent of respondents)

	2018	2017	2016	2015	2014
Determined Analytically	33.3	33.3	35.7	40.0	50.0
Estimated	66.7	66.7	64.3	60.0	50.0

Source: BMA

Groups and legal entities seem to be converging into how loading factors are determined. In 2018, 66.7% of groups estimated their factors non-analytically by relying on expert judgement.

Table 19. AMO Factor Consideration (In percent of respondents)

	2018	2017	2016	2015	2014
Near-Term Frequency	53.3	52.9	58.8	64.7	66.7
Long-Term Frequency	46.7	47.1	41.2	35.3	33.3

Source: BMA

Similar to legal entities but to a lesser extent in 2018, 53.3% of groups used the near-term frequency of the AMO compared to 52.9% in 2017. Model results are converging based on either near-term or long-term frequency of the AMO factor. Therefore, the BMA sees that insurers use both the near-term and the long-term view equally.

The BMA also has statistics on the model vendor licensing and model usage for Bermuda groups.

Table 20. Vendor Model Usage (In percent of respondents)

Model Usage	2018	2017	2016	2015	2014
AIR only	30.8	12.5	18.8	6.3	11.8
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	23.1	37.5	31.3	37.5	41.2
AIR and RMS	46.2	50.0	43.8	56.3	29.4
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	0.0	0.0	0.0	0.0	5.9
AIR, EQECAT and RMS	0.0	0.0	6.3	0.0	11.8
Model Licensing	**2018**	**2017**	**2016**	**2015**	**2014**
AIR only	15.4	11.1	16.7	5.9	11.1
EQECAT only	0.0	0.0	0.0	0.0	0.0
RMS only	23.1	22.2	16.7	17.6	11.1
AIR and RMS	61.5	66.7	61.1	70.6	55.6
AIR and EQECAT	0.0	0.0	0.0	0.0	0.0
EQECAT and RMS	0.0	0.0	0.0	0.0	5.6
AIR, EQECAT and RMS	0.0	0.0	5.6	5.9	16.7

Source: BMA

In groups, AIR usage is now taking the largest share either as standalone or in combination with other models such as RMS. This seems to be similar to legal entities which tend to inherit the vendor models from their parent groups. Again, the BMA notices the market concentrating upon two vendors.

Table 21. Model Frequency Usage (In percent of respondents)

	2018	2017	2016	2015	2014
Ad-hoc	6.7	0.0	0.0	0.0	0.0
Annual	6.7	5.6	5.6	5.9	11.1
Semi-annual	6.7	5.6	5.6	5.9	5.6
Quarterly	53.3	55.6	44.4	35.3	27.8
Monthly	13.3	16.7	27.8	35.3	33.3
Weekly	0.0	0.0	0.0	0.0	0.0
Daily	13.3	11.0	11.1	11.8	11.1
Real time	0.0	5.6	5.6	5.9	11.1

Source: BMA

Accumulation frequency follows similar patterns for groups and legal entities. Most groups perform accumulations quarterly (53.3% of respondents in 2018 compared to 55.6% in 2017.) In 2018, 6.7% of respondents performed annual accumulations and for the first time, ad-hoc model frequency usage was recorded.

Table 22. Model Frequency and Business Units Differences
(In percent of respondents)

	2018	2017	2016	2015	2014
Yes	61.5	64.7	64.7	52.9	56.3
No	38.5	35.3	35.3	47.1	43.8

Source: BMA

When it comes to whether different business units employ different frequencies of accumulations, the picture is reversed for groups compared to legal entities. 61.5% of groups have frequency differences compared to 37.8% of legal entities. The diversity of the groups is much more pronounced than that of legal entities and it is expected that groups will employ different modelling practices across their entities. The BMA also surveyed groups on the use of internal models.

Table 23. Internal Model Usage (In percent of respondents)

	2018	2017	2016	2015	2014
Yes	46.7	44.4	44.4	47.1	38.9
No	53.3	55.6	55.6	52.9	61.1

Source: BMA

As of 2018, 53.3% of groups do not use internally developed models, while 46.7% do. A similar picture is evident for legal entities.

Table 24. External Reinsurance Model Usage (In percent of respondents)

	2018	2017	2016	2015	2014
The company has minimal catastrophe exposure protection and as such gross is effectively net.	6.7	6.3	0.0	0.0	0.0
The accumulations are calculated on a gross basis with reinsurance protections calculated approximately outside the system.	0.0	0.0	0.0	0.0	0.0
The accumulations are calculated on a gross basis with reinsurance protections calculated explicitly outside the system.	6.7	0.0	5.6	5.9	5.6
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for some types of protection within the system.	20.0	31.3	22.2	29.4	33.3
The accumulations are calculated on a gross basis with the effect of reinsurance protections calculated explicitly for each type of protection within the system.	66.7	62.5	72.2	64.7	61.1

Source: BMA

On the group level, groups use models for their reinsurance treaties when they are cedents. In 2018, 6.7% of groups did not have external reinsurance treaties due to minimal catastrophe exposure. 66.7% of groups (compared to 46.7% of legal entities) modelled explicitly for all treaties within the Cat model.

Appendix I – Underwriting Loss Scenarios Guideline

1. Northeast Hurricane

The insurer should assume a US$81.0 billion industry property loss, including consideration of demand surge and storm surge from a northeast hurricane making landfall in New York State. The hurricane also generates significant loss in the States of New Jersey, Connecticut, Massachusetts, Rhode Island and Pennsylvania.

In assessing its potential exposures, the insurer should consider exposures in:

a. Both main and small ports that fall within the footprint of the event
b. Both main international and small airports that fall within the footprint of the event

The insurer should assume the following components of the loss:

a. Residential property US$49.50 billion
b. Commercial property US$31.50 billion
c. Auto US$1.75 billion
d. Marine US$0.75 billion

The insurer should consider all other lines of business that would be affected by the event.

Exclusion: The insurer should exclude contingent business interruption losses from this event.

2. Carolinas Hurricane

The insurer should assume a US$39.0 billion industry property loss, including consideration of demand surge and storm surge from a hurricane making landfall in South Carolina.

In assessing its potential exposures, the insurer should consider exposures in:

a. Both main and small ports that fall within the footprint of the event
b. Both main international and small airports that fall within the footprint of the event

The insurer should assume the following components of the loss:

a. Residential property US$26.0 billion
b. Commercial property US$13.0 billion
c. Auto US$0.53 billion
d. Marine US$0.27 billion

The insurer should consider all other lines of business that would be affected by the event.

Exclusion: The insurer should exclude contingent business interruption losses from this event.

3. Miami-Dade Hurricane

The insurer should assume a US$131.0 billion industry property loss, including consideration of demand surge and storm surge from a Florida hurricane making landfall in Miami-Dade County.

The insurer should assume the following components of the loss:

a. Residential property US$66.0 billion
b. Commercial property US$65.0 billion
c. Auto US$2.25 billion
d. Marine US$1.0 billion

The insurer should consider all other lines of business that would be affected by the event.

Exclusion: The insurer should exclude contingent business interruption losses from this event.

4. Pinellas Hurricane

The insurer should assume a US$134.0 billion industry property loss, including consideration of demand surge and storm surge from a Florida hurricane making landfall in Pinellas County.

The insurer should assume the following components of the loss:

a. Residential property US$94.5 billion
b. Commercial property US$39.5 billion
c. Auto US$2.0 billion
d. Marine US$1.0 billion

The insurer should consider all other lines of business that would be affected by the event.

Exclusion: The insurer should exclude contingent business interruption losses from this event.

5. Gulf Windstorm (onshore)

The insurer should assume a US$111.0 billion industry property loss, including consideration of demand surge and storm surge from a Gulf of Mexico hurricane making landfall.

In assessing its potential exposures, the insurer should consider exposures in:

a. Both main and small ports that fall within the footprint of the event

b. Both main international and small airports that fall within the footprint of the event

The insurer should assume the following components of the loss:

a. Residential property US$67.5 billion

b. Commercial property US$43.5 billion

c. Auto US$1.0 billion

d. Marine US$1.0 billion

The insurer should consider all other lines of business that would be affected by the event.

Exclusion: The insurer should exclude contingent business interruption losses from this event.

6. Los Angeles Earthquake

The insurer should assume a US$78.0 billion industry property (shake and fire following) loss, including consideration of demand surge.

The insurer should assume the following components of the loss:

a. Residential property US$36.0 billion

b. Commercial property US$42.0 billion

c. Workers Compensation US$5.5 billion

d. Marine US$2.25 billion

e. Personal Accident US$1.0 billion

f. Auto US$1.0 billion

The insurer should consider all other lines of business that would be affected by the event. For Personal Accident and Workers Compensation losses, the insurer should assume that there will be 2,000 deaths and 20,000 injuries as a result of the earthquake and that 50% of those injured will have Personal Accident cover.

Exclusion: The insurer should exclude contingent business interruption losses from this event.

7. San Francisco Earthquake

The insurer should assume a US$80.0 billion industry property (shake and fire following) loss, including consideration of demand surge.

The insurer should assume the following components of the loss:

a. Residential property US$40.0 billion
b. Commercial property US$40.0 billion
c. Workers Compensation US$5.5 billion
d. Marine US$2.25 billion
e. Personal Accident US$1.0 billion
f. Auto US$1.0 billion

The insurer should consider all other lines of business that would be affected by the event. For Personal Accident and Workers Compensation losses, the insurer should assume that there will be 2,000 deaths and 20,000 injuries as a result of the earthquake and that 50% of those injured will have Personal Accident cover.

Exclusion: The insurer should exclude contingent business interruption losses from this event.

8. New Madrid Earthquake

The insurer should assume a US$44.0 billion industry property (shake and fire following) loss, including consideration of demand surge.

The insurer should assume the following components of the loss:

a. Residential property US$30.5 billion
b. Commercial property US$13.5 billion
c. Workers Compensation US$2.5 billion
d. Marine US$1.5 billion
e. Personal Accident US$0.5 billion
f. Auto US$0.5 billion

The insurer should consider all other lines of business that would be affected by the event. For Personal Accident and Workers Compensation losses, the insurer should assume that there will be 1,000 deaths and 10,000 injuries as a result of the earthquake and that 50% of those injured will have Personal Accident cover.

For business interruption, the insurer should assume that the overland transport systems are severely damaged and business impacted, leading to significant business interruption exposure for a period of 30 days. This is restricted to the inner zone of maximum earthquake intensities.

9. European Windstorm

This event is based upon a low-pressure track originating in the North Atlantic basin resulting in an intense windstorm with maximum/peak gust wind speeds in excess of 20 metres per second (45 mph or 39 knots). The strongest winds occur to the south of the storm track, resulting in a broad swath of damage across southern England, northern France, Belgium, Netherlands, Germany and Denmark. The insurer should assume a €24.0 billion industry property loss.

The insurer should assume the following components of the loss:

a. Residential property €16.0 billion
b. Commercial property €6.5 billion
c. Agricultural €1.5 billion
d. Auto €0.75 billion
e. Marine €0.4 billion

The insurer should consider all other lines of business that would be affected by the event. The loss amount should be reported in Bermuda equivalent as noted under the general instructions above.

10. Japanese Typhoon

This event is based on the Isewan ('Vera') Typhoon event of 1959. The insurer should assume a ¥1.7 trillion industry property loss.

In assessing its potential exposures, the insurer should consider exposures in:

a. Both main and small ports that fall within the footprint of the event
b. Both main international and domestic airports, as well as small airports that fall within the footprint of the event

The insurer should assume the following components of the loss:

a. Residential property ¥750.0 billion
b. Commercial property ¥950.0 billion
c. Marine ¥50.0 billion

The insurer should consider all other lines of business that would be affected by the event. The loss amount should be reported in Bermuda equivalent as noted under the general instructions above.

11. Japanese Earthquake

This event is based on the Great Kanto Earthquake of 1923. The insurer should assume a ¥8 trillion insured industry property loss from this event.

In assessing its potential exposures, the insurer should consider exposures in:

a. Both main ports and small ports that fall within the footprint of the event
b. Both main international and domestic airports, as well as smaller airports that fall within the footprint of the event

The insurer should assume the following components of the loss:

a. Residential property ¥2.5 trillion
b. Commercial property ¥5.5 trillion
c. Marine ¥150.0 billion
d. Personal Accident ¥50.0 billion

The insurer should consider all other lines of business that would be affected by the event. The loss amount should be reported in Bermuda equivalent as noted under the general instructions above.

For Personal Accident losses, the insurer should assume that there will be 2,000 deaths and 20,000 injuries as a result of the earthquake and that 50% of those injured will have Personal Accident cover. Liability exposures should also be considered.

For business interruption, the insurer should assume that the overland transport systems are severely damaged and business impacted, leading to significant business interruption exposure for a period of 60 days. This is restricted to the inner zone of maximum earthquake intensities.

12. Aviation Collision

The insurer should assume a collision between two aircrafts over a major city, anywhere in the world, using the insurer's or group's two largest airline exposures.

The insurer/group should assume a total industry loss of up to US$4.0 billion, comprising up to US$2 billion per airline and any balance up to US$1.0 billion from a major product manufacturer's product liability policy(ies), and/or traffic control liability policy(ies), where applicable.

Consideration should be given to other exposures on the ground and all key assumptions should be stated clearly.

The information should include:

a. The city over which the collision occurs;

b. The airlines involved in the collision;

c. Each airline’s policy limits and attachment points for each impacted insurance contract (policy);

d. The maximum hull value per aircraft involved;

e. The maximum liability value per aircraft involved;

f. The name of each applicable product manufacturer and the applicable contract;

g. (Policy) limits and attachment points (deductibles); and

h. The name of each applicable traffic control authority and the applicable contract (policy) limits and attachment points (deductibles).

The insurer is to select one scenario from below which would represent its largest expected loss.

13. Marine Collision in Prince William Sound

A fully-laden tanker calling at Prince William Sound is involved in a collision with a cruise vessel carrying 500 passengers and 200 staff, and crew. The incident involves the tanker spilling its cargo and loss of lives aboard both vessels.

Assume 70% tanker owner and 30% cruise vessel apportionment of negligence and that the collision occurs in US waters.

Assume that the cost to the tanker and cruise vessel owners of the oil pollution is US$2 billion. This would lead to oil pollution recoveries on the International Group of P&I Associates’ General Excess of Loss Reinsurance Programme of US$1 billion from the tanker owner and US$0.55 billion from the cruise owner.

Assume: 1.) 125 fatalities with an average compensation of US$1.5 million for each fatality; 2.) 125 persons with serious injuries with an average compensation of US$2.5 million for each person; and 3.) 250 persons with minor injuries with an average compensation of US$0.5 million for each person.

14. Major Cruise Vessel Incident

A US-owned cruise vessel is sunk or severely damaged with attendant loss of life, bodily injury, trauma and loss of possessions. The claims were to be heard in a Florida court.

Assume: 1.) 500 passenger fatalities with an average compensation of US$2.0 million; 2.) 1,500 injured persons with an average compensation of US$1.0 million; and 3.) assume an additional Protection and Indemnity loss of US$500.0 million to cover costs such as removal of wreck and loss of life and injury to crew.

15. US Oil Spill

The insurer is to assume an oil spill releasing at least five million barrels of crude oil into the sea. In addition to property, the insurer is also to consider in its assumptions the following coverage: business interruption, workers compensation, directors and officers, comprehensive general liability, environmental/pollution liability and other relevant exposures. Assume: 1.) 15 fatalities; 2.) 20 persons with serious injuries; and 3.) an estimated insured industry loss of US$2.1 billion.

16. US Tornadoes

The insurer is to assume an EF5 multiple-vortex tornado touching down in several heavily populated cities and towns in the South, and Mid-West regions of the US. Assume: 1.) 125 fatalities; 2.) 600 persons with mild-to-serious injuries; 3.) 20,000 people displaced and left homeless; 4.) 50% to 75% of the 10,000 buildings (commercial, residential and other outbuildings included) have been damaged by the tornado's wind field; and 5.) an estimated insured industry loss of US$5.0 billion. Consideration should be given to the cumulative effect of such a large number of total losses.

17. Australian Flooding

The insurer is to assume heavy rainfalls across major cities in Australia causing severe flooding and/or repeated flash flooding. Assume: 1.) 40 fatalities; 2.) 200,000 people affected and displaced; 3.) 190 persons with mild-to-serious injuries; 4.) 70% of the 8,500 homes and businesses that are flooded could not be recovered; 5.) suspension of all agricultural and mining operations; and 6.) an estimated insured industry loss of US$2.2 billion. The insurer is to include landslides following flood.

18. Australian Wildfires

The insurer is to assume a series of bushfires during extreme bushfire-weather conditions across Australian states affecting populated areas. Assume: 1.) 180 fatalities; 2.) 500 people with mild-to-serious injuries; 3.) displacement of 7,600 people; and 4.) destruction of over 5,000 buildings (commercial, residential and other outbuildings included). Assume an estimated insured industry loss of US$1.3 billion.

Appendix II - Underwriting Loss Impact Analysis

Table 25. Impact of Names Perils (In US$)

Standardised Cat Peril	Gross Loss Impact	Ceded Loss Impact	Net Loss Impact	Gross Loss Impact Ceded (in Percent)
Northeast Hurricane	22,643,047,606	15,678,673,922	6,964,373,684	69
Carolinas Hurricane	12,742,271,731	9,584,102,376	3,158,169,355	75
Miami-Dade Hurricane	20,637,964,280	16,168,596,636	4,469,367,644	78
Pinellas Hurricane	20,899,953,133	15,287,514,655	5,612,438,477	73
Gulf Windstorm (onshore)	26,444,768,780	18,741,246,757	7,703,522,023	71
Los Angeles Earthquake	18,799,104,402	13,602,393,728	5,196,710,674	72
San Francisco Earthquake	20,640,136,940	14,702,138,356	5,937,998,583	71
New Madrid (NM) RDS	5,461,222,371	3,296,272,483	2,164,949,888	60
European Windstorm	9,979,319,260	5,734,647,892	4,244,671,368	57
Japanese Typhoon	4,094,615,606	2,294,977,843	1,799,637,763	56
Japanese Earthquake	11,866,751,383	7,423,960,702	4,442,790,682	63
Aviation Collision	3,182,475,244	2,223,243,825	959,231,419	70
Marine Collision in Prince William	2,919,478,269	1,865,038,285	1,054,439,984	64
Major Cruise Vessel Incident	2,673,074,183	1,513,362,599	1,159,711,584	57
US Oil Spill	3,017,076,482	1,886,581,579	1,130,494,904	63
US Tornadoes	2,126,199,722	1,123,916,225	1,002,283,497	53
Australian Flooding	1,943,398,066	993,594,114	949,803,952	51
Australian Wildfires	934,423,241	403,932,467	530,490,774	43
Total	**191,005,280,699**	**132,524,194,444**	**58,481,086,255**	**69**

Source: BMA staff calculations.

Table 26. Bermuda's Estimated Loss Impact Share Using Lloyd's Developed Realistic Disaster Scenarios (In US$)

Standardised Cat Peril	Estimated Total Industry Loss	Estimated Bermuda Share (Gross)	Bermuda Share (in percent)
Gulf Windstorm (onshore)	111,000,000,000	26,444,768,780	24
Northeast Hurricane	81,000,000,000	22,643,047,606	28
San Francisco Earthquake	80,000,000,000	20,640,136,940	26
Pinellas Hurricane	134,000,000,000	20,899,953,133	16
Los Angeles Earthquake	78,000,000,000	20,640,136,940	26
Miami-Dade Hurricane	131,000,000,000	20,637,964,280	16
Carolinas Hurricane	39,000,000,000	12,742,271,731	33
Japanese Earthquake	72,950,521,218	11,866,751,383	16
European Windstorm	27,555,484,115	9,979,319,260	36
New Madrid (NM) RDS	44,000,000,000	5,461,222,371	12
Japanese Typhoon	15,501,985,759	4,094,615,606	26
Total	**814,007,991,092**	**176,050,188,030**	**22**

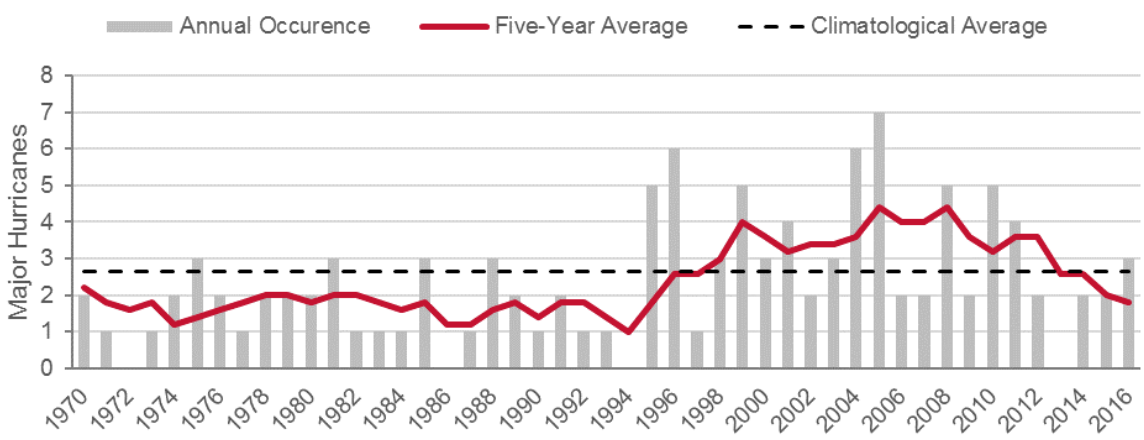
Source: BMA staff calculations.

Notes: The data provided in these Tables 25 and 26 above is for class 3B and 4 insurers only and was extracted from the CSR annual filings. The CSR filings for a handful of insurers that fall within these classes were still under review when this report was put together and that data was not included in this report. Therefore, one should view the results as being reflective of a segment of the industry and not the total potential total impact. Total Estimated Industry Loss numbers were taken from Lloyd's Realistic Disaster Scenarios report - January 2017.

Appendix III - Atlantic Multi-Decadal Oscillation (AMO)

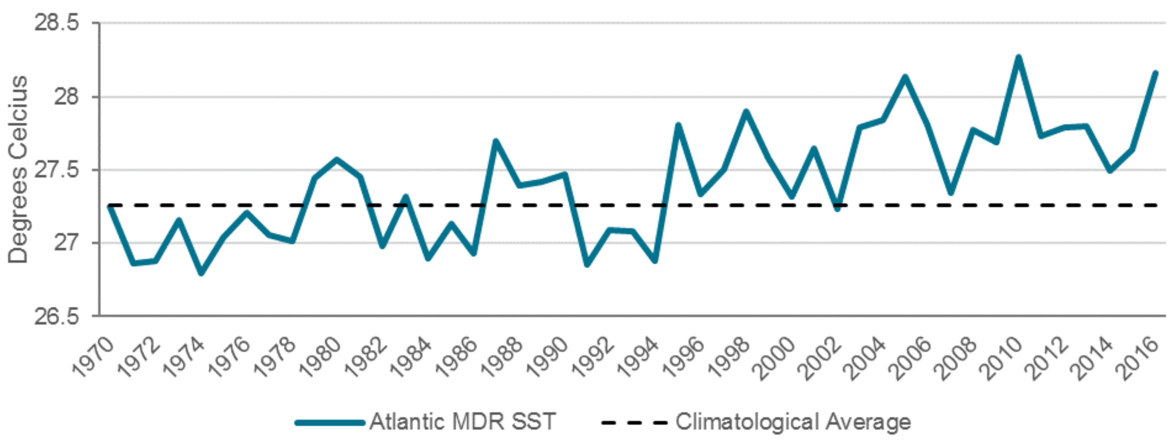
The AMO is a switch in many catastrophe risk models and is used as a predictor of future hurricane activity. As a predictor, it uses sea surface temperatures (SST) in order to estimate hurricane activities since warm water is one of the fuels of a hurricane. In past years, SSTs have been rising but the trend of the last four years shows hurricane numbers are declining. This is shown in figures 13 and 14.

Figure 13. Number of Hurricanes



Source: RMS

Figure 14. Sea Surface Temperature



Source: RMS

Assuming a four to five year near term trend, catastrophe models would show the number of hurricanes is expected to decline, while a longer term view over the past 20 years could indicate this is a temporary phenomenon. According to RMS, for the first time since its introduction, the RMS medium-term rate forecast (MTRof) has dipped slightly below the long-term rate. For the US as a whole, the new 2017-2021 medium-term rate forecast MTRof hurricane landfall frequency is now one percent below the long-term rate for Category 1–5 storms and six percent for major hurricanes (Category 3–5 storms). Therefore, for conservatism, more companies are switching to the long-term view.

Appendix IV - The Bermuda Framework for Catastrophe Risk Supervision

As one of the largest property catastrophe reinsurance centres in the world, Bermuda has a comprehensive framework of catastrophe risk supervision. The supervisory framework rests on three pillars:

1) Catastrophe capital charge in prudential filings
2) Supervisory assessment of prudential filings
3) Public dissemination of catastrophe risk data on an aggregated basis

The first pillar includes the capital charge for catastrophe risk that the insurer has to hold as part of its solvency capital requirement. The capital charge is a combination of a BMA in-house factor plus an insurer-specific factor which is supplied from the insurer. Once the capital charge for catastrophe risk has been calculated, it is further blended in the overall capital charge allowing for diversification.

Within the prudential filings, there are schedules which comprise the catastrophe risk return. The catastrophe risk return contains a questionnaire of qualitative information on the process of catastrophe risk modelling, such as the type of models and the frequency of the modelling process. In addition to the qualitative information, the insurer provides quantitative information such as AALs, PMLs and EP curves for major perils. In the second pillar, the supervisory process validates the prudential filings. Since part of the calibration of the catastrophe risk capital charge hinges on the assumptions of the insurer, the BMA validates the results with a set of tools.

The catastrophe risk return is one source of cross validation. Another source of validation is the stochastic scenario generator that has been developed in-house by the BMA. This model runs on a spreadsheet and performs Monte Carlo simulations on the balance sheets of individual insurers by shocking assets and liabilities, and producing income statements which are used to estimate probabilities of insolvency, as well as financial results based on different return periods.

Finally, the BMA prescribes a set of stress tests based on the Lloyd's Realistic Disaster Scenarios (RDS) which are reported on the prudential filings. The insurer has to show the capital position before and after the relevant RDSs, while the insurer should provide its own scenarios should the RDSs be insufficient for the type of exposures of its portfolio. The insurer is also obligated to provide a reverse stress test that will render its business non-viable.

Regarding the third pillar, the BMA publishes aggregated data of the catastrophe risk returns for information purposes of the market, as well as for its macroprudential surveillance framework for the insurance sector.