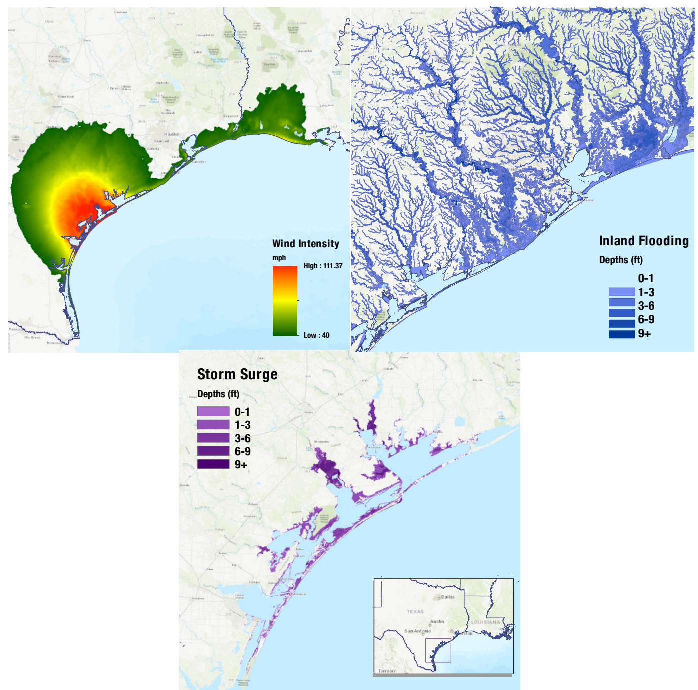
AIR Hurricane Model for the United States

Hurricanes Harvey and Irma in 2017 and Michael and Florence in 2018 caused billions of dollars in insured losses in back-to-back years. Companies need a robust model that provides reliable and detailed information about potential wind, storm surge, and precipitation-induced flood losses before they occur, as well as the ability to differentiate these risks at a granular level.

AIR founded the catastrophe modeling industry in 1987 with the development of the first U.S. hurricane model for use by the insurance industry. With each update since, AIR has advanced the state of the art of hurricane modeling, incorporating the latest scientific research on the formation and impact of these complex storms.

> "I am impressed by the level of knowledge and understanding of the AIR research team. In my view, the AIR wind field model gives reasonable results, given a peak gradient wind and radius of maximum wind."
>
> –Dr. Kerry Emanuel (MIT)

The steady increase in the number and value of coastal properties continues to raise the risk of catastrophic losses from hurricanes. To facilitate risk assessment and risk differentiation at a highly granular level, AIR has also amassed an unparalleled body of knowledge about the vulnerability of structures exposed to hurricane winds, storm surge, and precipitation-induced flood, augmented by independent research, post-event damage surveys, external peer review, and a vast wealth of claims and industry insured loss data from clients and from within the Verisk network, as well as a comprehensive model validation process. As scientific knowledge and the landscape of insured property evolve, AIR's commitment to innovation makes the AIR Hurricane Model for the United States the most reliable and trusted in the industry.



Wind speed, inland flooding, and storm surge footprints of Hurricane Harvey in 2017. (Source: AIR, using ESRI base maps)

Unified Catalog Enables Comprehensive Basin-Wide Risk Assessment

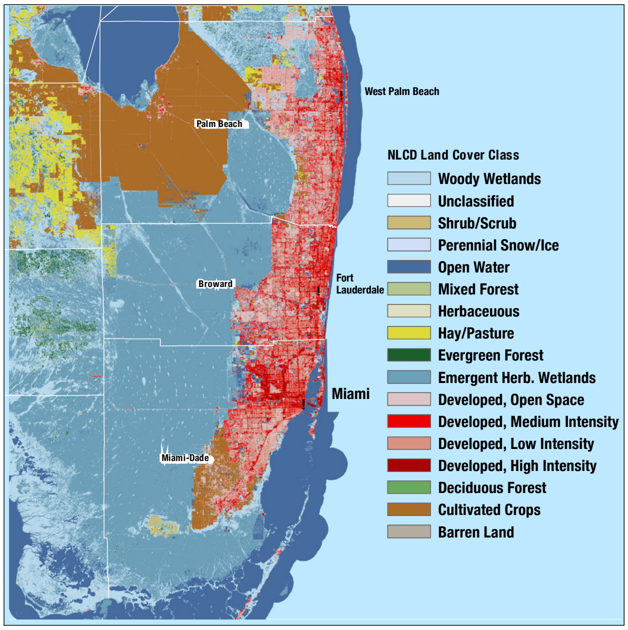
The AIR hurricane model features a unified basin-wide catalog of simulated events affecting the United States, Canada, the Caribbean, Mexico, and offshore assets in the Gulf of Mexico. Because a significant percentage of storms in this region affects more than one model domain, this comprehensive event set allows companies to more accurately model losses to insurance policies and portfolios that span multiple countries.

Providing Multiple Views of Risk in a Warm Ocean Environment

Sea surface temperatures (SSTs) in the North Atlantic basin have been anomalously high since 1995. To help U.S. hurricane model users understand the sensitivity of hurricane risk to a warmer ocean climate from natural variability or climate change, the AIR model offers a version of our 100K catalog that considers additional landfall activity in the years since 1900 with higher-than-average SSTs, reflecting the potential increased risk if these conditions persist. AIR's ensemble approach provides multiple credible views of risk based on objective and scientifically defensible research.

Accounting for Directional Effects Is Key

Knowing the location and intensity of the strongest surface-level winds in a hurricane is critical to producing reliable loss estimates. The AIR model incorporates the latest research in wind field modeling to achieve an unprecedented level of detail and accuracy.



AIR explicitly models the effects of surface friction on wind speeds based on wind direction. In south Florida, a northeast wind will be relatively unobstructed as it comes in off the Atlantic Ocean, while a wind from the west will have to travel over the built-up urban environment of the Miami-Dade, Broward, and Palm Beach Counties. (Sources: AIR, USGS)

Realistic modeling of surface-level wind fields requires properly accounting for the effects of the local environment on wind speeds. Along the coast of southern Florida, for example, where swampy surfaces, rough urban surfaces, and ocean surfaces are often located alongside each other, wind speeds can vary quite dramatically as a result of surface friction. By incorporating the latest satellite-derived, high-resolution, land use/land cover (LULC) data, the AIR model captures the accumulated surface friction effects of land and water based on the direction of the wind at each location.

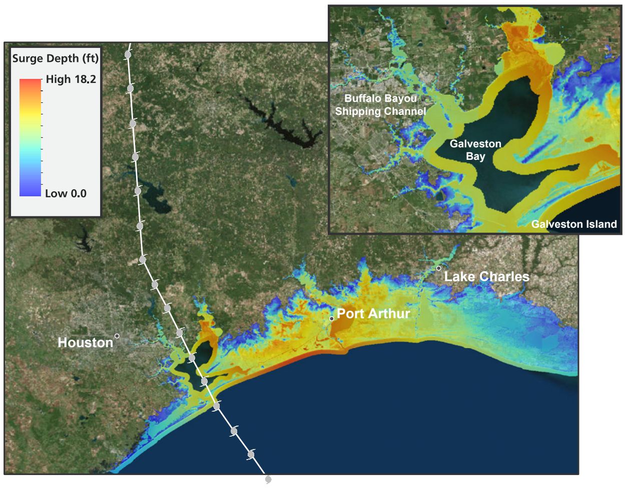
Full Spatial Coverage Ensures Realistic Inland Losses

The remnants of a hurricane can combine with pre-existing storms and re-intensify, as dramatically demonstrated in 2008 by Hurricane Ike, which caused damage as far north as Ohio and Michigan. The AIR model explicitly allows for the small possibility of re-intensification after landfall, consistent with historical experience. Even storms that don't re-intensify can travel hundreds of miles inland after landfall. To reflect the full spatial extent of potential losses, the AIR U.S. hurricane model extends far inland from coastal states, covering a total of 29 states and the District of Columbia.

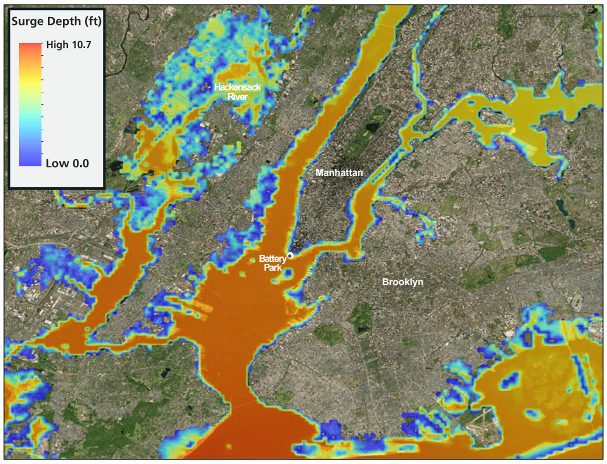
Hydrodynamic Storm Surge Module Captures Complexity of This Costly Sub-Peril

There are nearly 3,000 miles of U.S. coastline at risk along the Gulf of Mexico and Atlantic shoreline, with the value of insurable property totaling more than USD 13 trillion in coastal counties. Depending on the characteristics of a given storm, hurricane-induced storm surge can be more devastating than wind. With AIR's hydrodynamic storm surge module, high-resolution storm surge extent and depth footprints are now a reality.

The module, which has been rigorously validated at the most detailed level, accounts for spatial and temporal tidal variability, complex coastal geometry, and localized changes in elevation. Steeper slopes and rougher terrain onshore cause more rapid surge attenuation than gradual slopes and smoother terrain. The physical characteristics of a given hurricane play a significant role in determining the storm surge intensity as well: A slowly moving storm, which extends the time that wind stress interacts with the ocean surface, can have greater surge potential than a storm with a faster forward speed. AIR uses high-resolution terrain information to model the change in water depth as storm surge is propagated inland.



AIR's modeled surge depth for Hurricane Ike in 2008, whose large wind field pushed storm surge over 15 miles inland, into the low-lying marshes and wetlands of eastern Texas and western Louisiana. Inset: Ike's Galveston Island landfall produced a 15-foot surge to the east of Galveston Bay that penetrated into Houston via Galveston Bay and the Buffalo Bayou Shipping Channel. (Source: AIR)



AIR's modeled surge depth for Hurricane Sandy in 2012, whose 9.4-foot storm surge combined with a full moon high tide to create a record 14-foot storm tide (above Mean Lower Low Water, or MLLW) at Battery Park, at the tip of Manhattan. (Source: AIR)

The destructive impact of storm surge—which includes property inundation, damage from the force of moving water, debris collision, and sedimentation—can affect residential and commercial exposures from the immediate coast to miles inland. The current New Orleans flood protection system—reflecting reconstruction and upgrading since Hurricane Katrina—as well as probabilistic failure scenarios for the system, have been accounted for explicitly.

Flood Modeling Captures Hurricane-Induced Precipitation at High Resolution

Hurricanes Harvey and Florence demonstrated how precipitation-induced flooding caused by hurricanes can significantly contribute to insured losses. The precipitation footprints of hurricanes typically extend for hundreds of miles, so even storms far offshore can cause significant inland flood damage. Furthermore, the intensity of hurricane-related precipitation can actually increase as it moves inland.

Flood risk is driven in part by antecedent conditions, such as the moisture content of the soil and river levels. To model this aspect, AIR first developed a unified view of flood hazard, capturing all large- and small-scale precipitation patterns across the U.S. AIR employed a technique that couples a state-of-the-art Global Circulation Model (GCM) with a high-resolution Numerical Weather Prediction (NWP) model and an advanced statistical downscaling algorithm. This innovative approach simulates realistic and statistically robust precipitation patterns over space and time.

AIR also developed an innovative data-driven method employing machine learning to map realistic tropical precipitation patterns onto the existing hurricane catalog tracks. This combined physically and statistically based approach produces a robust estimate of the full risk potential from hurricane-induced flooding while retaining continuity in risk assessment across our existing hurricane catalogs.

The modeled hurricane precipitation was suitably blended into the non-tropical precipitation catalog. This resultant unified precipitation catalog was then employed to model the hydrological response on a continuous basis throughout the year. The flooding impacts due to non-hurricane precipitation and hurricane precipitation were then segregated into AIR's

U.S. inland flood and U.S. hurricane models, respectively. When these models are used in combination, they provide a comprehensive, unified view of flood risk.

Comprehensive View of Risk Both On and Off the Floodplain

By incorporating rainfall rates from modeled precipitation, the model determines the spatial and temporal distribution of accumulated runoff in rivers and over land. River data and up-to-date information on flood mitigation measures inform the model, including the level of upkeep on levees and dams. A high-resolution (10-meter) digital terrain model (DTM) with data on soil characteristics, land use/land cover, and slope is used to provide a realistic, physically based simulation of the flow and pooling of water over land throughout the model domain. This off-floodplain risk—a significant source of flood losses—is also informed by data on drainage systems in urban/populated regions.

ALERT - AIR LOSS ESTIMATES IN REAL TIME

AIR's ALERT™ (AIR Loss Estimates in Real Time™) has provided estimates of insured losses from extreme events in real time since Hurricane Hugo in 1989. AIR uses the storm parameters reported by the National Hurricane Center, including forecast track, landfall location, and wind speeds, to produce a realistic distribution of potential industry losses, as well as tools for insurers to assess the impact of each storm on their own portfolios. ALERT keeps companies well informed at critical times, allowing them to communicate effectively within their organizations and to set expectations for investors.

AIR's real-time loss estimates can help insurers manage reserves and determine if reinsurance is adequate; ALERT can also help insurers decide how and where to effectively deploy claims resources, and even to understand where to suspend or continue writing business. Timely information is also extremely valuable in light of increasingly common financial instruments for hedging against catastrophe losses.

AIR's U.S. Industry Exposure Database

The United States Industry Exposure Database is a detailed collection of exposure data containing information on insurable properties and their respective replacement values, along with information about the occupancy and physical characteristics of the structures, such as construction types and height classifications. AIR's Industry Exposure Database provides the foundation for all modeled industry loss estimates. It provides breakdowns of all insurable properties by line of business (LOB), as well as replacement values and policy conditions by coverage for each ZIP Code.

Companies can use our U.S. industry exposure for benchmarking their own exposure, better estimating the vulnerability of unknown exposure, assessing real-time losses, and much more. AIR's Industry Exposure Database is provided in a model-ready format, making it easy for companies to begin using it for their own analyses. With AIR's Industry Exposure Database, (re) insurers and brokers can: analyze potential growth strategies; disaggregate exposure data to a highly detailed level; perform sensitivity analyses; conduct real-time analytics; validate models; and utilize exposure data for market share analysis.

Damage Functions Reflect Variations in Vulnerability Across Regions and Time

The AIR U.S. hurricane model reflects a detailed understanding of the evolution of building vulnerability in the United States. For better differentiation of vulnerability across regions and time periods, the model incorporates information on the adoption and enforcement of building codes throughout the country, changes in building materials and construction practices, and structural aging and mitigation features, as well as the specific year of construction. The model has been validated with a significant amount of claims data from storms occurring during the past 25 years.

AIR damage functions incorporate not only primary risk characteristics—construction, occupancy, size, year built and height—but also many secondary characteristics that affect vulnerability to wind, storm surge, and precipitation-induced flood. In addition, the AIR U.S. hurricane model leverages the results of detailed damage survey reports and claims data, as well as engineering data generated from full-scale testing, and explicitly accounts for many secondary building and environmental characteristics, such as roof geometry and type, connection details, wall and glazing type, foundation type, and the presence of a basement.

The AIR U.S. hurricane model explicitly captures the vulnerability of different types and sizes of residential properties to wind damage—from manufactured homes to large-square-footage homes—accurately accounting for individual building characteristics and mitigation features.

The storm surge and precipitation-induced flood damage functions for the U.S. hurricane model reflect a unified view of water-based risk. These are generated from a detailed component-level framework for buildings and contents that integrates primary and secondary building features explicitly, with buildings divided into several key components including outer structure, foundation, interiors, and service equipment such as mechanical, electrical, and plumbing systems. Views of risk can be refined with foundation and basement information (foundation type, basement level, and basement finish), surrounding detail (custom flood standard of protection, custom elevation, base flood elevation, custom flood zone), and building detail (floor of interest, first-floor height, service equipment protection, content vulnerability, wet floodproofing and FIRM compliance).

AIR explicitly captures the wind and flood vulnerability of large industrial facilities, with an enhanced framework that accounts for facility design, location, and possible levels of protection.

Accounting for Both Direct and Indirect Business Interruption Losses

For commercial interests, business interruption (BI) can account for a significant proportion of total losses. Damage to company headquarters alone, however, cannot explain total BI losses. Using an event-tree approach, the AIR U.S. hurricane model accounts for business resiliency, such as the capacity to relocate or for operations to continue while repairs are under way. Losses that result from supplier downtime, utility service interruption, and actions taken by civil authorities are also captured.

Validating Insured Losses Using Extensive Claims Data

To produce realistic and robust model results, AIR builds its models from the ground up, validating each component independently against multiple sources. AIR modeled wind speeds, precipitation totals, and storm surge inundation depths are validated using data from various sources, including the U.S. Geological Survey, the National Oceanographic and Atmospheric Administration (NOAA), the Federal Emergency Management Administration (FEMA), the Federal Insurance and Mitigation Administration (FIMA), and the U.S. Army Corps of Engineers (USACE).

AIR also validates from the top down, comparing modeled losses to industry loss estimates and company data. Modeled losses for the AIR Hurricane Model for the U.S. have been validated against actual loss and claims data from major hurricanes since 1982, from clients and from within the Verisk network. AIR's comprehensive approach to validation confirms that overall losses are reasonable and that the final model output is consistent with both basic physical expectations of the underlying hazard and unbiased when tested against historical and real-time information.

Model at a Glance

Modeled Perils	Hurricane wind, storm surge, and precipitation-induced flood
Model Domain	Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Mississippi, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Vermont, Virginia, West Virginia, and Washington, D.C.
Supported Construction Classes and Occupancies	— 84 construction classes and 111 occupancy classes — Marine lines (inland marine or transit warehouse, inland or oceangoing marine cargo, marine hull, pleasure boats and yachts), builder's risk, and automobiles
Secondary Features Supported (Reflecting Regional Variations)	The model supports more than 30 secondary risk characteristics across wind, storm surge, and precipitation-induced flooding to accurately reflect and differentiate vulnerability
Supported Policy Conditions	The model supports a wide variety of location, policy, and reinsurance conditions, including limits and deductibles by site or by coverage, blanket and excess layer limits, minimum and maximum layer and sublimit deductibles, and sub-limits. Reinsurance terms include facultative certificates, surplus share and quota share treaties, and various types of excess of loss treaties, with occurrence and aggregate limits.

Model Highlights

— Support for precipitation-induced flood to all events in all the stochastic catalogs, including the 10,000-, 50,000-, and 100,000-year standard and warm sea surface conditioned catalogs.
— Explicitly accounts for the effect of wind duration, a significant loss driver
— Provides hydrodynamic and probabilistic storm surge hazard modeling
— Accounts for precipitation-induced flooding both on and off the floodplain, informed by a high-resolution (10-meter) digital terrain model, with enhanced and up-to-date river flow and levee data
— Explicitly models variations in vulnerability across regions and time periods
— Accounts for the effects of residential building square footage on wind risk
— Accounts for spatial and temporal variation in vulnerability of manufactured homes
— Estimates risk from business interruption (BI)—often a significant source of loss—based on published research and detailed loss data, using an event-tree approach
— Event-level demand surge reflects the updated values in the 2019 U.S. Industry Exposure Database
— Provides 116 historical events, 15 of which support precipitation-induced flood such as Harvey (2017) and Florence (2018); 10 extreme disaster scenarios (EDS); and five Lloyds realistic disaster scenarios (RDS)

ABOUT AIR WORLDWIDE

AIR Worldwide (AIR) provides risk modeling solutions that make individuals, businesses, and society more resilient to extreme events. In 1987, AIR Worldwide founded the catastrophe modeling industry and today models the risk from natural catastrophes, terrorism, pandemics, casualty catastrophes, and cyber incidents. Insurance, reinsurance, financial, corporate, and government clients rely on AIR's advanced science, software, and consulting services for catastrophe risk management, insurance-linked securities, longevity modeling, site-specific engineering analyses, and agricultural risk management. AIR Worldwide, a Verisk (Nasdaq:VRSK) business, is headquartered in Boston, with additional offices in North America, Europe, and Asia. For more information, please visit www.air-worldwide.com.

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