North Atlantic Hurricane Models—U.S. and Canada
RiskLink® 17.0 and 17.0.1 Non-Proprietary Information Related to ASOP No. 38

May 25, 2018

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Overview

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This document addresses only the hurricane wind peril for the North American mainland. A separate document provides details for Hawaii. The RMS North Atlantic Hurricane Models software includes a storm surge component that may be selected by the user. A separate document has been prepared for the storm surge peril.

Full references cited in this document can be found in the References section of this document.

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Introduction

This document has been prepared by RMS to provide assistance to actuaries and others who use the model and/or its results but believe parts of the model are outside their areas of expertise and is non-proprietary. The document follows the structure and numbering of ASOP No. 38 (Doc. No. 155), which is available from the Professionalism section of the American Academy of Actuaries website.

RiskLink 17.0 (Build 1825) and RiskLink 17.0.1 (Build 1825) have been found acceptable by the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM). Substantial portions of the information RMS provided to the FCHLPM are responsive to the ASOP No. 38 requirements. Where this is the case, the reader can refer to the RMS submission to the FCHLPM document for the relevant information.

The RMS submission document, the FCHLPM letters of acceptability, and the FCHLPM standards can be found at https://www.sbafla.com/method/.

Wind Perils

The actuary may need to distinguish among various wind-related causes of loss. RMS has developed models for winter storm, severe convective storm, and hurricane/storm surge. The following definitions are provided to assist in delineating historical and projected losses by peril.

Hurricane

Hurricanes are a class of tropical cyclones that occur in the Atlantic, the Eastern Pacific, and the Central Pacific basins; tropical cyclones that originate in other regions of the world are referred to as typhoons and cyclones. All tropical cyclones are intense, cyclonic wind systems that develop over tropical waters. Tropical cyclones develop from tropical depressions—which are non-frontal closed-circulation regions of localized low-pressure—in the presence of favorable environmental conditions, such as low wind shear and warm sea-surface temperatures (SSTs). The process of cyclonic atmospheric depression generally starts in regions where the SSTs are greater than 80° F (26.5° C).

North Atlantic tropical cyclones often develop from low-pressure atmospheric disturbances—known as easterly waves—that form near the coast of West Africa and are carried westward across the Atlantic Ocean by the prevailing atmospheric flow. In addition, hurricanes can also form in the Caribbean Sea, the subtropical and tropical northern Atlantic Ocean, and the Gulf of Mexico. The regions in which hurricanes can form are collectively referred to as the Atlantic Basin.

The structure of a hurricane is distinguished by the eye, which is surrounded by high walls of thick clouds and rotating winds. Hurricane winds normally increase in velocity toward the center of the storm. However, wind velocity is rarely symmetrical around the storm track. Generally, for the tropical cyclones of the Northern Hemisphere in which the circulation is rotating counter-clockwise, the right side of the storm (as viewed in the same direction as the hurricane's forward motion) experiences higher velocity winds than the left side. In addition to intense winds, hurricanes often create heavy to torrential precipitation and internal, localized wind vortices resembling tornadoes, which may locally affect the extent of resulting damage. Hurricanes typically range from 100 to 700 miles (160 to 1,100 km) in diameter. The farther north a hurricane moves, the more likely it is to encounter the mid-latitude jet stream. When this occurs, the system becomes more asymmetric, with strong winds largely on the right-hand-side of the system, and covering a broader region than in a hurricane. These systems are undergoing extratropical transition and are known as transitioning storms.

When hurricanes make landfall, they can cause loss of life, extensive damage to buildings, their contents, and other infrastructure, as well as crop and forest destruction and water contamination. In addition to wind- and rain-related damage, hurricanes also produce effects known as storm surge. Storm surge, covered in a separate document, refers to the rising ocean water levels along coastlines affected by a hurricane that can cause widespread flooding.

The Atlantic and Gulf coasts of the United States are exposed to hurricane risk from June to November. The southern coastal states tend to be impacted by more frequent and intense hurricanes than the northeastern states. The most active months for hurricanes are August to October, when the Atlantic-Caribbean Basin experiences its peak sea-surface temperatures, fueling storm formation. The North Atlantic Hurricane Models stochastic event set includes losses from tropical cyclones that make landfall or bypass with an intensity of Saffir-Simpson Category 1 or greater (i.e., Vmax[1] greater than or equal to 74 mph) in at least one modeled region. RMS determines the intensity of a storm by checking the Vmax at the 6-hourly track point before landfall, each track point over land, and the 6-hourly track point occurring after moving back over water, if applicable. If none of these track points has an intensity of Category 1 or greater, the event is not included in the model.

The stochastic event set captures events that are transitioning or have transitioned from a tropical cyclone to an extratropical cyclone, except for the states of Alabama, Florida, Georgia, and Mississippi. Standards set by the FCHLPM require that modeled losses be calculated from tropical cyclones. Thus, in order to meet these standards, RMS has chosen to remove all events that make landfall or by-pass any of the four states as an extratropical storm. It is important to note that if an event makes landfall or bypasses as an extratropical storm outside of these four states or becomes extratropical after landfall, the event is maintained in the event set.

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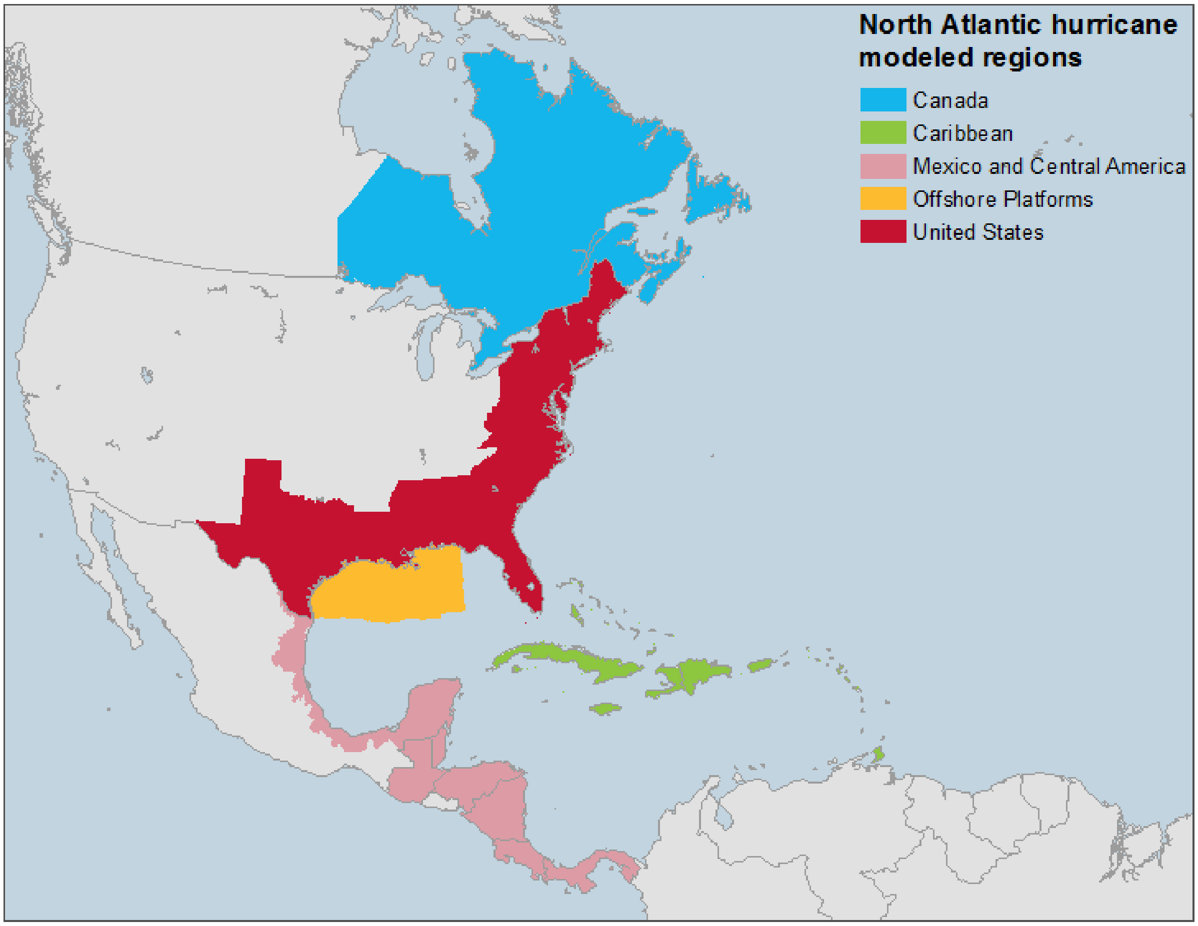
[1] Vmax is the maximum 10 meter 1-minute mean wind speed calculated over open water terrain.

Figure 1: North Atlantic Hurricane Models Coverage



Winter Storm

Winter storms in the U.S. and Canada are extratropical cyclones that can produce various types and combinations of damage from the perils of snow, ice (or freezing rain), freeze (extremely cold temperatures), and wind. The combination and intensity of the winter storm perils at a particular location are governed by the location of storm origin, the region impacted, and the large-scale weather pattern. Winter storms can be generally characterized as follows:

- Storms that develop over the Pacific Ocean impact the West Coast, from British Columbia through the Pacific Northwest and California. These storm systems bring high wind speeds along the coast, and snowfall to the interior and in the higher elevations.
- Alberta-clipper storms develop as maritime Pacific air masses move over the Canadian Rocky Mountains and interact with the cold polar air in the Canadian prairies. These fast-moving storm systems can bring a combination of winter storm perils, dependent upon synoptic conditions, to the central and eastern provinces of Canada, the Great Lakes region, and the northeast United States. Typically, these storm systems are followed by cold arctic air that is responsible for freeze-related losses.

- Winter storms that develop east of the Rockies and travel to the east and northeast rapidly intensify and bring a combination of winter storm perils to the eastern half of the U.S. and Canada, depending on large-scale weather conditions.
- Nor’easter storm systems have the same genesis location but take a more southerly track that allows these storms to rapidly intensify over the relatively warm Gulf Stream in the Atlantic Ocean. As these storm systems intensify, extreme snowfall, high winds, and occasionally ice can be observed from the East Coast of the U.S. through Quebec and the Atlantic Provinces of Canada.
- Lake-effect snowstorms are generally caused in the wake of a storm system as cold air from Canada travels over the relatively warm waters of the Great Lakes. If the instability is great enough and temperatures are cold enough in the atmosphere, clouds and snow can occur on the windward side of the Great Lakes.

Severe Convective Storm

The RMS U.S. and Canada Severe Convective Storm Models include insured property damage from tornado, hail, straight-line wind events, and lightning. Severe convective storms are separate weather events from hurricanes, and do not include tornadoes generated within or by tropical cyclonic events.

A severe convective storm is defined by the Storm Prediction Center as any vertically developed thunderstorm that produces hail 1 inch (25 millimeters) in diameter or larger, any tornado, and/or a straight-line wind gust of 58 mph (50 knots) or greater. These storms can occur in all states and provinces in the U.S. and Canada and have been recorded to occur during all months of the year, although there is generally strong seasonality exhibited. The United States has the most active severe convective storm climatology in the world. Canada ranks as the second most active.

Hail is an aggregate term in reference to one or more ice particles, or hailstones of pea size (approximately 5 millimeters in diameter) or larger that are often produced by vertically developing clouds. The damage potential of a given hailstone is related to its size, shape, and density. The portion of a vertically developing cloud that produces hail can span widths ranging from less than 1to greater than 20 miles (32 kilometers). As these clouds move, areas of hailfall are formed that are continuous in space and time. Each of these areas, referred to as hailstreaks, have unique characteristics such as hail size and streak area. Each hailstreak generally has a width of about 1 mile (1.6 kilometers) and a length of about 6 miles (about10 kilometers). The damage potential of individual hailstones can vary over the hailstreak area, yielding variability in damage potential along and across a given streak. The largest recorded hailstone on record fell on July 23, 2010, in the town of Vivian, South Dakota, and measured 8 inches (20 centimeters) in diameter.

A tornado is a rotating column of air, extending upward from the earth’s surface to the base of a vertically developing cloud that is intense enough at the surface to cause damage. A tornado may last for less than a minute or be sustained for an hour or more, yielding path lengths ranging between a few yards to over 100 miles (160 kilometers). The wind field associated with a tornado, and therefore its damage potential, generally decreases in strength sharply with increasing distance from its immediate path. In addition, a given tornado may weaken or intensify with time, yielding variability in damage along the length of the tornado’s path. Due to the very intense and localized nature of tornadoes, the exact wind speed cannot generally be measured directly. For this reason, the Fujita and Enhanced Fujita (EF) scales were developed to estimate the approximate wind speed range produced by a tornado, using post-event damage survey studies. Both scales use prescribed engineering analysis to determine the force of wind as it relates to the amount of expected damage to a structure, based on attributes such as construction type. The Fujita Scale was developed in 1971. The Enhanced Fujita Scale was first used in the United States in February 2007, and in Canada in April 2013, and builds upon the science used for the original scale. Both the Fujita and Enhanced Fujita Scales are used in the severe convective storm model. This document uses the symbol “F” to describe intensity associated with the Fujita Scale, and “EF” to describe the Enhanced Fujita Scale. For example, an “F4” tornado refers to a tornado with an intensity of “4” on the Fujita scale.

Straight-line winds are defined as any convectively driven winds that occur from a thunderstorm aside from the more well-known tornadoes. These winds include downbursts, outflows, microbursts, and even larger more organized storms called derechos. Derechos can be hundreds of miles long, and are driven by clusters of thunderstorms that produce powerful downdrafts, causing a nearly continuous field of high winds that can last for several hours. For straight-line winds to be deemed “severe” by the National Weather Service (NWS), a peak gust of 58 mph (50 knots) or greater must be recorded. Damaging convective winds are typically between 60 and 80 mph (100 and 130 km per hour / 52 to 70 knots) peak gust, but have been recorded to exceed 100 mph (87 knots) in rare cases. These winds are one of the most commonly recorded perils from severe convective storm outbreaks, and significantly contribute to average annualized losses in the U.S. and Canada.

Lightning also contributes to insured losses from convective storms. Damage to exterior elements, such as roof cover, burn/singe marks, as well as electrical power surges that cause loss to expensive electrical equipment, is responsible for the bulk of the loss from this peril. These losses are highly correlated to the hail hazard and are dominated by losses to contents. Lightning is an implicit source of loss in this model.

Appropriate Reliance on Experts (ASOP Section 3.2)

Experts in Applicable Fields (ASOP Sections 3.2.a and 3.2.b)

See the RMS submission to the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM), Standards G-2.2 and G-2.3 and Appendices B, C, and D of that document for this information.

These are not intended as an exhaustive listing of experts in all applicable or related fields of expertise, but are provided to assist actuaries in determining the level of reliance on experts that is appropriate concerning those aspects of RMS models that are outside the actuary's own area of expertise.

The external, independent experts reviewed specific aspects of RiskLink 11.0. Those aspects have not changed.

Known Significant Differences of Opinion (ASOP Section 3.2.b)

Applicability of Long-Term Historical Hurricane Frequency Rates

RMS probabilistic models produce stochastic events, each of which is associated with an event rate, which defines the annual probability of that event occurring. The North Atlantic Hurricane Models provide the following event rates:

- Medium-Term Rates, representing the five-year, medium-term outlook of North Atlantic hurricane activity
- Long-Term Rates, representing the event rates that are consistent with the long-term historical average

There is consensus within the scientific community that hurricane activity levels are not stationary, i.e., they exhibit cycles of alternating high and low activity periods. However, there are differences of opinion on the cause(s), predictive value, and applicability to various financial products of these fluctuations. The actuary should evaluate the purpose for which the model output is produced to decide the most appropriate setting(s). Some jurisdictions, as well as some rating agencies, have prescribed event rate selections.

Model Standards (ASOP Section 3.2.c)

RiskLink 17.0 (Build 1825) was found acceptable by the FCHLPM on May 12, 2017. RiskLink 17.0.1 (Build 1825) was found functionally equivalent and acceptable for projecting hurricane loss costs and probable maximum loss levels for residential rate filings in Florida on January 9, 2018. The RiskLink 17.0.1 (Build 1825) documentation submitted for acceptability can be found at https://www.sbafla.com/method/ModelerSubmissions/CurrentYear2015ModelerSubmissions.aspx. All standards in the FCHLPM's 2015 Report of Activities were met. The model settings used in the certified model can be found in Table 17 of the RMS submission to the FCHLPM.

Understanding the Models (ASOP Section 3.3)

Changes from Previous RiskLink Versions

Introduction

As part of an ongoing commitment to core model development, leadership, and quality, RMS is updating and enhancing its North Atlantic Hurricane Models in RiskLink and RiskBrowser® 17.0.

In line with the RMS resilient risk management strategy, the updates focus on ensuring that the view of hurricane risk remains up to date. RMS is therefore updating the North Atlantic Hurricane Models to reflect the latest hurricane hazard and building vulnerability research. Version 17.0 also incorporates comprehensive, proprietary research focusing on improving vulnerability modeling in key regions outside of the U.S. mainland, including Hawaii, the Caribbean, Mexico, and Central America. The release also enables RMS to continue to comply with the standards of the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM).

Overall, in the U.S. mainland, losses based on the RMS reference view of risk, i.e. using medium-term rates (MTRs) and post-event loss amplification, decrease due to the version 17.0 changes, although some locations may see increases in loss depending on vulnerability updates. Texas, the Gulf, and Florida exhibit the largest decreases, between 15 and 25 percent, regions along the U.S. East Coast exhibit more moderate decreases, between 5 and 10 percent. However, individual portfolios, particularly those affected by vulnerability updates, may produce loss changes outside these ranges. Losses based on the long-term view of risk, rather than the medium-term view, also change due to an update of the (long-term rate) LTR rate set with the June 2015 vintage of the North Atlantic HURDAT2 dataset—the official historical record of hurricane activity provided by the National Hurricane Center (NHC). The revisions to historical events between 1946 and 1955, based on new research, have the biggest impact on the LTR view of risk.

As in the U.S. mainland, the medium-term rate (MTR) forecast dominates loss changes observed in Canada. The MTR forecast in Canada increases slightly and remains above the LTR, driven by the forecast's regionalization. The version 17.0 update typically produces portfolio loss increases of up to 6 percent in Canada, although some portfolios may be more sensitive to vulnerability updates.

The following describes which components have been updated in this release, the nature of each update, and the rationale behind each component update, along with information on the impact of the changes.

The Latest Science and Data on Hurricane Event Rates

Version 17.0 keeps the RMS view of hurricane risk up-to-date by incorporating the most recent available research, science, and data on activity rates and historical events. RMS provides two sets of hurricane activity rate sets that clients can use to explore the impact of activity rate variability on loss. The long-term rates (LTRs) reflect the long-term historical record, whereas the MTRs incorporate a best estimate five-year forecast of near-term future activity. Version 17.0 updates both sets of activity rates for the Atlantic Basin.

The changes to the Atlantic Basin LTR rate set are primarily influenced by updates within the June 2015 vintage of the HURDAT2 dataset—the official historical record of hurricane activity provided by the National Hurricane Center (NHC). The NHC revisions to historical events between 1946 and 1955, based on new research, have the biggest impact on the LTR view of risk.

The MTR forecast now reflects hurricane activity through the 2016 Atlantic hurricane season, the latest sea surface temperature (SST) forecasts, and revisions to historical events between 1951 and 1960.

These enhancements enable clients to continue to manage their hurricane risk with confidence, based on the latest information on hurricane landfalling activity and trends.

Enhanced Differentiation of Risk

Version 17.0 enhances vulnerability modeling for several regions and lines of business. The following data sources underpin these vulnerability enhancements:

- New claims data from recent events, such as Superstorm Sandy (2012) and Hurricane Irene (2011), and reanalysis of existing claims data from past hurricane seasons
- Published research from the Insurance Institute for Business and Home Safety (IBHS)
- Thorough review of recent and historical building codes and regulations in Hawaii, the Caribbean, Mexico, and Central America
- Observations from recent RMS reconnaissance trips, including a three-week visit to key regions in the Caribbean and a visit to the Bahamas following Hurricane Matthew (2016)

The key vulnerability changes include:

- **Recalibration of selected residential lines of business**, focused on multi-family dwellings and manufactured homes, based on claims data analysis, IBHS research, and RMS proprietary research
- **Enhancements to primary characteristic relationships**, in all onshore modeled regions, introducing newly-supported masonry construction classes and expanding square footage differentiation for low-rise commercial buildings
- **Recalibration of regional vulnerability functions and building inventory data in key regions outside the U.S. mainland**, based on RMS reconnaissance, comprehensive building code and stock research, and new claims data
- **Changes for various lines of business**, including new vulnerability curves representing aircraft lines, alternative salvage, and movable risk assumptions for automobile lines, and revised business interruption vulnerability for temporary lodging lines

Overall, these updates strengthen vulnerability modeling and better reflect the latest market practices, thereby enabling users to gain deeper insights into vulnerability risk differentiation and to underwrite hurricane risk more appropriately across many lines of business and regions.

Long-Term Rates

To maintain an up-to-date basis of historical hurricane activity, version 17.0 introduces updates to the LTRs, or historical rates, in the North Atlantic Hurricane Models. Two addition hurricane seasons (2013 and 2014) were included and contain three hurricanes that made landfall in the North Atlantic domain. The new seasons add Hurricane Arthur, a Category 2 hurricane, to the U.S. Southeast, and a pair of hurricanes in Bermuda.

These updates include a new vintage of the NHC's North Atlantic hurricane database, known as HURDAT2, which RMS uses to develop the landfall probability distributions in the model.

The National Oceanic and Atmospheric Administration (NOAA) Hurricane Research Division (HRD) runs a continuous reanalysis project (Landsea et al., 2012) that regularly publishes new updates. Using historical observations and modern scientific understanding, the HRD is reanalyzing each storm from 1851 to present in the record to remove errors and biases. Resulting changes include track and intensity adjustments and the addition or removal of storms. The process of maintaining the long-term rates incorporates the reanalysis updates to keep the historical baseline view up-to-date.

Version 17.0 incorporates the June 2015 vintage of the HURDAT2 dataset into the development of the LTRs. The new rates include two additional hurricane seasons and ten more years of reanalysis results than version 15.0.

The updated HURDAT2 dataset differs from the vintage used in version 15.0 in two key ways:

- The addition of the 2013 and 2014 seasons of North Atlantic Basin hurricane activity.
- The reanalysis period covers updates to historical tracks and wind intensities for storms occurring between 1946 and 1955. For further information on these changes, see http://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html.

The version 17.0 long-term rate updates reduce Category 3–5 hurricane rates in all U.S. regions, primarily driven by reanalysis updates. In almost all U.S. regions, this reduction drives small to moderate loss decreases; however, losses increase in the U.S. southeast region (region 5), including Georgia and the Carolinas. These region 5 loss increases reflect changes in the number of landfalling hurricanes within each individual Saffir-Simpson category. Specifically, the 1946–1955 event reanalysis updates in the U.S. southeast decrease the number of Category 3 hurricanes but increase the number of Category 4 hurricanes in region 5. With the addition of new years with no major hurricane landfalls, the overall Category 3–5 rate in this region decreases. However, a larger proportion of these storms are now classed as Category 4 than in version 15.0, and therefore losses increase.

Medium-Term Rate Forecast

Version 17.0 of the North Atlantic Hurricane Models includes both long-term historical, and forward-looking medium-term perspectives on hurricane occurrence. The medium-term perspective represents the RMS forecast of the average annual landfall rate along the Atlantic and Gulf coastlines on a rolling five-year time horizon. The medium-term rate forecast is the RMS scientific reference view on hurricane activity rates in the North Atlantic Basin.

As a neutral party in risk modeling, RMS designs the MTR forecast to deliver unbiased probabilistic estimates of the forecast annual average number of landfalls over the next five years. Being probabilistic, the forecast estimates the number of landfalling hurricanes that can be expected, on average, over many such five-year periods. RMS revisits and upgrades the five-year medium-term forecasts regularly—to incorporate the latest scientific knowledge behind drivers of hurricane activity, include up-to-date data, and improve the forecast methodology.

The absence of a major hurricane landfall in the U.S. since 2005 sparked debate among the scientific community in early 2015, with many scientists referring to this period as a “hurricane drought” (Hall and Hereid 2015). A later publication argued that the definition of such a drought may be arbitrary (Hart et al., 2016); indeed, RMS observes that this most recent quiet period of hurricane activity exhibits different characteristics to past periods of low landfall frequency. Unlike the last quiet period—between the late 1960s and early 1990s—the number of hurricanes forming in the Atlantic Basin in many seasons since 2005 has been above average, despite a below average landfall rate.

Changes to the version 17.0 MTR forecast, which covers the 2017 through 2021 seasons, fall into two categories:

- New Methods and Scientific Enhancements—Although the core methodology of the MTRs remains unchanged, enhancements include (a) refinements to calculations of the uncertainty of shifting between phases of Atlantic Basin hurricane activity, (b) enhancements to forecast SST projections, and (c) improvements to statistical rate model hindcasting.
- Up-To-Date Data—Updates to historical input data include the addition of the 2014 to 2016 hurricane season statistics, as well as updates to select historical storms from 1951 to 1960 as part of the HURDAT2 reanalysis project. Historical SST data is updated to include 2014 to 2016 data in areas of the Atlantic and Indo-Pacific regions. Forecast SST models project Atlantic and Indo-Pacific temperatures between 2017 and 2021 to align with the MTR forecast period.

Important: The HURDAT2 vintage used in the LTR update is different than that used in the MTR update. The MTR forecast update includes an additional five years of HURDAT2 reanalysis data (1956–1960) and the 2015–16 seasons of North Atlantic Basin activity.

Historical Reconstructions

Updates to Historical Reconstructions fall into two categories:

- HURDAT2 Reanalysis Updates—Update of the U.S. wind fields for selected historical storms triggered by the ongoing HURDAT2 reanalysis project updates for period 1946 to 1955.
- New Caribbean Events—Addition of storms that impacted the Caribbean.

Vulnerability Updates

Version 17.0 introduces enhancements and improvements to hurricane vulnerability in many modeled regions. Some changes impact entire regions, such as the recalibration of vulnerability curves in Hawaii and the Caribbean, while some changes only affect select lines of business. The changes made to the vulnerability module fall into these main classes:

- Residential Lines Updates
- Primary Characteristic Updates
- Regional Vulnerability Curves Recalibration
- Secondary Modifiers Option Updates
- Changes to Specific Lines of Business

Residential Lines Updates

Updates to multi-family dwelling and manufactured home vulnerability in version 17.0 focus primarily on the U.S. and Canada; however, RMS considered these changes when recalibrating vulnerability functions in Hawaii, the Caribbean, Mexico, and Central America.

Multi-Family Dwelling

Version 17.0 revises multi-family dwelling (ATC 2 occupancy) and condominium (ATC 42 and 43 occupancies) vulnerability curves based on proprietary analytical models simulating expected exterior and interior damage during hurricanes for typical building configurations. RMS re-analysis of location-level claims data for multi-family dwellings across several recent historical storms, enhanced with information on building height, also supported these changes. Consequently, changes to multi-family dwelling vulnerability and the resulting impacts vary by building height, e.g., low-rise, mid-rise, and so on.

In general, the vulnerability of low-rise multi-family dwellings reduces notably in version 17.0 compared to version 15.0, with reductions varying regionally; the largest decreases occur in low-hazard regions, such as inland counties. Mid-rise and high-rise multi-family dwellings exhibit low to moderate increases in ground-up average annual loss, in the range of 5 percent to 10 percent, in most U.S. regions.

Mid-rise, masonry multi-family dwellings built before 1994 exhibit small loss decreases in the Northeast and Mid-Atlantic, regions with a high prevalence of Brownstone-style construction. Modelers considered the unique characteristics of

Brownstones when calibrating the vulnerability curves of these regions. Brownstone-style buildings typically feature fewer exposed openings, increased roof area, and reduced edge zones, which all contribute to lowering their susceptibility to damage in hurricanes.

Version 17.0 also updates the vulnerability of condominium association and unit owner occupancies. The net change for these occupancies includes the impact of all multi-family dwelling vulnerability updates. In addition, this change also considers the types of damage represented by the condominium association occupancy, primarily covering exterior structural damage, and the condominium unit owner occupancy, primarily covering interior damage. A building's exterior is more vulnerable at lower wind speeds than its interior, which is typically only damaged once the building envelope is breached. As a result, condominium association damage is greater at lower wind speeds, whereas condominium unit owner damage is greater at higher wind speeds, compared to multi-family dwelling policies covering both exterior and interior damage.

Manufactured Homes

Version 17.0 improves manufactured home vulnerability modeling through explicit consideration of the U.S. Department of Housing and Urban Development (HUD) wind zones. The HUD Manufactured Home Construction and Safety Standards (MHCSS; 24 CFR 3280) and its Model Manufactured Home Installation Standards (24 CFR 3285) defines three wind zones in the United States:

- HUD Zone III: Areas where the basic wind speed (i.e., three-second gust speed at 10 meters above the ground) is 110 mph
- HUD Zone II: Areas where the basic wind speed is 100 mph
- HUD Zone I: All areas not identified as either HUD Zone II or HUD Zone III and not associated with a specific wind speed

Based on claims reanalysis, version 17.0 revises manufactured home year-built bands and introduces a new band for recent construction, 2009 or later. In addition, the following data sources also informed vulnerability updates to this class of risk: data on installation standards for manufactured homes from 2007; Insurance Institute of Business and Home Safety (IBHS) research (2015) on the performance of manufactured homes; and published research on the effect of age and corrosion in weakening tie-down performance in high winds.

Primary Characteristic Updates

Construction Classes

Version 17.0 introduces two newly-supported masonry construction classes in all onshore modeled regions. It also expands the ability to differentiate low-rise commercial floor area, introducing this facility for additional occupancy classes, and expanding this functionality to all onshore modeled regions.

Floor Area Bands for Low-rise Commercial Buildings

Version 17.0 expands the ability for users to differentiate low-rise commercial risks using the floor area primary characteristic (FLOORAREA). This facility adds the ability to differentiate risk based on the total building square footage. The differentiation reflects the fact that normalized loss ratios decrease with increasing building size, due to several factors, including: differences in the increase in peak wind loads at corner zones compared to the overall area; differences in roof to structure values; and differences in repair or replacement practices.

Regional Vulnerability Curves Recalibration

Version 17.0 recalibrates vulnerability curves across all lines of business in Hawaii for wind and storm surge, and in the Caribbean, Mexico, and Central America for wind only. These updates largely reflect learnings from over 18 months of detailed research on local building codes and industry practices, including nearly four weeks of on-site RMS reconnaissance in the Caribbean. The loss impact of these recalibrations varies by region and line of business.

Secondary Modifiers

Version 17.0 adds options and makes minor revisions to selected secondary modifiers and their associated credits and penalties. Most modifiers have not changed.

Construction Quality

Given the importance of age and corrosion in determining tie-down performance, version 17.0 activates the construction quality secondary modifier for manufactured homes to infer any retrofits or enhancements to tie-down systems.

Roof Covering

To simplify and clarify roof covering options related to shingles, version 17.0 revises some option names.

Based on RMS reconnaissance, version 17.0 adds two roof covering options predominantly found in the Caribbean.

Roof Equipment Hurricane Bracing

A new roof equipment hurricane bracing option introduced in version 17.0 allows users to specify that there is no roof equipment. This option provides a vulnerability credit, relative to the case where equipment bracing is unknown. All other roof equipment hurricane bracing options and associated impacts on losses remain unchanged in version 17.0.

Commercial Appurtenant Structures

New options introduced for the commercial appurtenant structures modifier allow users to highlight roof-mounted solar panels, commonly called photovoltaic (PV) arrays, or a complete lack of appurtenant structures.

Cladding Type

Modified cladding type options enable users to separate the impact of exterior insulation and finish system (EIFS) from stucco cladding and specify situations in which a building features no additional cladding.

Residential Appurtenant Structures

Version 17.0 revises options relating to screen enclosures or lanais and introduces options to highlight the presence of PV arrays.

Changes to Specific Lines of Business

Alternative Automobile Salvage and Movable Risk Assumptions

Automobile risk in hurricane modeling must consider unique features that differentiate this line of business from traditional property lines. For instance, damaged vehicles residing in auto dealer lots can be partially salvaged, easing the total loss. Additionally, hurricane watches and warnings provide personal auto owners with early warning time to move their automobile out of harm's way or store it inside a building that offers shielding from impact.

RMS peril models consider the influence of automobile salvage and mobility on insured losses within the personal and dealership automobile vulnerability functions.

Aircraft

Version 17.0 introduces new wind and storm surge curves to represent aircraft risks in all modeled regions. In previous model versions, these risks were mapped to the Trains, Trucks, and Airplanes construction class.

In developing new aircraft vulnerability curves, RMS modelers researched storm preparation and evacuation procedures, damageability of aircraft components, valuation of aircraft exposures, repair, and salvage practices, and observed damaged in past hurricanes. Version 17.0 differentiates vulnerability by aircraft size.

Business Interruption Updates

RMS observations show that temporary lodging lines typically exhibit higher business interruption impacts after hurricanes than other lines of business for several reasons:

- If wind and water enter a hotel room once the building envelope is breached, the interior and contents usually require replacement, even for small magnitudes of damage.

- Visitors are often reluctant to stay at hotels that have been recently damaged or are under repair.
- While damage to residential properties typically increases the demand for temporary lodging, the travel industry will often divert customers from areas recently damaged by hurricanes.

RMS has recalibrated the effective downtime of temporary lodging structures, particularly at low levels of structural damage, based on field reconnaissance data. While business interruption losses for hotels decrease in version 17.0, temporary lodging lines still demonstrate higher downtimes compared to all other lines for the aforementioned reasons.

New Industrial Facility Curves

Version 17.0 introduces new occupancy types to the RMS® Industrial Facilities Model (IFM), representing solar farms and airports. Modelers used several published reports to build and validate the vulnerability curves associated with these occupancy types.

Also refer to the RMS submission to the FCHLPM, response to Standard G-1.5A.

Model Components (ASOP Section 3.3.1)

RMS responses to the FCHLPM's Standards G-1.2 and G-1.3 provide a comprehensive basic understanding of the North Atlantic Hurricane Models. Although the FCHLPM response describes the model in response to standards applicable only to personal and commercial residential property lines of insurance covering properties in the state of Florida, the methodology is the same throughout the U.S. and Canada.

User Input (ASOP Section 3.3.2)

User Data

The model requires exposure (insured property) data inputs. Analysis results depend on how the exposures are characterized and what analysis settings are chosen by the user.

Location

The location of the insured property, plus its structure and contents characteristics, is used in quantifying expected damage. In general, users input address information for each property, the characteristics of the property, and insurance policy/contract information.

The model determines geographic location in the geocoding module. Geocoding is the process that matches a geographic resolution, such as postal code or city, to a specific longitude or latitude. It sorts through source data files and selects the most accurate geographic resolution available for each location. The accuracy and resolution of the geo-coding depend on the quality of the source data. The model includes only geocoded locations in an analysis.

Given the wide range of address information quality, there is a range of possible resolutions in geocoding. For example, after you enter an address, the geocoder may be able to identify the exact location, or it may only be able to identify the centroid of the postal code in which the location resides. This scaled level of spatial detail is called a “match level.” The match level achieved depends on the type of geographic data available to the geocoder and the quality of the address information that the user provides.

The most accurate and meaningful model output is obtained when property locations are detailed, such as street address. RMS does not recommend using locations less precise than postal code for personal lines ratemaking. However, that is not always possible or feasible, and the actuary should use their best judgment in determining the appropriateness of the level of detail provided and output.

The RMS response to FCHLPM Standard G-3.3 provides additional information related to insured exposure location.

Exposure Characteristics

Besides location information, various informational characteristics can be entered. A few are “primary,” which are required inputs. If one or more of them is unknown, the model will assign an average value based on the information that is available. There are also secondary modifiers which are optional and refine the primary-characteristic-specific expected losses. Many characteristics vary by peril and some are applicable to all perils.

Assumptions and Validation Related to Input Data

Exposure data is owned and input by the client and is not modified by RiskLink. The assumption is that all data input is accurate. The RMS response to FCHLPM Standard A-1.B lists assumptions related to exposure input and the response to FCHLPM Standard A-1.6 describes the validity checks made.

Analysis Settings

The response to FCHLPM Standard A.1-5 and the Analysis Summary Report in the RMS submission to the FCHLPM Appendix F show the settings which were used in the model to create the information provided to the Commission.

Model Output (ASOP Section 3.3.3)

Interpreting Output

There is a large quantity of information produced by RiskLink. Some of the most commonly used output is described below.

Exceedance Probability (EP) Curves and Pure Premium

EP curves are cumulative distributions showing the probability that losses will exceed a certain amount, from either single or multiple occurrences. These losses are expressed in the OEP (occurrence exceedance probability) and the AEP (aggregate exceedance probability) curves.

AEP and OEP curves are two different curves that offer different information. Both curves show the probability that losses will exceed a given threshold. The AEP curve deals with aggregate loss dollars in a one-year time period. It shows the probability that aggregate losses in a year (i.e., the sum of all losses from all occurrences in a year) will be greater than a certain amount. The OEP curve deals with individual occurrences in a year. It shows the annual probability that the losses for at least one occurrence will exceed a certain amount.

The area under the AEP curve equals the pure premium since the pure premium statistic incorporates all losses incurred during a one-year time period.

The calculations performed within the financial component to generate the EP curves consist of the following four steps:

1. Frequency distribution generation
2. Severity distribution generation
3. OEP loss distribution generation
4. AEP loss distribution generation

The frequency distribution is the distribution of the number of event occurrences in a year. The severity distribution is the distribution of the size of losses, given that an event has occurred. From these two pieces of information, we can calculate the OEP and the AEP distributions.

The frequency distribution gives us information about how often events are likely to occur. To model it we use a Poisson distribution with parameter lambda (λ); the sum of all the event rates. The parameter λ can be interpreted as the mean frequency. An implication of the Poisson distribution is that multiple occurrences in a year are possible. We also assume that the occurrence of each specific event is completely independent of the occurrence of any other specific event.

The severity distribution is the distribution of the size of loss, given that an event has occurred. It gives us information about how big the event losses will be. To model it we start with a discrete distribution consisting of a set of loss thresholds, each one with a corresponding conditional exceedance probability (CEP), which is the probability of the event loss being greater than the threshold, given that an event has occurred.

The building blocks used to construct this severity distribution are the individual event severity distributions; that is, the distributions followed by the size of each event loss. Using these building blocks we can calculate the contribution of each event to the overall severity distribution.

Return Period Loss and Probable Maximum Loss

Return period loss (RPL) is also referred to as value at risk (VaR), a familiar statistic in the banking industry. Along with other statistics such as the average annual loss and standard deviation, return period loss summarizes the underlying loss distribution using a single number. Return period losses show the probabilities that the maximum or aggregate losses in a given year will exceed a given loss threshold. They are expressed in the OEP and the AEP curves, respectively.

Given α as the selected risk tolerance threshold (e.g., 0.5 percent, or 200-year return period), the corresponding return period loss is the loss value $L_{0.5\%}$ such that the probability of exceeding $L_{0.5\%}$ in a given year is 0.005 b.

Probable maximum loss (PML) is often used as a synonym for RPL.

Return period loss has the advantages of its simplicity and its popularity among credit rating agencies and insurance markets. However, there are some limitations with using return period loss as the only risk measure for making critical decisions.

RPL statistics have some risk management limitations that may not be obvious. Specifically:

- Return period loss does not account for the tail portion of the loss distribution
- Return period loss can fail to reflect the benefit of diversification for portfolios

Tail Conditional Expectation

Tail conditional expectation (TCE) is the conditional expectation of losses that are greater than or equal to a specified loss threshold RPL_α, where α is the selected risk tolerance threshold and RPL_α is the corresponding return period loss. In other words, TCE is the expected value of loss given that a loss at least as large as RPL_α has occurred. The conditional nature of TCE leads to another description for this risk metric: TCE is the average severity of losses that are greater than or equal to a specified threshold.

Some advantages of TCE for risk management are:

- TCE is more informative than return period loss at a specified risk tolerance level
- TCE is subadditive
- TCE and always captures the diversification benefit of risk pooling.
- TCE takes into account the severity of an insolvency

Appropriateness of the Model for the Intended Application (ASOP Section 3.4)

As stated in Actuarial Standard of Practice No. 39, Treatment of Catastrophe Losses in Property/Casualty Insurance Ratemaking, there are certain types of occurrences that preclude exclusive reliance on historical information in developing rate levels. The potential impacts of these occurrences also need to be considered in other risk management practice areas besides ratemaking. Hurricanes belong to this category of events. In these cases, the actuary should consider

> *using noninsurance data (including models based thereon) as input to ratemaking procedures … (so) that the resulting ratemaking procedures appropriately reflect the expected frequency and severity distribution of catastrophes, as well as anticipated class, coverage, geographic, and other relevant exposure distributions (ASOP 39 p. 4).*

RMS models are intended for client use related to managing risk. RMS can provide further information regarding the use of RMS models for many applications.

Applicability of Historical Data (ASOP Section 3.4.a)

Insured and economic losses from past hurricanes provide valuable information for use in projecting potential future occurrences. However, there are limitations to the use of this data. The historic record is not fully representative of the frequency and severity of hurricanes. Each event is unique in its genesis, path, wind field, decay, bathymetry, landfall location, and land use/land cover characteristics, among other things. In addition, for future occurrences, the conditions likely to prevail at the time the loss occurs needs to be reflected. These include items such as coverages, the underlying portfolio of insured risks, building codes and the enforcement of these codes, building practices, population shifts, settlement and indemnity costs, correlation among risk locations, and demand surge.

Table 1 provides a summary of the data used in the RMS U.S. and Canada Hurricane Models.

Table 1: RMS® U.S. Hurricane Model Data Source Summary

Component	Data Sources
Wind Hazard	■ The National Hurricane Centre's (NHC) June 2015 vintage HURDAT2 (North Atlantic Hurricane Database; (Landsea and Franklin 2013) historical tracks catalog: a compilation of tropical cyclone track data from 1851 to 2014, which includes the latest findings of the on-going National Oceanic and Atmospheric Administration (NOAA) Hurricane Research Division's (HRD) reanalysis project. The June 2015 vintage HURDAT2 dataset includes a reanalysis of the historical record up to and including 1955. ■ NHC Reports and Numerical Simulations (Colette et al., 2010)

Component	Data Sources
	■ For key post-1955 events (not yet reanalyzed by the HRD), RMS performs its own research to update historical storm landfall intensities
	■ The NHC's July 2016 vintage HURDAT2 (Landsea and Franklin 2013) "best track" dataset (1851–2015), with the 2016 hurricane season manually added. This vintage includes a reanalysis of the historical record up to and including 1960. Although the record contains information on tropical storms back to 1851, RMS uses only the data from 1900 onward to determine landfall statistics such as the annual landfall count, and from 1948 onward for basin statistics. ■ Hadley Centre Sea Surface Temperatures (HadISST: 1870 to 2016) dataset produced by the U.K. Met Office (Rayner et al., 2003), downloaded in November 2016. The HadISST dataset consists of records from the U.K. Met Office Data Bank (1982–2016), augmented by data from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). ■ In addition to the raw sea surface temperature (SST) data, RMS also used the Coupled Model Intercomparison Project 5 (CMIP5; as submitted to the Fifth Assessment of the Intergovernmental Panel on Climate Change) ensemble models in several of the SST forecast (or hindcast) models. Weighted combinations of the six (Indo-Pacific) and nine (Main Development Region) SST forecast (or hindcast) model outputs form the basis of the medium-term rates (MTRs) that take into account SSTs.
	■ Extended Best track dataset (Demuth et al., 2006) spanning the hurricane seasons 1988–2008 ■ HWind (Powell et al., 2010)—surface wind field maps for storms since 1996 incorporating wind observations from aircraft, GPS dropsondes, satellites and surface instruments. May 2009 vintage used—spanning hurricane seasons 1998–2008, with some additional data from Hurricane Andrew (1992)
	Weather Research and Forecast model (WRF) numerical simulations (Skamarock et al., 2005)
	Surface wind observations from a number of sources including: ■ NOAA (~15,000 observations: http://www.noaa.gov/) ■ The National Data Buoy Center (NDBC, ~6,000 observations, http://www.ndbc.noaa.gov/) ■ The Florida Coastal Monitoring Program (FCMP, ~300 observations, http://fcmp.ce.ufl.edu/) ■ Texas Tech University Hurricane Research Team (TTU-HRT, ~200 observations) ■ The Weatherflow station network (~10,074 observations, http://www.weatherflow.com/) ■ Flight Level Data (http://www.aoml.noaa.gov/hrd/HRD-P3_fl.html) ■ HWind (over 9,000 observations, http://www.aoml.noaa.gov/hrd/data_sub/wind.html)
	■ **U.S.**: Surface roughness data from the U.S. Geological Survey (USGS) National Land Cover Data set (NLCD: http://landcover.usgs.gov/landcoverdata.php), supplemented with information from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER; vintages range from 2007 to 2014, depending on availability) satellite imagery (http://asterweb.jpl.nasa.gov/), and U.S. Census housing and population density data)

Component	Data Sources
	▪ **Canada**: Surface roughness data from the USGS Global Land Cover Characterization (GLCC) dataset, supplemented with information from ASTER satellite imagery (http://asterweb.jpl.nasa.gov/) for key cities. ▪ **Caribbean**: ▪ For key cities (populations of more than 500,000, or more than 100,000 if within 20 km of the coast): 15–30 m resolution ASTER (http://asterweb.jpl.nasa.gov/) satellite imagery of 2001–2007 vintage ▪ For rural areas: 300 m resolution GlobCover data of 2005 vintage ▪ **Mexico and Central America**: ▪ For key cities (populations of more than 500,000, or more than 100,000 if within 20 km of the coast): 15–30 m resolution ASTER (http://asterweb.jpl.nasa.gov/) satellite imagery of 2001-2007 vintage ▪ For rural areas: 300 m resolution GlobCover data of 2005 vintage ▪ RMS assigned representative roughness lengths to each of the 10 land use/land cover classes, based on published mapping schemes from the scientific literature
Wave Hazard	DHI's MIKE Spectral Wave model
	RMS developed an empirical crest equation model, based on applicable wave theories such as Stokes V and Stream Function
Wind Vulnerability	**Claims data:** ▪ **U.S.**: Over $21 billion of claims data (and corresponding exposure information) from 1989 through 2012, including claims from the 2004, 2005 and 2008 seasons (including $2.3 billion from Hurricane Ike for 100,000 locations from more than 20 clients), and 2011 and 2012 seasons (including $3 billion from Irene and Sandy) ▪ **Caribbean**: Over $220 million of claims data (and corresponding exposure information) from key hurricanes, including Georges (1998) in Puerto Rico, Ivan (2004) in the Cayman Islands, and Ike (2008) in the Turks and Caicos ▪ **Canada, Mexico and Central America**: No claims data or RMS reconnaissance information available, so RMS bases the vulnerability functions in these regions on post-event reconnaissance, external expert input, published literature, reports and studies **RMS post-event reconnaissance, including:** ▪ Observations gathered by the RMS reconnaissance team deployed to Texas after Ike's landfall ▪ Observations from Irene (2011) and Sandy (2012) ▪ Four weeks of comprehensive, on-site Caribbean reconnaissance in 2015 and 2016, including meetings with over 20 local companies and 10 engineers, supporting past RMS site visits to various locations to confirm regional relativities **External expert input:** ▪ RMS worked with an expert panel of experienced engineering consultants to characterize and quantify the impact of workmanship and building code compliance and enforcement on the hurricane performance of buildings in different regions of the U.S. in order to define regional vulnerability relativities

Component	Data Sources

	- Input of Caribbean-based experts in hurricane hazard mitigation including Tony Gibbs, recipient of the United Nations 2007 Sasakawa Award for his contributions to hazard awareness and disaster risk reduction for earthquakes and hurricanes in the Caribbean
	- RMS contracted with engineers based in Mexico, Belize, and Costa Rica to compile information related to hurricane vulnerability in these regions. In addition to local consultants, Tony Gibbs (based out of the Caribbean) was hired to oversee the work and contribute his expertise. With the assistance of these experts, RMS conducted studies focused on the evolution of building code requirements, construction quality, and prevalent construction materials and methods over time for each region and for each major building type.
	Published literature, reports and studies:
	- Information and data on wind engineering and wind damage to structures gathered from analysis of published research studies, technical reports, special publications and books, building design codes and analytical building simulations tools. For example:
	  - Information from the Insurance Institute of Business and Home Safety (IBHS 2013) about building code enforcement practices
	  - Published research on civil structure vulnerability (Ferrara 2013; DesRoches 2006)
	  - Published research on the building aging process and roof deterioration (IBHS 2007; IBHS 2012; Dixon et al., 2013)
	- **Canada**: Based on the RMS understanding of the construction practices and quality in Canada relative to the Northeast U.S. (a large part of which originates from the input of a panel of practicing engineers engaged by RMS to define regional vulnerability relativities, similar to the method used in the Northeast U.S.), there is no reason to believe the building stock in Canada is any worse or better than that in the U.S. Northeast, so the Canada vulnerability functions are the same as those implemented in the Northeast U.S.
	- **Mexico and Central America**: Based on the RMS understanding of the construction practices and quality in Mexico and Central America relative to parts of the Caribbean (based on an engineering-based study of construction practices in Mexico and Central America; see below), there is no reason to believe the building stock in Mexico and Central America is any worse or better than that in parts of the Caribbean, so the Mexico and Central America vulnerability functions are the same as those implemented in parts of the Caribbean

Wave Vulnerability (Offshore Platform only)	- Research publications on the principles of wind and wave-structure interaction - Numerous structural analyses of representative offshore platforms using EDI's (Engineering Dynamic Incorporated) Structural Analysis Computing Software (SACS®), a marine-specific software program used in offshore platform design—used to gain an understanding of platform behavior when subject to a wide range of loading combinations from wind, wave, and currents, and to study the effects of wave-in-deck forces when a storm intensifies enough to cause waves that begin hitting an offshore platform deck. Enabled modelers to quantify the relative performance of platforms across different water depths, deck heights, and design codes. - For shallow water platform calibration, RMS obtained five client portfolios, representing exposure of approximately $38 billion and approximately $1.7 billion in loss - Hurricane damage reports, including Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) reports on Hurricanes Andrew (1992), Lili (2002), Ivan (2004), Katrina (2005), Rita (2005), Gustav (2008) ,and Ike (2008)

Component	Data Sources
	■ Minerals Management Service (MMS) and American Petroleum Institute (API) design codes, including: ■ API 2INT-MET ■ Interim Guidance on Hurricane Conditions in the Gulf of Mexico ■ API 2A-Fixed Platforms ■ API 2T-Tension-Leg Platforms ■ API 2FP1-Mooring for Floating Production Systems ■ API 2SK-Station-Keeping Systems for Floating Structures ■ DNV RP F109-On Bottom Stability of Pipelines ■ Research studies commissioned by API and Bureau of Safety and Environmental Enforcement (BSEE) after the 2004 and 2005 hurricane seasons, including the BSEE-commissioned hazard maps delineating the susceptibility of the Mississippi River Delta region to mudslides ■ RMS sample network analyses on the impacts of damage to downstream gathering or processing hubs and terminals on upstream platform downtimes (i.e., contingent business interruption)
Builders Risk (U.S. only)	■ The same dataset used to calibrate the standard vulnerability functions was used for Builders Risk Phase 5 (completion Phase) calibration
	■ Value ramp up associated with project phases was based on detailed construction project data provided by clients and relevant RSMeans building construction cost data (provided by Reed construction: http://www.rsmeans.com/)
	■ Information from experts, clients, published research studies, technical reports and building codes was incorporated ■ Builders Risk damage functions for each phase of construction were developed primarily using engineering principals
Post-Event Loss Amplification	■ 2004 and 2005 hurricane season claims data ■ Analyzed economic drivers of increases in labor costs and materials (e.g., gross domestic product (GDP), contribution of construction sector to GDP, insurance take-up-rate, etc.) ■ Bureau of Economic Analysis Gross Regional Product (GRP): http://www.bea.gov/regional/index.htm) ■ Xactimate data (http://www.xactware.com/en-gb/) ■ Interviews with Caribbean insurers, brokers. claims adjusters, engineers and building contractors ■ RMS investigation into the impacts of recent hurricanes (including 2005 Hurricane Katrina and Rita) on the cost of repairs, through research into rig dayrates and feedback from insurers and claims adjusters

Developments in Relevant Fields (ASOP Section 3.4.b)

As can be seen from the credentials of the professionals involved in model development, RMS employs the highest caliber experts in relevant fields. Each of these individuals expends substantial effort to keep abreast of recent developments and on-going research. Employees are encouraged to publish findings when appropriate in both peer-reviewed and less formal journals, and to maintain working relationships with academicians and other experts in relevant scientific fields. RMS partners with entities who offer expertise and knowledge that complement what is known and developed in-house.

RMS hosts an annual multi-day conference where clients hear about the latest scientific developments related to catastrophic events that may impact risk management activities.

Frequent internal seminars are held to allow employees opportunities to remain current with RMS-related issues.

The RMS Blog contains useful information that is frequently updated.

Appropriate Validation (ASOP Section 3.5)

This document is not intended as a substitute for the actuary's determination that appropriate validation of the model has occurred. It contains summary descriptions and selected examples of key model validations performed by RMS during the development of the model. Table 2 summarizes the validation performed.

Table 2: U.S. Hurricane Model Validation Summary

Component	Data Sources and Validation Approach
Wind Hazard	RMS performed Kolmogorov-Smirnov and chi-square goodness-of-fit tests for the cumulative distribution function of translational speed at landfall. RMS also compares modeled and historical distributions of storm heading at landfall.
	RMS compares stochastic and observed (HURDAT database) central pressure distributions in various regions.
	RMS performed Kolmogorov-Smirnov and chi-square goodness-of-fit tests for the cumulative distribution function of Vmax at landfall. Historical data used: HURDAT database.
	Comparison of historic (HURDAT2) rates to modeled rates.
	The storm frequencies in the stochastic module are validated against history by comparing modeled and observed historical landfall frequencies and distributions of landfall parameters at various levels of resolution.
	▪ Development methodology reviewed by Professor Kerry Emmanuel of Massachusetts Institute of Technology (MIT). RMS also consulted with other renowned scientists working in this field to derive this methodology. ▪ Loss exceedance probability (EP) curve comparisons between "active baseline" and "inactive baseline" models and empirical-historic loss data during active and inactive phases. ▪ Comparisons of the hindcast medium-term and long-term views from 1950 onward by year and by landfall gate. ▪ Investigations into whether the version 17.0 medium-term rate (MTR) methodology would have performed skillfully if used to predict hurricane landfalls in each period from 1970–74 to 2012–16. ▪ Investigation of the volatility of the RMS MTR forecast on a year-to-year basis. ▪ Comparison of the observed and modeled response of tropical cyclone intensity to sea surface temperature (SST) changes.
	The distributions of all modeled wind field parameters are checked for consistency with available data sources e.g., the modeled distribution of Rmax at landfall is plotted with the corresponding distribution from extended best track (EBT) dataset.
	RMS validated the 2007 to 2014 ASTER imagery against Google Earth.
	▪ **U.S.**: The wind field model has been validated through the reconstruction of all damaging storms in the HURDAT database.

Component	Data Sources and Validation Approach
	- **Caribbean**: As a result of a lack of high-quality in-situ measurements, modeled footprints cannot be validated against actual observations. In the Caribbean, outside of Puerto Rico, wind observations are nearly non-existent. Reconstructions of historical storm footprints can only be compared to wind estimates from damage reports (including reports published by the North Atlantic Hurricane Center (NHC), National Oceanic and Atmospheric Administration (NOAA: www.noaa.gov/), Economic Commission for Latin America and the Caribbean (ECLAC: https://www.cepal.org/en) and Dr. Simon Young of GeoSY Ltd (http://www.caribrm.com/). - **All non-U.S. models**: The validation of the U.S. wind field model shows that the wind field model produces footprints with an acceptable range of the historical data, for a wide variety of hurricanes and landfall locations. As the same wind field model is used for Canada, the Caribbean, Mexico and Central America, and the Offshore Platform with region-specific land use data, we can assume that the model also performs well outside the U.S.
	- The results of the WRF simulations—in terms of intensity and forward speed—are validated against HURDAT records from 1900 to 2008. The simulation results for size, in terms of Rmax, are validated against the EBT dataset (1988 to 2008). - Back-testing the ability of the RMS model to simulate historical storms pressure filling rates compared to a model that is based on historical data alone. - Inland filling model reviewed by Professor Dave Nolan (University of Miami). - The RMS inland filling methodology (Collette et al, 2010) was accepted into Monthly Weather Review, a peer-reviewed publication, validating its scientific soundness.
	- **U.S.**: Wind speed—return period relationship validated by comparing the model to the latest wind-hazard map (derived from historical analysis of meteorological data (for non-hurricane events) and hurricane modeling developed by independent researchers) underlying the latest wind speed design standards for the U.S., as published by the American Society of Engineers in May 2010. - **Other models**—RMS did not do wind speed-return period relationship validation for Canada, Caribbean or Mexico and Central America specifically, but relied on what had been done in the U.S., where the information was of a quality and quantity to provide meaningful comparisons.
	- The RMS methodology was accepted into peer-reviewed publication to validate the scientific soundness of the new methodology. - The hazard model was independently reviewed by Dr. Bob Hart (Associate Professor, Meteorology Department of Earth, Ocean, and Atmospheric Science) at Florida State University.

Component	Data Sources and Validation Approach
Storm Surge Hazard (U.S. and Caribbean only)	- **U.S.**—RMS reconstructed 34 key historical storm surge footprints (including Hurricanes Ike, Katrina, Rita, Ivan, New England (1938) and Hurricane Sandy) using the same modeling methodology as used in the stochastic event set. RMS then compared the historical reconstructions with storm surge inundation extent and depth observations. For Superstorm Sandy (2012), RMS also compared the reconstructed and observed water levels over time to validate the model's ability to capture both the maximum water level in the footprint across a large spatial distribution and water levels throughout the lifetime of a storm. - **Caribbean**—In the Caribbean, empirical observations for storm surge are limited. The primary source of data used to validate the storm surge hazard module in the Caribbean is a detailed comparison of claims data for Hurricane Ivan (2004) in the Cayman Islands. This set of data includes comprehensive assessments from local adjusters regarding the level, extent, and probable source of flooding at each location where a claim was filed.
Wave Hazard (Offshore Platform only)	As part of the validation of MIKE Spectral Wave model, observed Significant Wave Heights, maximum wave height, wave period, and currents at specific offshore buoys were compared with model output over the entire time history of a given storm for key historical storms affecting Gulf of Mexico in the last decade, that is, Lili (2002), Ivan (2004), Katrina (2005), Rita (2005), Gustav (2008), and Ike (2008).
	The RMS empirical equation for calculating wave crest elevation was validated by comparing to wave crest elevation output from the SACS model.
Wind Vulnerability	**Claims data:** - **U.S.**—Over $21 billion of claims data (and corresponding exposure information) from 1989 through 2012, including claims from the 2004, 2005 and 2008 seasons (including $2.3 billion from Hurricane Ike for 100,000 locations from more than 20 clients), and 2011 and 2012 seasons (including $3 billion from Irene and Sandy) - **Caribbean**—Over $220 million of claims data (and corresponding exposure information) from key hurricanes, including Georges (1998) in Puerto Rico, Ivan (2004) in the Cayman Islands, and Ike (2008) in the Turks and Caicos - **Canada, Mexico and Central America**—No claims data or RMS reconnaissance information available - **Canada**—Based on the RMS understanding of the construction practices and quality in Canada relative to the Northeast U.S., there is no reason to believe the building stock in Canada is any worse or better than that in the Northeast U.S., so the Canada vulnerability functions are the same as those implemented in the Northeast U.S. - **Mexico and Central America**—Based on the RMS understanding of the construction practices and quality in Mexico and Central America relative to parts of the Caribbean, there is no reason to believe the building stock in Mexico and Central America is any worse or better than that in parts of the Caribbean, so the Mexico and Central America vulnerability functions are the same as those implemented in parts of the Caribbean

Component	Data Sources and Validation Approach
	External reviews: ▪ External review of the vulnerability module conducted by Tom Smith (TLSmith Consulting: an internationally recognized expert on wind performance in buildings)
Storm Surge Vulnerability (U.S. and Caribbean only)	▪ **U.S.**—RMS compared modeled storm surge losses from seven historical events (spanning 2004–2012) with losses incurred by the National Flood Insurance Program (NFIP). RMS used information about historical NFIP-specific exposure and NFIP event loss data for this exercise. ▪ **Caribbean**—The principal source of Caribbean surge claims is Hurricane Ivan (2004) in the Cayman Islands, for which RMS has compiled U.S. $110 million in surge-only claims. Adjustor notes on 871 property claims discuss the level, extent, and probable source of flooding. The claim locations are spread throughout the Grand Cayman (including Georgetown, Prospect Park, Bodden Town, Seven Mile Beach, West Bay, and some portions of the east side of the island. Additional vulnerability validation comes from first person accounts in the literature, as well as satellite imagery and photographs in the aftermath of events.
Wave Vulnerability (Offshore Platform only)	For shallow water platform validation, RMS obtained five client portfolios, representing exposure of approximately $38 billion and approximately $1.7 billion in loss
Builders Risk (U.S. only)	Extensive sensitivity tests have been performed to calibrate the model results while RMS used the complete phase (phase-5) as a reference to validate the function by comparing it with the RiskLink general model new year band damage functions
	External review of the entire builders risk vulnerability model

Post-Event Loss Amplification	▪ **U.S.**—Comparison to historical hurricanes including Hugo and Andrew
	▪ **Caribbean**:
	    ▪ Insurance industry, local expert, consultant and RMS post-event reconnaissance reports
	    ▪ Interviews with local insurers, claims adjusters, and building contractors on the impacts of Hugo (1989) in the U.S. Virgin Islands and Montserrat, Marylyn (1995) in the U.S. Virgin Islands, Luis (1995) in Sint Maarten, Ike (2008) in the Turks & Caicos Islands, and Ivan (2004) in the Cayman Islands and Grenada
	    ▪ Construction industry data e.g., national housing index data in the Cayman Islands for the period 2002–2009, thereby covering both hurricanes Ivan (2004) and Gustav (2008)

U.S. Loss Validation	Individual insurance company exposure databases are used as model input to produce model losses, which are compared to the company's actual event loss experiences (typically reported to RMS in insurance claims datasets). RMS compares modeled and incurred losses for: ▪ 79 residential portfolio/storm combinations, including 19 portfolio/storm combinations with significant storm surge coverage leakage contributions ▪ 38 commercial portfolio/storm combinations, including 14 portfolio/storm combinations with significant storm surge coverage leakage contributions

Component	Data Sources and Validation Approach
	RMS compared residential modeled storm surge losses from specific historical events with losses incurred by the NFIP based on a database obtained from the Federal Emergency Management Agency (FEMA) that included NFIP claims paid from 1978 to 2010
	RMS compared market-wide estimates of insured losses by line of business, adjusted for trends in exposure density, with modeled losses for significant hurricanes since 1989. Industry insured loss estimates are obtained from Property Claims Services (PCS), supplemented in Florida by Florida Office of Insurance Regulation (FL OIR) industry loss estimates in Florida based on insurance data calls from the 2004 and 2005 hurricane seasons. Modeled losses are compared with losses from: ▪ All lines—37 storms with combined losses of nearly $300 billion in 2017 values ▪ Residential—27 storms with combined losses of over $107 billion (PCS) in 2017 values ▪ Commercial—27 storms with combined losses of over $80 billion in 2017 values ▪ Automobile—27 storms with combined losses of over $12 billion in 2017 values
	RMS compares the stochastic modeled AAL (average annual loss, based on the version 17.0 Historical Event Rates, also known as the long-term rates) against an historical proxy AAL (based on the model historical reconstructions of the HURDAT historical record, as validated in the above step) to validate the frequency distribution of events and the reasonableness of the stochastic model
	RMS validates the modeled loss distribution through the comparison of modeled EP curves with historical EP curves (derived through the combination of all the historical reconstructions with a simple event frequency assumption)
Canada Loss Validation	This type of validation provides information that demonstrates that the sum of the components of the model is calibrated appropriately related to actual losses on an aggregate basis. Historical industry loss data is very limited for Canada, but as the hurricane vulnerability for Canada is the same as that implemented in the Northeast U.S., RMS believes that the industry loss validation performed for the U.S. is also equally valid for Canada.
	Company/Client portfolio losses provide a more granular analysis of specific geographic regions, lines of business, constructions types, and so on. These validations demonstrate that the model can produce realistic scenarios, but do not validate whether the model set contains, for example, appropriate frequency distributions for different types of events. Similar to the industry loss validation process, the detailed loss validation performed for the Northeast U.S. is assumed to be equally applicable to Canada.

Component	Data Sources and Validation Approach
Caribbean Loss Validation	Individual insurance company exposure databases are used as model input to produce model losses, which are compared to the company's actual event loss experiences (typically reported to RMS in insurance claims datasets). Detailed claims are not widely available for storms in the Caribbean, but RMS has compiled claims from multiple clients for key hurricanes, including Georges (1998) in Puerto Rico, Ivan (2004) in the Cayman Islands, and Ike (2008) in the Turks and Caicos.
	In the Caribbean, insurance industry losses are often unknown or highly uncertain. Modelers instead compare the “reconstructed” incurred losses that are estimated using information about the total economic impact of each storm, with a modeled estimate of the total economic loss, based on an internal economic exposure database developed by RMS, for significant hurricanes in the Caribbean since 1989. Modeled economic losses are compared with estimated incurred economic losses for 18 storms with combined losses of over $38 billion.
	RMS compared the stochastic modeled AAL (average annual loss, based on the version 17.0 Historical Event Rates, also known as the long-term rates) against a historical proxy AAL (based on the model historical reconstructions of the HURDAT historical record, as validated in the above step) to validate the frequency distribution of events and the reasonableness of the stochastic model.
	RMS validates the modeled loss distribution through the comparison of modeled EP curves with historical EP curves (derived through the combination of all the historical reconstructions with a simple event frequency assumption).
Offshore Platform Loss Validation	Individual insurance company exposure databases are used as model input to produce model losses, which are compared to the company's actual event loss experiences (typically reported to RMS in insurance claims datasets). RMS compares modeled and incurred losses for five portfolio/storm combinations representing approximately $1.7 billion in offshore claims data from Hurricanes Ivan (2004), Katrina (2005), Rita (2008), and Ike (2008).
	RMS compared $21.2 billion of market-wide insured loss estimates, with modeled losses for recent significant hurricanes, including Ivan (2004), Katrina (2005) and Ike (2008). Industry insured loss estimates for upstream platform damage (PD), operators extra expenses (OEE), and business interruption (BI) are obtained from the 2008 Willis Energy Market Review.
	RMS compares the stochastic modeled AAL (based on the version 17.0 Historical Event Rates, also known as the long-term rates) against a historical proxy AAL (based on the model historical reconstructions of the HURDAT historical record, as validated in the above step) to validate the frequency distribution of events and the reasonableness of the stochastic model.
	RMS validates the modeled loss distribution through the comparison of modeled EP curves with historical EP curves (derived through the combination of all the historical reconstructions with a simple event frequency assumption).

Component	Data Sources and Validation Approach
Mexico and Central America Loss Validation	- This type of validation provides information that demonstrates that the sum of the components of the model is calibrated appropriately related to actual losses on an aggregate basis. Historical industry loss data is very limited for Mexico and Central America, but as the hurricane vulnerability for Mexico and Central America is the same as that implemented in parts of the Caribbean, RMS believes that the industry loss validation performed for the Caribbean is equally valid for Mexico and Central America. - For the relatively small number of historical events for which aggregate insurance industry loss, or economic loss estimates are available (Wilma 2005, Isidore 2002, Emily 2005, Dolly 2008 and Dean 2007), RMS scaled the observed historical losses with factors that capture changes in the building stock and the cost of construction over time, to enable comparison with modeled losses based on 2011 internal insurance industry and economic exposure developed by RMS. - In addition, for Belize, RMS qualitatively reviewed the impacts of a number of hurricanes (including Iris 2001, Dean 2007, and Mitch 2007) with local engineering consultants to confirm that modeled loss ratios are consistent with observed building performance.
	Company/Client portfolio losses provide a more granular analysis of specific geographic regions, lines of business, constructions types, and so on. These validations demonstrate that the model can produce realistic scenarios, but do not validate whether the model set contains, for example, appropriate frequency distributions for different types of events. Similar to the industry loss validation process, the detailed loss validation performed for the Caribbean is assumed to be equally applicable to Mexico and Central America.

Validation of User Input (ASOP Section 3.5.1)

The accuracy and validity of user input can best be assessed by the model user. Actuaries may wish to refer to ASOP No. 23, Data Quality, for guidance. Pre-defined and custom exposure profiles, as well as the actuary's own evaluation, may be useful when reviewing model input. For validations done during data import or while entering the data, see RMS response to Florida Commission on Hurricane Loss Projection Methodology (FCHLPM) Standard A-1.6.

Validation of Model Output (ASOP Section 3.5.2)

See Appendix A for "Principles of Validation of RMS Natural Catastrophe Models." RMS responses to Statistical Standards and Forms in the RMS submission to the FCHLPM document provide additional information.

Results Derived from Alternate Models or Methods, where Available and Appropriate (ASOP Section 3.5.2.a)

One way to assess the reasonability of model output is to compare the output of the model to the results from earlier versions of the RMS model. Changes that have been made to the various components and calculations should be reflected in the model output. While the impact of each change cannot always be accurately isolated and quantified, the direction and magnitude of the change often can be. Details can be found earlier, in the section entitled Changes from Previous RiskLink Versions.

Specified output for Florida Personal Residential losses can be compared for several models using submissions to the FCHLPM (https://www.sbafla.com/method/).

How Historical Observations, if Applicable, Compare to Results Produced by the Model (ASOP Section 3.5.2.b)

See Appendix A in this document and the Statistical Standards and Forms in the RMS submission to the FCHLPM.

Select historical events are contained within the RiskLink software. These events do not contribute to the modeled (expected) loss, but can be used to compare company portfolio recorded losses to company portfolio model losses. These analyses can help determine how costly these historical events would be if the same storm occurred today.

Consistency and Reasonableness of Relationships among Various Output Results (ASOP Section 3.5.2.c)

RMS has reviewed the consistency and reasonableness of various output relationships and has not found any unexplained anomalies.

Various Standards and Forms in the RMS submission to the FCHLPM, particularly in the Actuarial sections, provide information that describe and demonstrate consistent and logical relationships of output results.

Sensitivity of the Model Output to Variations in the User Inputs and Model Assumptions (ASOP Section 3.5.2.d)

RMS has investigated the sensitivity of losses to changes in various storm parameters in the stochastic and wind field modules. The RMS submission to the FCHLPM under the 2009 Standards contains a detailed description of a sensitivity study carried out for RiskLink 11.0. Changes made in RiskLink since then have not affected the validity or results of the study.

In addition to the sensitivity testing completed by RMS staff, users have options to conduct sensitivity tests on specific portfolios. For example:

- Event Rate Sensitivity

  The results from a long-term historical average view of future event rate can be compared to a medium-term view set of results by selecting the pertinent event rate set.

- Vulnerability Sensitivity Test

  In areas where there are limited claims data, there is greater uncertainty in the quality of the building stock and the vulnerability functions used to estimate losses compared to data-rich areas. To characterize this uncertainty, two sets of vulnerability functions, in addition to the default set that represents the RMS view of risk, are provided. These additional sets of vulnerability functions enable users to stress test model results by providing scenarios that represent lower and higher views of the vulnerability risk. The range between the lower and higher sets of vulnerability functions represents the RMS view of the variability that one might expect to see in the ratio of modeled losses to incurred claims between different portfolios of insured exposure. The range is narrowest in Florida where hurricane claims data is available to guide the derivation of the wind vulnerability functions and widest in the Northeast where historical claims data is scarce or non-existent. These low and high views of the risk are not meant to be bounds on the expected loss, which can lie outside of the range defined by the low and high vulnerability functions. The low and high vulnerability functions are provided only for the purpose of conducting sensitivity tests around the default vulnerability functions that represent the RMS view of risk.

- Primary and Secondary Building Characteristic Sensitivity

  The user can use “Exposure Modifications” to set any combination of primary characteristics and/or all secondary characteristics to “unknown” without modifying the underlying data. If all of these are set to “unknown,” then the only variation from industry average is due to the location of the insured property. Each characteristic plus combinations of characteristics can be analyzed to determine the sensitivity of the portfolio to each feature as well as the interactions among them. This feature facilitates sensitivity testing for many characteristics by automating the temporary data adjustments that may need to be made to "hold all else equal.”

- Sensitivity to Exposure Data

  Coverage terms such as deductibles, limits, replacement cost versus actual cash value and insurance to value, as well as primary and secondary characteristics can be modified by the user to quantify the sensitivity to these parameters.

Appropriate Use of the Model (ASOP Section 3.6)

Section 3.6 requires the actuary to disclose whether any adjustments to the model results have been made in the intended application and to make a professional judgment to determine whether the results, adjusted or otherwise, are appropriate to use. While RMS may be able to offer additional details related to its models, each actuary has a duty to disclose and document adjustments made and judgments used.

The following items, while not a complete list, may be useful in determining what types of adjustments to model output could be appropriate.

Loss Development

Claims data used to calibrate the model are believed to have stabilized at the time they are used, and include both paid and estimates for unpaid losses (reserve amounts). Client data is usually as of 6–18 months post-occurrence.

Event characteristics may influence speed of payment. In addition, any client portfolio is likely to have specific features and follow unique claims-paying practices which should be taken into account when evaluating maturity.

Non-Modeled Losses

Since every expected loss element should be considered exactly once (both double-counting and omission are problematic), the actuary needs to know areas of potential loss related to the peril that are not included in model results.

Table 3: Model's Limitations and Non-Modeled Perils

Non-Modeled Risk	Description/Explanation	Applicable to...
Non-modeled exposures and coverages		
Category “0” Events	Losses from tropical storms that do not reach the minimum hurricane intensity according to the Saffir-Simpson wind speed scale are not included in the model's event set.	All North Atlantic Hurricane Models
Abnormal Coverage Leakage Resulting from Adverse Legal Interpretation	Coverage leakage, which reflects that there are different claims severities in wind/water cases and is a part of the hurricane model, can be affected by legal interpretations. Following Hurricane Ivan, the Mierzwa v. Florida Windstorm Underwriting Association ruling forced insurers in Florida to pay storm-surge-related losses under wind-only policies when there was an actual or constructive total loss, regardless of the amount of wind damage sustained. This ruling, which was over-turned in 2007, most likely inflated the claims paid out in Florida following Hurricane Ivan, and possibly	All North Atlantic Hurricane Models

Non-Modeled Risk	Description/Explanation	Applicable to...
	other events in 2005 such as Hurricane Rita and Hurricane Katrina. The North Atlantic Hurricane Models assume that this interpretation will not be applied to future events and therefore is excluded from the models.	
Inland Flooding	As demonstrated by events such as Tropical Storm Alison (2001) and Hurricane Ivan (2004), inland flood losses can be responsible for a significant fraction of the overall loss, if not the majority of the losses, from small and moderate events. The impact of inland flood is not included in either the wind or the storm surge vulnerability functions implemented in RiskLink.	All North Atlantic Hurricane Models
Assessments from Residual Markets	The North Atlantic Hurricane Models do not include losses due to assessments from residual markets.	All North Atlantic Hurricane Models
Certain Aspects of Claims Inflation	RMS does not model certain client-specific risks concerning the relaxation of the claims process due to political pressure, issues surrounding undervaluation, and hard fraud.	All North Atlantic Hurricane Models
Rainfall Infiltration	The wind component includes damage from rainfall penetrating through openings in the outer shell of a building, implicitly within the vulnerability curves. The vulnerability curves are calibrated against claims data that contain this damage. However, this component is not modeled explicitly (or stochastically) and a storm that is considerably wetter than any considered in our vulnerability development could cause above-average losses.	All North Atlantic Hurricane Models
Tree Fall	The impact of tree fall damage is considered implicitly within the vulnerability curves. RMS used events such as Hurricane Isabel (2003) and others to calibrate and validate the vulnerability curves. However, this component is not modeled explicitly (or stochastically), and a storm with a higher degree of tree fall impacts than any considered in our vulnerability development could cause above-average losses.	All North Atlantic Hurricane Models
Storm Surge	The exposure at risk to storm surge is minimal in Canada, as only a limited amount of exposure lies directly on the coastline.	Canada
	Damage resulting from the increased water levels associated with hurricanes is modeled only for the Bahamas, Turks & Caicos Islands, and the Cayman Islands.	Caribbean
	Damage resulting from the higher water levels associated with hurricanes is not modeled in Mexico and Central America. Detailed exposure data is not yet routinely captured by the market, rendering a high-resolution storm surge model unusable by a majority of the users.	Mexico and Central America
Builders Risk	Explicit vulnerability curves for buildings under construction, including value ramp-up over time, are not currently available in Canada. The RMS® Builders Risk Model is intended for large, multi-story type projects, risks that are rare in Atlantic Canada.	Canada

Non-Modeled Risk	Description/Explanation	Applicable to...
	Explicit vulnerability curves for buildings under construction, including value ramp-up over time, are not currently available in the Caribbean. The Builders Risk Model is intended for large, multi-story type projects, and has not yet been identified as a key concern for the market.	Caribbean
	Explicit vulnerability curves for buildings under construction, including value ramp-up over time, are not currently available in Mexico or Central America. The Builders Risk Model is intended for large, multi-story type projects. This detailed data is typically not available for these types of risks in these regions, and is therefore difficult to accurately model on a location basis.	Mexico and Central America
	Explicit vulnerability curves for buildings under construction, including ramp-up value over time, are not currently available in the RMS Offshore Platform Model.	Offshore Platform
Wind and Flood Losses in Non-coastal States or Provinces	The U.S. Hurricane Model captures the possibility of wind damage in some non-coastal states such as Pennsylvania, West Virginia, and Vermont from events that would cause damaging wind speeds relatively far inland from the coast. It does not cover states such as Ohio, Kentucky, and Indiana that are further inland and generally understood not to be at risk of hurricane wind. The risk in these states is dominated by winter storm and tornado/hail events.	U.S.
	The RMS® Canada Hurricane Model does not cover inland provinces, as these are generally understood not to be at risk of hurricane wind. Risk in these areas is thought to be dominated by winter storm and tornado/hail events instead.	Canada
Industry Exposure Database/Industry Loss Curves	The lack of consistent data capture and subsequent quality by the market does not allow for the construction of high-resolution industry exposure databases.	Mexico and Central America
Mold Damage	It is common during a hurricane for a building's interior to be damaged by rain infiltration through breaches in the building envelope. However, if measures are not (or cannot) be taken following a hurricane to dry the interior quickly, mold will grow and increase the damage to the interior of a building considerably. Mold-related damage was wide-spread following Hurricane Katrina as a result of the humid environment following the storm and the mandatory evacuations that prevented property owners from quickly drying the interiors of their buildings. This increased damage caused by mold is not explicitly modeled in RiskLink.	All North Atlantic Hurricane Models
Beach Erosion	Storm surge can erode the foundations of buildings sited on beaches. A foundation failure caused by beach erosion can result in a catastrophic loss at surge levels that normally would cause little or no damage. The storm surge and wave vulnerability functions implemented in RiskLink do not include losses caused by beach erosion and, therefore, will under-estimate the losses for any claims that are caused by beach erosion.	All North Atlantic Hurricane Models

Non-Modeled Risk	Description/Explanation	Applicable to...
Loss Adjustment Expenses	The modeled losses computed by RiskLink do not include loss adjustment expenses. Consequently, any loss adjustment expenses included in the claims data must be identified and removed before the data can be used for calibration or validation of the model. In most claims datasets received by RMS, the loss adjustment expenses are readily apparent and can be easily separated from the paid claims.	All North Atlantic Hurricane Models
Offshore Platform Non-Modeled Risks	The RMS® Offshore Platform Hurricane Model can model approximately 85% of typical Offshore Platform losses. Examples of non-modeled loss include the costs associated with Removal of Wreck (ROW/ROD), which can contribute between 10 to 20% of storm losses and can be handled outside RiskLink through a workaround, as well as Seepage & Pollution (S&P), OIL Insurance Ltd. (OIL), Sue & Labor (S&L), and Third Party Liability (TPL).	Offshore Platform
Non-modeled aspects of business interruption		
Time-Element Coverages (e.g., business interruption) where structural damage has not occurred	RMS has observed that in most cases, the extent of structural damage is the primary indicator of the extent of downtime for a specific occupancy; buildings with no structural damage are assumed to have no significant business interruption.	All North Atlantic Hurricane Models
Contingent Business Interruption (CBI)	CBI coverage entitles the policyholder to damages based on loss of income due to damage to a property that the insured does not own, but upon which the insured's income depends. CBI is not modeled across the RMS model suite (with the exception of the Offshore Platform Hurricane Model, which models CBI for platforms impacted by damage to connecting pipelines) at this time.	All North Atlantic Hurricane Models (except the Offshore Platform Hurricane Model)
Business Interruption—losses resulting from extended power outages	Losses due to business interruption and the spoilage of perishable goods caused by extended power outages are not explicitly modeled in the North Atlantic Hurricane Models. When longer-than-expected power outages occur, as was the case in Hurricane Katrina (2005), the model will not fully represent this component of the reported industry loss.	All North Atlantic Hurricane Models

Reliance on Model Evaluation by Another Actuary (ASOP Section 3.7)

RMS has actuaries on staff who can assist other actuaries for the purposes of satisfying ASOP No. 38 (Doc. No. 155). For a specific model and intended application, the actuary on staff may have conducted some or all of the evaluations and processes described in the standard. On a case-by-case basis, the actuary on staff may be able to affirm that a model evaluation, in accordance with all or part of the standard, has been performed. The relying actuary can then proceed to document the extent of such reliance in accordance with the required communications and disclosure section of the standard.

Proprietary Information (ASOP Section 4.2)

RMS will clearly communicate whether any documentation provided by RMS contains proprietary information. The actuary relying on proprietary information agrees not to release such information to unauthorized parties or individuals.

RMS will not provide or comment on client data or information.

Prescribed Statement of Actuarial Opinion (ASOP Section 4.4)

This document is not a prescribed statement of actuarial opinion, nor is it intended to serve as one. However, if an actuary provides a PSAO as part of a specific assignment or task, this document or parts thereof may be included in the PSAO as deemed appropriate by the actuary.

Appendix A: Principles of Validation of RMS Natural Catastrophe Models

Introduction

Catastrophe models integrate scientific knowledge of the underlying phenomena, engineering principles governing the performance of buildings and other elements at risk, and financial and actuarial models, to derive the potential financial, human, and economic consequences to different affected groups.

As catastrophe modeling plays an increasingly important role in informing insurance and reinsurance capital management and transactions, the importance of understanding the uncertainties inherent in catastrophe risk and models is also growing, together with recognition that learning is ongoing. RMS is taking a leading role in providing more openness into model assumptions, to help insurers and reinsurers to better understand key modeling decisions, to adapt faster to new information, and to own their view of risk. As part of this ongoing role, RMS is committed to providing the tools and model transparency necessary to help users establish resilient risk management strategies, which are based on a full understanding of all aspects of catastrophe risk, and explicitly consider the implications of model uncertainty on their portfolios.

This document therefore discusses the main principles of model validation followed by RMS during model development, and demonstrates the principles underlying robust validation techniques. As such, it forms part of a range of broader RMS initiatives, each aimed at providing full transparency into model development, calibration, and validation. In addition, for every new model release, RMS provides model licensees with access to a detailed suite of model-specific validation materials, to contextualize their loss results. Furthermore, during each release, a range of expert RMS advisers can advise clients about additional validation with their specific exposure and claims datasets as appropriate.

In keeping with this principle, RMS also encourages catastrophe model users to conduct their own validation of catastrophe model output.

While this document equips catastrophe model users with a framework they can use to evaluate the validation metrics of a catastrophe model, it is not designed to provide a comprehensive validation of RMS models. Instead, it directs the reader to more detailed documentation, available to model licensees, that describes the validation procedure applied to specific RMS models.

Validation Considerations

RMS uses a variety of techniques for validating catastrophe models during and following model development, and when updating models. This process is particularly important when we update models with new methods for estimating parameters, or after a catastrophe event provides us with additional hazard and risk benchmarks.

Appropriate validation techniques for a model component depend on its role in the overall model and the availability of necessary data for comparison. We validate each component of contributing models individually, as well as overall risk and loss metrics. In each case, we assess the appropriateness of the comparative data.

During model development, independent internal and external experts review component model methods, component model results, and loss results. During these review cycles, we validate model components iteratively, as initial comparisons highlight areas requiring refinements or additional research. As clients can find it challenging to perform these sorts of component-level validations, we provide licensed users with detailed documentation of this process.

During validation, we take care to compare equivalent metrics, to consider uncertainty in both the model components and the validation metrics, and to evaluate the significance of each test, to avoid drawing false conclusions. Similarly, we advise clients to note five Key Considerations when evaluating validation techniques.

Key Considerations

> 1. Catastrophe models extrapolate beyond a limited historical record in a rational and consistent manner.

Catastrophe models represent complex physical processes by characterizing multiple components (e.g., stochastic, hazard, and vulnerability), each of which describes a unique aspect of the overall process. We calibrate components and their contributing parameters both independently and together. The resulting models produce a range of possible outcomes beyond those indicated by the historical record. Catastrophe models are particularly applicable for modeling low-frequency and high-severity catastrophe losses, as the historical record for such extreme events is often quite limited and potentially flawed. However, despite this lack of completeness in historical loss data, we always validate catastrophe models, both by component and overall, against all the available historical data, to ensure consistency with observations.

> 2. Calibration of model components balances physical relationships with signals and patterns found in observation records.

In general, we focus on ensuring that catastrophe models are consistent with known physical principles related to the underlying hazard. However, sometimes strong signals in the observation record run counter to the prevalent physical theories. In all cases, we therefore evaluate the theory against observations to ensure consistency with both physical principles and the historical record.

> 3. Model enhancements are based on long-term research programs designed to improve the modeling process.

We supplement analysis based on the historical record with substantial research investments across our global modeling suite. We partner with local experts and academic centers of excellence to derive additional insights, and publish snapshots of our ongoing research activities, both in external, peer-reviewed academic papers, and in the semi-annual client-focused Horizons publication. As we do not adjust models in reaction to single events without additional research, it can take some time after events to release model updates.

4. Catastrophe models are validated against appropriate measures of historical experience both by component and across the complete model.

Comparisons to industry losses form one important part of the validation framework. We commonly use the following industry loss experience benchmarks to validate overall model performance: historical event losses, industry average annual loss (AAL), and the exceedance probability (EP) curve. Each benchmark has limitations, and individually cannot be used to judge a model's validity. In addition, because historical industry loss experience alone cannot conclusively validate the model, we validate model components individually, using the science and data specific to each component. We publish the results of our component and industry level validations to our client base with full transparency.

5. Model users should be aware of the potential for inappropriate model validation metrics.

We encourage users of catastrophe models to validate catastrophe model output. Nevertheless, we advise caution in misinterpreting validation comparisons. For example, some model validation metrics may be incomplete or misleading. These include real-time validation, incomplete comparison to public datasets, and erroneous conclusions derived from statistics based on the limited historical record. Some limitations of these other types of validation metrics are discussed in Misleading Validation Comparisons.

Types of Model Validation

During the model development process, RMS uses a range of tests to validate model output at the individual component and overall model level. Our models therefore capture individual processes accurately, and produce losses consistent with historical experience. This section discusses the general types of validation tests we use, and the limitations associated with each type.[2]

- **Component validation** tests the stochastic event, hazard, vulnerability, and financial loss modules of a catastrophe model, and their contributing parameters. These tests provide assurance that the methodologies are built on a robust framework.
- **Overall validation** includes both industry-wide and client portfolio validation tests, demonstrating that, together, the model components reproduce reasonable loss estimates. Components may contain simplifying or efficiency-driven assumptions, which we evaluate to confirm that their impact on the losses is non-material through validation with industry- or portfolio-level data.

Loss validation tests compare industry or client portfolio modeled losses to reported losses from historical events. Industry losses provide a general understanding of how the model performs on an aggregate level; company portfolio losses provide a more granular analysis of specific geographic regions, lines of business, constructions

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[2] RMS documents detailed descriptions of all model validation tests performed which can be accessed by licensed clients.

types, and so on. The actual techniques and processes for validating a given model depend on which aspect of the model is being validated, the role it plays in the overall model, and the availability of necessary data for comparison.

A key challenge in validating modeled losses is the deficiency of historical loss data. Catastrophe losses, unlike other types of insured losses, have only a small number of data points, while losses to properties at risk are highly correlated. Therefore experience-based models, used for pricing automobile insurance, for example, are insufficient to estimate the risk.

Thanks to our ongoing commitment to model transparency, clients can review specific loss validation materials for the models that they license, in either specific loss validation documents or overarching model validation documents, for all RMS models released since 2011.

As shown in Table 4, both component and loss validation tests can be further characterized into those that test specific values for individual events, and those that test distributions of values across a set of events. In the latter case, we compare distributions resulting from the historical event with distributions resulting from the model's stochastic event set. The purpose of each type of validation test is described in the following table. Each test provides an additional degree of confidence in the model.

Depending on data availability, where possible we emphasize (a) component validation and (b) portfolio loss validation for events with contemporary portfolio exposure and loss data. In contrast, we do not advise relying solely on industry loss validations, which are prone to errors, due to uncertainties in producing credible industry loss estimates for events far back in time. Instead, we prefer to use industry loss validation primarily as a qualitative reasonableness check.

Table 4: Types of Validation Tests for Catastrophe Models

Validation Level	Validated Element	Description
Component Validation	1. Event-Based Component Output Variables	Ensures that variables predicted by a component match observed values for specific historical events.
	2. Historical Distributions of Component Output Variables	Validates the distribution of component output variables against historical observations or other independent analyses.
Overall Validation	3. Portfolio Validation (Historical Portfolio Event Loss)	Validates the overall model losses by comparing insurance--company claims data with modeled loss estimates for the underlying insurance-company portfolios. We model historical event losses using reconstructed hazard footprints and compare the modeled losses to the reported claims.
	4. Historical Industry Event Loss	Validates modeled industry losses produced using an RMS industry exposure database (IED) by comparing them to trended, reported market-wide losses. The industry loss observations are trended to reflect changes in exposure concentrations over time in the footprint of the event. Due to uncertainties in both trending and reported loss values, this test is limited to events from the last 20 to 25 years.

Validation Level	Validated Element	Description
	5. Historical Industry Average Annual Loss (AAL)	Uses reconstructed footprints to approximate industry losses for the entire event history. We use this historical proxy to validate the model's stochastic event set, by comparing the AAL of the historical industry loss proxy with the AAL of the model.
	6. Historical Industry Exceedance Probability (EP)	Compares an EP curve derived from historical reconstructions with the modeled stochastic EP curve.

Component Validation

Components of a typical model include a stochastic event module that describes a range of possible events, a hazard module that describes, for each event, its potential impact, and a vulnerability module, which describes how the event severity relates to the damage. A financial module then evaluates the financial consequences of each event from various financial perspectives, as discussed in other RMS documentation.

Each of these components itself comprises several independently validated components. For example, in an earthquake model the stochastic event module includes various component modules, each of which describes a different earthquake source (e.g., crustal faults, intraslab, interface, background seismicity) in terms of its geometry, fault rupture mechanisms, event severity/recurrence relationships, time-dependence, etc. Similarly, the hazard module describes, for each event, the resulting ground motion, plus secondary consequences such as liquefaction and landsliding, in all affected locations.

The full scope of component-level validation is described in detail in RMS documentation for each product, and is available to licensed clients on a product by product basis. In addition, specific public documents fulfil obligations under certain legislations—for example, for the U.S. Hurricane Model, material provided by RMS in its submission to the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM) (RMS 2017) illustrates several tests used to validate hurricane model components.

Stochastic Event Module Validation

The stochastic event set is a database of simulated events, each characterized by a specific strength or size, location, or path, and probability of occurring (known as event rate). We simulate thousands of possible event scenarios, based on realistic parameters and historical data.

To validate the stochastic event modules for each peril model we use historical data currently accepted in the scientific community. In some cases, we construct our own historical catalogs with assistance from local and global scientific agencies, extending beyond “publicly” available catalogs or building a catalog from scratch. Over time more historical data becomes available, either because events happen, more research into historical events (such as using sand cores for long-history earthquakes) is completed, or an agency may make previously unavailable data available. Additional data can sometimes necessitate a re-calibration of the stochastic event set.

Hazard Module Validation

The hazard component of catastrophe models quantifies the severity of the event in a geographical area, once the event has occurred. Hazard validation tests typically demonstrate the degree to which a model can reproduce an “event footprint,” which is a spatial representation of hazard intensity from a specific event. For example, an earthquake model calculates the peak ground acceleration (PGA) across a region for each earthquake in the event set. For hurricanes, the model calculates the peak wind speeds at each location affected by the storm.

In addition, if the historical record is robust enough, hazard validation tests compare probabilistic distributions of hazard intensity between the historical and stochastic event sets.

Vulnerability Validation

RMS peril models capture property vulnerability in various ways. Most current models capture property vulnerability as mean damage ratios (MDR), expressed as a percent of value, for a given hazard level (e.g., ground motion or wind speed), and the uncertainty around that MDR, expressed as a coefficient of variation (CV).

Thanks to recent technological advances, and the use of cloud-based applications to speed up analyses, the latest generation of RMS high-definition (HD) models benefit from ground-up simulation, which enables more granular loss calculations. Therefore, HD models characterize property vulnerability using a mixed four-parameter distribution, which explicitly captures the observed probabilities of zero and total losses at any hazard intensity, and improves sampling efficiency during ground-up simulation.

The process of developing and validating vulnerability curves can be difficult, as outwardly identical buildings subject to the same level of hazard can sustain different levels of damage. The uncertainty in building performance may come from differing construction quality (e.g., different spacing of roofing nails because a different building contractor was used), unknown building characteristics, or from the inherent uncertainty in building response to the intensity and duration of the hazard.

To validate the vulnerability component in RMS models, we review and assimilate local and global engineering literature, which provides insights into the impact of local and regional building practices, design codes, and enforcement on the performance of buildings. In addition, we use insights from both internal and external structural and civil engineering experts on the performance of key structural elements of typical building types, and we build partnerships with local and global centers of academic excellence.

Finally, vulnerability component validation considers local impacts of recent historical events on the building stock, and the resulting losses. As such, the component validation process for vulnerability is supported by the overall loss validation from insurance company portfolios.

Overall Loss Validation

As catastrophe models are designed to estimate expected losses, a key step in the development process is to validate the model output against various loss benchmarks (items 3 to 6 in Table 4). This process of overall model loss validation is generally split into two types—portfolio loss validation and industry loss validation.

Portfolio Loss Validation

To validate overall model performance, we compare insurance company portfolio claims data with modeled losses from historical events (item 3 in Table 4). These analyses ideally use contemporaneous client exposure data (from the time of each event) as an input to the model. This overall portfolio loss validation test confirms that the model's historical footprints and vulnerability components are collectively able to recreate observed losses from actual insurance portfolios.

In many regions, including the United States, this test provides multiple data points for each event, as many companies share such data for a number of events. By basing modeled losses on exposures at the time of the event, we eliminate the need to make trending adjustments to the exposure or incurred loss. The model passes this validation test if the modeled losses are well correlated with actual losses without systematic bias to over or under-predict actual losses.

Portfolio loss validation uses insurance portfolio claims and their associated exposure datasets. Increasingly, client portfolios report both loss and exposure at a more granular level than is available for the industry level losses (for example, providing exposures and losses at account or location level losses). Therefore, portfolio loss validations rely less on assumptions associated with vulnerability characteristics (i.e., inventory distributions), hazard aggregation (i.e., modeling of wind speeds on a postal code basis), and financial assumptions (i.e., penetration rates and average deductibles) than industry loss validations.

Portfolio Data Collected

RMS collects loss data from partner clients for developing, calibrating, and validating model vulnerability functions. Where available, clients also disclose construction characteristics and insured value information for the associated exposure.

Depending on typical practice in the region and insurance market concerned, or company practice in capturing data, the use of observed claims sets must deal with a variety of issues concerning data accuracy, completeness, vintage, and resolution.

Table 5: Common Issues with Portfolio Exposure and Loss Data

Type of Data	Common Issues	Workarounds and Assumptions
Loss Data	Reported losses do not include losses below the deductible, or losses that exceed the insurance policy limit	Discuss with insurer to apply appropriate adjustments to the data
	Reported losses not broken down by coverage	Assume coverage loss breakdown

Type of Data	Common Issues	Workarounds and Assumptions
	Concurrent causation losses, such as wind and flood, lack claims information at the detailed level needed	Apply assumptions about order of loss, proximate cause, and relative contribution of each peril
	Reported losses aggregated, and thus difficult to allocate to location level	Apply loss disaggregation assumptions, or hazard aggregation assumptions, to match hazard and loss resolution
	Claims not finalized	Allow at least six months to elapse after an event before gathering portfolio loss data from clients, to allow the claims departments enough time to settle the majority of claim files.
Exposure Data	Accurate geolocation data not available (common in some regions, particularly for older vintage data)	Apply assumptions based on higher-resolution industry exposure database (IED) data
	Exposure data may capture only proxy information, i.e., year built, rather than actual physical attributes.	Apply assumptions based on RMS property inventory
	Exposure data does not differentiate between total sums insured and exposed limits	Apply limit to value assumptions
	Lack of information about undamaged properties	Request full exposure data from client. Data cannot be used to validate mean damage ratio, although it can be used to validate conditional mean damage ratio
	Characteristics of an individual company portfolio may not reflect all segments of the population at risk depending on the geography and underwriting criteria for the contributing company.	Gather data from a large number and variety of clients, so that representative building characteristics and locations are included in the validation process.

We follow an extensive review and analysis process to minimize the issues associated with claims data analysis used in the validation process.

The amount of portfolio client data available depends on the region and peril. Hazards that occur more frequently, or have happened more recently, or both offer more opportunities to collect data.

Industry Loss Validation

Industry loss validation involves comparing total insurance industry modeled loss to historical industry loss. These aggregate comparisons require modeling of the insurance industry exposure. RMS industry exposure databases (IEDs) capture all lines of business covered for the relevant peril, and can be used in industry loss validation comparisons.

Industry loss validations have greater uncertainty than component and portfolio level validation. Model users need to ensure that they are comparing relevant information, as several potential pitfalls exist with this test.

We suggest that the best practice for validating a model against industry losses involves comparing model loss output to three benchmarks (items 4 to 6 in Table 4):

- Historical Industry Event Loss Validation—Adjusted industry loss observations for individual events over the last 20–25 years (item 4 in Table 4)
- Historical Industry Average Annual Loss Validation—The historical average annual loss (AAL) derived across the known historical record of industry event losses, based on modeled output from an industry exposure database and reconstructed historical event footprints (item 5 in Table 4)
- Historical Industry Exceedance Probability Validation—The implied historical exceedance probability curve based on the entire historical industry event losses combined with a simple event frequency assumption (item 6 in Table 4)

These historical reconstructions use observed and modeled losses developed on the same exposure and time basis:

- Either—estimate model loss for the same time frame and state of the exposure set as at the time of the event
- Or—convert observed loss into equivalent losses for today’s environment and exposure.

Each method has limitations. The choice of whether to bring losses forward in time or exposures backward to the time of the event depends on the data sources available.

The observed industry loss estimates must reflect a significant degree of stability. For example, industry loss estimates created by the Property Claims Service, Ltd. (PCS), can be used to validate modeled estimates in the U.S., and are based on loss experience of Insurance Services Office, Inc. (ISO) member companies combined with market share information. Since these estimates tend to evolve in the months after a given event, RMS allows at least six months after an event for PCS loss estimates to stabilize. Similar procedures are followed when working with observed loss estimates for other countries and regions.

There is uncertainty in the actual industry loss estimates used as comparisons. For example, PCS does not have 100 percent market share, so they use an extrapolation model to project up to 100 percent. Similarly, in Europe, the PERILS organization has in recent years been releasing industry loss estimates for recent events by scaling losses across some representative market participants up to 100 percent. However, further back in time, industry loss estimates become increasingly uncertain.

In assessing industry loss benchmarks, RMS considers as much data as possible, to obtain reasonable measurements across multiple events.

The RMS IEDs contain insured values and building characteristics in force by peril and by line of business for major insurance markets of the world at a given time. For each peril region, insured values are developed for geographic regions (e.g., county or ZIP Code in U.S., prefecture or CRESTA zones in Japan, and postal code or CRESTA zone in Europe) based on available data such as:

- Census demographics
- Building square footage data
- Macroeconomic data
- Population and household demographics
- Business statistic
- Property information
- Representative policy terms and conditions
- Sampled company premium information

We first released IEDs in the U.S. for earthquake and hurricane exposures in 1997, subsequently releasing a growing number of such datasets worldwide. We trend IEDs to account for growth in the building stock and in property values, where applicable. In addition, every few years, we integrate new data sources and new methodologies, resulting in larger step-changes in the estimated insured values at risk.

Historical Industry Event Loss Validation

We compare reported industry losses, adjusted for trends in exposure density, to modeled losses from reconstructed events, to validate historical reconstructions. Individual event comparisons may be variable, but overall across a wide variety of events we expect such comparisons to show that the model has no discernible biases.

However, the number and character of properties and values exposed to events changes over time. In addition, governments respond to events by changing construction codes, and inhabitants also respond by retrofitting and applying temporary or portable protection measures (e.g., for flood protection). Therefore, the vulnerability of the exposed inventory of properties also changes over time. It follows that reported losses must be adjusted or trended to a comparable vintage before making comparisons to the model output, which is based on a present-day representation of insured exposure. As these adjustments are subject to increasing uncertainties for events further back in time, we advise that no more than the past 20–25 years should be used to compare model with reported industry losses.

Historical Industry Average Annual Loss Validation

Validated historical losses can be used for further model validation tests. For example, a further validation test involves checking whether summary statistics based on historical loss observations are consistent with the model statistics. The previous section establishes that there is diminishing confidence in industry loss reporting and trending going backwards in time.

Historical Industry Exceedance Probability Validation

In addition, we validate the stochastic model using an implied historical EP curve. This test compares the stochastic EP curve to an EP curve constructed from historical losses. It involves creating an assumed historical EP curve using some approximation of the historical industry event losses. Although the historical event losses used in this way can be derived directly from the record of historical industry losses, these losses are not equivalent to one another, and must be trended forward to a common vintage. These uncertainties are compounded for relatively infrequent, high severity events. For this reason, we typically create a proxy for the historical industry losses by calculating historical modeled losses to the IED, using modeled, historical event reconstructions. This process lengthens the reliable historical record of event-loss approximations. We apply a simple event frequency assumption to the approximated total historical record of industry event losses to produce an EP curve that can be compared to the stochastic event EP curve.

Misleading Validation Comparisons

RMS welcomes outside scrutiny of catastrophe models, and supports model users undertaking their own catastrophe model validations. However, some validation techniques are not scientifically valid and others can be misleading. This section discusses some of the potential pitfalls that clients may encounter during the model validation process, and associated avoidable errors.

Comparison to Real-Time Events

At first glance, a catastrophe model's ability to produce loss estimates for real-time events could potentially be considered a form of model validation. However, catastrophe models are not designed to be predictive forecast tools of single events, but instead to reproduce a range of possible events that can be used to extrapolate the historical record, and price and mitigate risk accordingly.

Predicting losses for a real-time event requires selecting input parameters that reflect scattered, uncertain, and unverified hazard observations and estimates of affected exposure within days of the event's occurrence. Real-time losses established in this way are themselves uncertain, and subject to change over time as claims are settled.

Thus, we consider that the validation techniques outlined in this paper are more effective in examining the validity of a catastrophe model than comparisons between model output and real-time loss estimates.

Comparison to Public Domain Publications

Several authors have published works in the public domain that describe techniques for estimating annual losses from subsets of catastrophe events. For example, Pielke et al. (2008) converted economic hurricane losses reported in newspaper and weather service reports from 1900 to 2005 to losses in 2005 dollars. Barredo (2009) normalized Europe-wide reported economic flood losses in the period 1970 to 2006, from the Emergency Events Database (EM-DAT) and from Munich Re's Natural Hazards Assessment Network (NATHAN) databases (Munich Re), to a common date.

Similarly, in a 2010 publication the same author normalized Europe-wide reported economic windstorm losses in the period 1970 to 2008 from the NATHAN database (Barredo 2010).

Such “rule of thumb” studies do not necessarily aim to establish an accurate average annual loss baseline for the insurance industry, but instead to depict trends in loss over time, and thus to understand how climate hazard activity may be changing, for example in response to anthropogenic climate change.

In addition, insurance industry commentators such as Swiss Re publish catastrophe loss estimates for key global historical events, normalized to the present day. Such publications focus on indicating, at a high level, the relative risks posed by contrasting global events. They use simple inflationary trends to estimate the present-day losses, and do not explicitly account for changes in insured inventory or vulnerability over time. In addition, they tend to apply simplified assumptions to trend losses. For example, they may apply trending factors only to original losses converted to a single common currency, such as U.S. dollars, and ignore currency volatility, gross domestic product (GDP) growth, construction, and other macroeconomic complexities that may influence the reality of local, present day losses from a similar event. We therefore recommend applying them with caution in validating models, firstly because they are not designed for that purpose, and secondly because of this lack of transparency in the underlying trending techniques.

Conclusion

Catastrophe models have become an integral component of insurance risk management strategies, and are valuable tools for dealing with high-severity, low-probability events like hurricanes and earthquakes. Their component based design allows models to extrapolate beyond a limited historical record. They are specifically designed to overcome the limitations of working only with highly skewed historical loss distributions.

We validate all aspects of our models, from individual components of hazard and vulnerability to overall loss output from a wide variety of sources. This paper describes some of our validation methods, with worked examples to illustrate these methods in practice.

We encourage users of our models to investigate the uncertainties inherent in catastrophe modeling. By detailing our model validations, we provide users with the tools they need to take ownership of their view of risk. This paper provides a framework through which model users can both validate models, and understand the strengths and limitations of the different validation methods available.

As the science of catastrophe modeling continues to evolve, we will rigorously validate further model enhancements in similar ways to the methods described in this paper.

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