The AIR Inland Flood Model for the United States

In August 2016, a week of unprecedented rains across southern Louisiana produced catastrophic flooding that damaged or destroyed more than 50,000 homes, 20,000 businesses, and 100,000 vehicles. Events such as these underscore the high loss potential of the flood peril. The AIR Inland Flood Model for the United States realistically and comprehensively captures the risk for flood on and off the floodplain at high resolution, allowing insurers to expand into new markets profitably.

AIR

Floods are the most frequent and costly natural disaster in the United States. At any given time, there is a flood occurring somewhere in the contiguous United States. While thousands of towns and cities located on floodplains continue to grow, concentrations of exposure in off-floodplain urban areas also continue to expand, creating more impermeable surfaces and exacerbating the hazard and potential damage and loss.

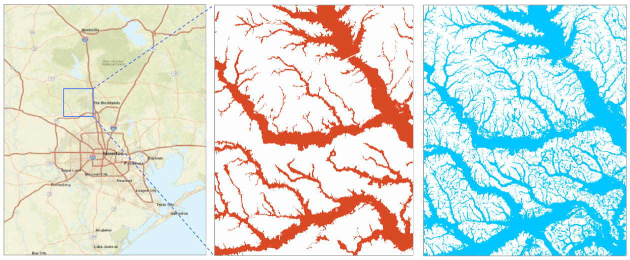
As seen during the Mississippi River floods of 2011 and the Louisiana Flood of 2016, even sophisticated flood defense systems cannot always protect homes and businesses in harm's way. The enormous watershed of the Mississippi River covers an area of 1.2 million square miles, and major floods can overwhelm defenses and cause a huge amount of destruction while disrupting businesses and infrastructure.

The AIR Inland Flood Model for the United States accounts for the complex flooding processes that affect the severity, frequency, and location of potential losses on and off the floodplains, providing risk management tools to confidently assess and manage inland flood exposure for all lines of business.

A Comprehensive View of Flood Risk across the United States

The AIR U.S. inland flood model simulates weather systems and the flooding they cause at a high resolution of 10 meters across the contiguous U.S. The model domain covers 18 hydrological regions comprising more than 8.2 million square kilometers (3.2 million square miles) and accounts for more than 2.2 million km (1.4 million miles) of river networks, as well as every smaller creek and stream, through explicit physically based pluvial modeling for a detailed and accurate flood risk assessment. In addition, the model includes 46,660 km (29,000 miles) of levee systems (and their probabilities of failure), as well as urban drainage capacity in flash floods—all in a seamless view of flood risk. Vulnerability to flood is explicitly determined at the component level, and considers regional differences in building construction, including flood zone code compliance.

AIR's model captures inland flood risk for 18 hydrological regions across the contiguous U.S., an area of more than 8.2 million square kilometers (3.2 million square miles), with a river network 2.2 million kilometers (1.4 million miles) long represented by over 335,000 distinct drainage catchments.



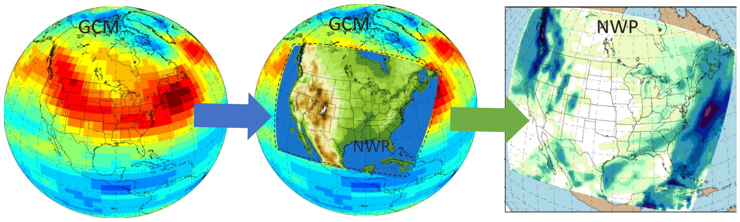
Study area near Houston (left), FEMA 100-year hazard map (middle), and AIR 100-year unified flood hazard map (right). The model includes any waterway visible on the terrain—integrated physically based fluvial and pluvial flood estimation approaches provide a detailed, seamless view of the flood hazard.

AIR's 10,000-year stochastic precipitation catalog accurately captures events of all levels of severity; from catastrophic floods that produce insured losses in excess of USD 25 million—the ISO Property Claim Services® (PCS®) threshold for issuing a catastrophe serial number—to non-catastrophic floods with smaller losses. It also includes a set of 20 historical events, including the recent 2016 Louisiana Flood and 2015 South Carolina events.

An Innovative Approach to Modeling Precipitation for a Robust View of Flood Risk

To realistically capture the varied meteorological conditions that contribute to the flood hazard, AIR first developed a unified view of flood hazard capturing tropical and non-tropical precipitation, and all large- and small-scale precipitation patterns, including bursts of extreme rainfall that contribute to highly localized flooding, across the United States. 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 physically realistic and statistically robust precipitation patterns over space and time.

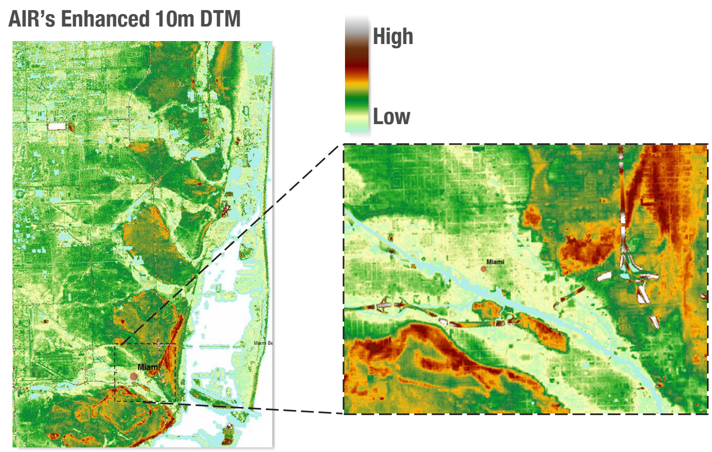
This resultant unified precipitation catalog was then employed to model the hydrological response on a continuous basis throughout the year. The flooding impacts due to non-hurricane precipitation and hurricane precipitation were then segregated into AIR's U.S. inland flood and U.S. hurricane models, respectively. When these models are used in combination, they provide a comprehensive, unified view of flood risk throughout the country.



The global Community Atmospheric Model is coupled with a regional Weather Research and Forecasting NWP model. The output is then downscaled with an advanced statistical algorithm to yield realistic precipitation patterns.

Hydrology and Hydraulics Modules Provide Highly Accurate View of Floodwaters' Movement and Location

The potential for flooding depends greatly on the antecedent conditions—the amount of prior rainfall or snowmelt—which determine the saturation levels of the soil and potential for runoff. AIR's hydrology module calculates the spatial and temporal distribution of accumulated runoff in rivers and over land. Incorporating detailed LIDAR data, our 10-meter digital terrain model (DTM) with data on soil characteristics, land use/land cover, and surface roughness informs the river channel and flood extent modeling and is used to realistically simulate the flow and pooling of water throughout the model domain.



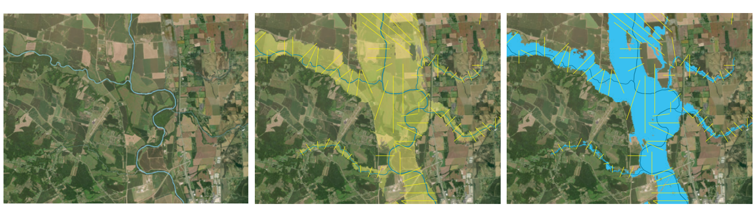
AIR's 10-meter DTM, with enhanced geoprocessing and LIDAR data, informs our river channel and flood extent modeling, providing a highly accurate view of where floodwaters will flow and pond.

Defining Flood Events

Floods can be the result of a distinct rain event or multiple back-to-back and overlapping rain events. The AIR Inland Flood Model for the United States defines flood events based on a physical understanding of what causes flooding, how floods propagate through the country's extensive river networks, and the potential for flooding far away from the floodplain. Extreme runoff and river flows are clustered into separate flood occurrences based on their spatial and temporal proximity and riverine topology or connectivity. The methodology allows the model to accommodate the current practice in the industry of defining events using the 168-hour clause.

Sophisticated Methodology for Determining Flood Inundation Depth

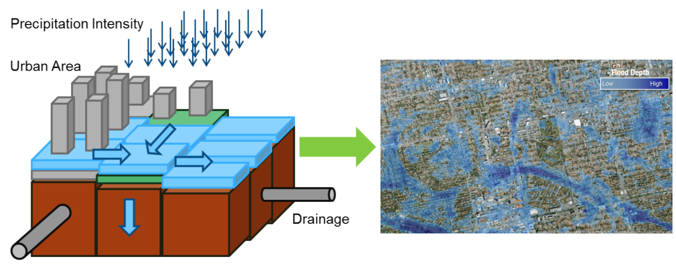
The AIR model uses a physically based hydraulics component that calculates the extent and depth of flood inundation at each location of interest. Incorporating water flow from the hydrology module, AIR's hydraulics module realistically simulates flood depth and extents using flood elevation levels at cross sections along rivers. Hydraulic calculations are performed at more than 4 million river cross sections at approximately 500-meter intervals, incorporating details of the terrain from the high-resolution DTM. Riverine flood propagation also accounts for the effects of more than 20,000 lakes and reservoirs whose storage capacity is uniquely captured through leveraged machine learning techniques.



Modeled water elevation along the river network indicated by cross sections (middle) and the corresponding modeled flood extent (right); flood depth is derived by subtracting terrain elevation from water elevation.

A Two-Dimensional Hydraulics Module for Realistic Flood Extent Simulations

Off-floodplain (pluvial) flooding—a significant source of loss—occurs when heavy precipitation falls on saturated soil, paved urban surfaces, and/or on areas with poor drainage conditions. The hydraulics module features a physically based pluvial component that realistically models off-floodplain risk over the course of an event using a two-dimensional grid methodology that determines the water balance in and movement between each grid cell in the model domain over time. Because storm drainage capacity in urban areas is highly variable and can greatly impact flood extent and depth, AIR researchers compiled nationwide data on drainage systems in urban/populated regions, their design capacity, and their upkeep to assess off-floodplain risk.



The physically based two-dimensional (2D) shallow water wave model uses a grid-based methodology that calculates the precipitation input, drainage loss, and flows between grid cells at each time step in an event to determine the location and depth of the flow, for a realistic view of flood extents.

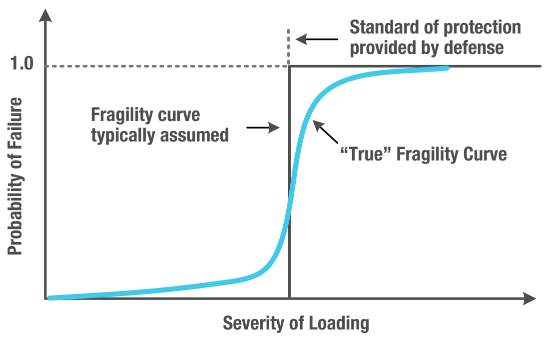
Two-dimensional modeling has also been applied in the on-floodplain (fluvial) component for floodplain regions on major rivers such as the Mississippi, for a robust view of the risk under more complex conditions, e.g., a levee breach.

AIR's physically based pluvial and fluvial modeling allows for detailed continuous flood extents and depths with location-level event intensities to assess potential damage.

Flood Defense Modeling

Recognizing that levees can fail is critical to understanding and managing U.S. flood risk comprehensively. A sizable portion of the nation's extensive levee network was built more than 50 years ago and has been unevenly maintained, adding to the complexity of flood risk estimation. The AIR model accounts for the current state of the country's levees—and their probabilities of failure—by analyzing detailed design data from more than 25,000 miles of the levee network.

Although each levee is designed for a specific standard of protection, it may fail at flood levels below the standard, or even withstand floods above the standard. AIR's model uses fragility curves that incorporate this uncertainty in determining if and when a levee fails.

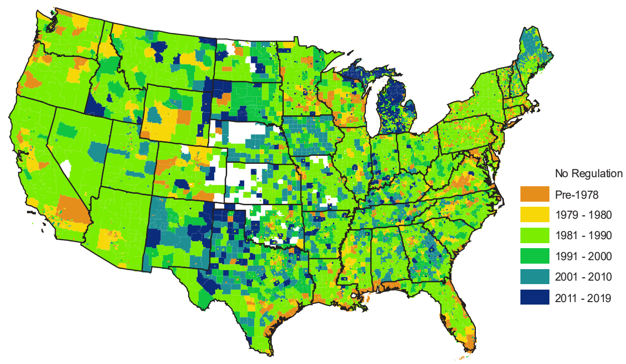


AIR's fragility curves provide the probability of flood defense failure.

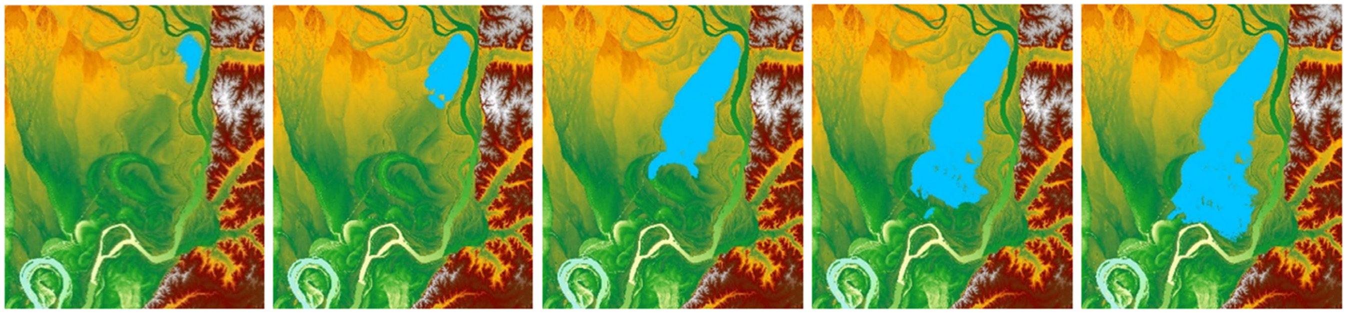
The levee system along the Mississippi River is one of the world's largest, particularly along the lower stretch of the river, where millions of homes rely on more than 1,600 miles of the mainstem flood protection system. Here, the model relies heavily on levee data and fragility curves to simulate floods along incremental stretches of the river.

A Component-Based Framework for Assessing Flood Vulnerability

The majority of the damage caused by most floods is to nonstructural components and contents. Among the building characteristics influencing the extent of damage from floods are first floor height and foundation type, as well as the location of—and strategies for mitigating risk to—service equipment, including mechanical, electrical, and plumbing systems (MEP). The year built relates to the design codes that might have been employed in the design, construction, and mitigation; these codes vary both spatially and temporally.



Flood mitigation varies across the United States, even within states. (Source: AIR)



Modeled levee breach producing a 250-year flood extent along the Lower Mississippi River at the New Madrid Floodway, Missouri. (Source: AIR)

Based on extensive research, including published engineering studies, AIR's post-event damage surveys, local data about property risk features, and claims data, AIR designed a unified flood vulnerability framework that functions at the component level to better capture how residential, commercial, and industrial buildings respond to the flood hazard, taking these features and many more into consideration to accurately quantify the risk.

The framework divides each building into multiple components that represent the foundation, structure, MEP equipment, and finishes, as well as the location of these components relative to the flood event water levels used in calculating the overall potential losses. Underlying component-level flood damage functions are then aggregated, based on their proportion to the overall replacement value, to yield the building-level damage function. The same framework underpins the flood module in both the AIR Inland Flood Model for the United States and the AIR Hurricane Model for the United States.

The model incorporates damage functions by height and year built for 81 different construction classes and 111 occupancy classes. Users can further refine information on characteristics such as basement finish, service equipment protection, content vulnerability, wet floodproofing, and level of FIRM compliance—more than 14 secondary risk characteristics allow users over 50 combination options to refine their risk differentiation and assessment.

Other highlights of the model's vulnerability framework include:

— Flood mitigation features are explicitly considered for structures such as engineered commercial and industrial buildings that follow higher standards
— To estimate time element losses, damage functions vary by occupancy and account for building damage level and business characteristics, such as resilience and ability to relocate
— When detailed exposure data is unavailable, the model applies an "unknown" damage function that takes into account regional differences in the building inventory by leveraging data from several Verisk data sets

Specialty Risks Include Large Industrial Facilities

AIR explicitly captures flood vulnerability of large industrial facilities with an enhanced framework that accounts for facility design, location, and possible levels of protection. The AIR model also allows users to override the facility standard of protection by assigning the flood height above the ground surface for which the facility has been designed—giving users the flexibility to assess the risk at multiple protection levels. Other specialized risks include infrastructure and marine lines encompassing marine cargo, marine hull, inland transit, and builder's risk.

Comprehensive Model Validation

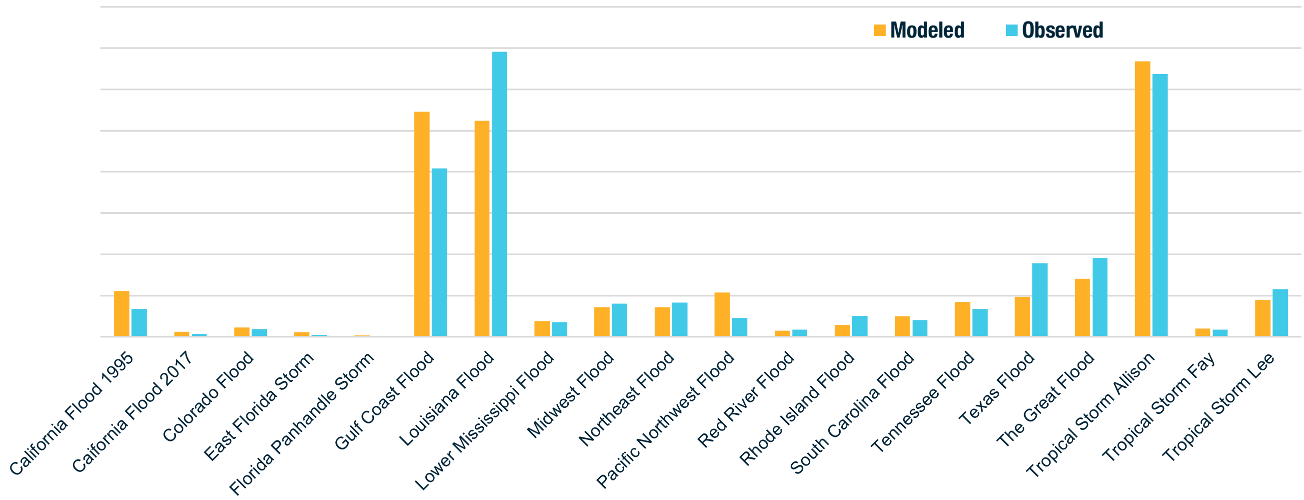
Validation is not limited to final model results in terms of losses. All components of the inland flood model were rigorously validated, from the spatial distribution of precipitation and its accumulation to modeled precipitation amounts for different return periods, and from modeled historical events to river flow characteristics using data from more than 9,000 river gauging stations across the country. The modeled historical flood extents compare well with event footprints captured from satellite imagery.

AIR-modeled flood extent (left) and aerial imagery of maximum flood extent from DigitalGlobe (right) near Ashland City, Tennessee, during the 2010 Cumberland River flood.

To ensure the reliability of modeled loss estimates, the AIR Inland Flood Model for the United States has been thoroughly validated against loss data from several sources. In addition to leveraging more than four decades of actual loss data from the National Flood Insurance Program (NFIP) and industry insured loss estimates from sources including PCS, AIR used company-specific claims data specific to individual historical events and time histories alike for all-around validation.

The 10,000-year stochastic catalog has been extensively validated to ensure it represents the near-present climate and, in particular, the possible extrema (i.e., the 100- to 1,000-year return period values and beyond).

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.



Comparison of AIR-modeled (orange) and observed (blue; NFIP claims data trended to 2019) insured non-hurricane precipitation-induced flood losses for the 20 historical events included in the AIR Inland Flood Model for the United States

Model at a Glance

Modeled Perils	Precipitation-induced inland flood—on and off the floodplains—from non-hurricane atmospheric system events
Model Domain	Contiguous United States with an enhanced 10-meter DTM
Event Catalogs	10,000-year catalog, 20 historical events
Supported Construction and Occupancy Classes, and Specialty Lines	– 81 construction classes and 111 occupancy classes, including large industrial facilities – Infrastructure, marine lines (inland or transit warehouse, inland or oceangoing cargo, marine hull, pleasure boats and yachts, and builder's risk), personal and commercial automobiles
Supported Secondary Features (For Better Risk Differentiation)	– Supports more than 14 secondary risk characteristics including foundation type; number of basement levels; basement finish type; first-floor height; base flood elevation; custom elevation; service equipment protection; contents vulnerability; builder's risk (project completion, project phase code); and custom flood protections, such as wet floodproofing, custom standard of protection, as well as FIRM compliance and custom flood zones. – Unknown damage functions account for regional construction characteristics, including flood mitigation features.

Model Highlights

- Innovative and sophisticated approach to simulating precipitation couples a Global Climate Model and a Numerical Weather Prediction (NWP) model with downscaling to produce realistic and statistically robust rainfall patterns in space and time at high resolution
- Physically based explicit and comprehensive modeling of fluvial and pluvial flooding incorporates an enhanced 10-meter digital terrain model, providing a detailed, continuous view of flood risk at location level to assess hazard severity and potential damage
- Incorporates the latest and much enhanced levee information and accounts for flood defenses and their probabilities of failure
- Identifies separate flood occurrences spatially and temporally, reflecting the physical properties of flood events while accommodating a 168-hour clause
- Features a component-level physically based flood vulnerability framework to estimate the vulnerability of buildings, their contents, and business interruption for all lines of business shared with the U.S. hurricane model for a unified view of flood risk
- Explicit modeling of large industrial facilities and their mitigation features is included in specialty lines
- Accounts for regional construction differences and FIRM compliance when estimating the impact of flood mitigation measures
- Validated through extensive analyses of detailed peril and loss experience data
- Enables improved risk selection and accurate assessment of portfolio risks

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