AIR Earthquake Model for the United States

The United States faces significant earthquake risk, both from crustal seismic sources throughout the country and from the Cascadia subduction zone off the Pacific Northwest Coast. If a major earthquake were to occur near a high-population area, insured losses could exceed USD 100 billion. AIR's U.S. earthquake model provides the most up-to-date view of risk from tectonic and induced seismicity, enabling companies, government agencies, and nongovernmental organizations to prepare for and mitigate the financial impacts with confidence.

AIR

The probability that an earthquake of magnitude 7.0 or greater will strike California before 2044 is 93%, according to the Working Group on California Earthquake Probabilities (WGCEP). Using innovative methodologies and the highest quality data available, the AIR Earthquake Model for the United States provides a probabilistic approach for determining the likelihood of loss from earthquake ground shaking, as well as from five earthquake-related sub-perils: fire following, tsunami, liquefaction, landslide, and sprinkler leakage.

EXTENSIVE MODEL DOMAIN

The AIR Earthquake Model for the United States shares a catalog with the AIR Earthquake Model for Canada. The U.S. model captures the effects of earthquakes occurring anywhere within the model domain—a region extending well beyond the contiguous United States to offshore subduction zones, Canada, and parts of Alaska, Greenland, and Mexico—and reports losses for the contiguous United States.

The Most Comprehensive View of Seismic Hazard in the United States

To capture the complex nature of earthquakes in the many diverse tectonic settings of the United States, the AIR earthquake model considers hazard from a comprehensive set of crustal faults in the Western and Central United States, earthquakes within a number of special zones in the Central and Eastern United States, and large interface earthquakes on the Cascadia subduction zone, as well as shallow and deep background seismicity to capture hazard from unknown sources. The AIR earthquake model closely follows the United States Geological Survey (USGS) seismicity model, which integrates historical earthquake catalog data, paleoseismic data, and the results of regional kinematic models using GPS data and fault slip rates.

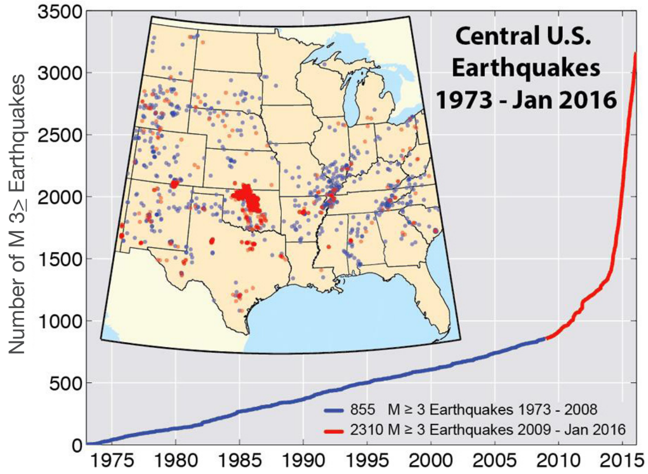
California faces the greatest seismic hazard in the United States. Although seismicity in California has remained relatively low during the past century, the boundary of the Pacific and North American tectonic plates that forms the San Andreas Fault has a 53% chance along the South San Andreas and a 33% chance along the North San Andreas of producing an M6.7 quake or greater in the next 30 years, according to WGCEP.

In the Pacific Northwest, Oregon and Washington lie within the Cascadia subduction zone and are exposed to hazard from active crustal faults where damaging earthquakes have occurred in recent history, including the 1993 M6.0 Klamath Falls earthquake in southern Oregon and the 2001 M6.8 Nisqually earthquake near Olympia, Washington.

The area of the Central and Eastern United States located within the stable continental region of the North American tectonic plate has a significantly lower rate of seismicity compared to the Western United States, yet notable earthquakes have occurred in this part of the country. In particular, the New Madrid Seismic Zone and the Charleston Seismic Zone have the potential to produce large, destructive earthquakes, as occurred in 1811-1812 and 1886, respectively. Also, the Charlevoix Seismic Zone in Quebec poses a hazard to the northeastern United States. Aside from select seismic zones, however, little is known about active faults in this part of the country. The AIR earthquake model formulates the complex seismicity of these regions by capturing the epistemic uncertainties on seismicity formulated by the USGS with a comprehensive set of logic trees.

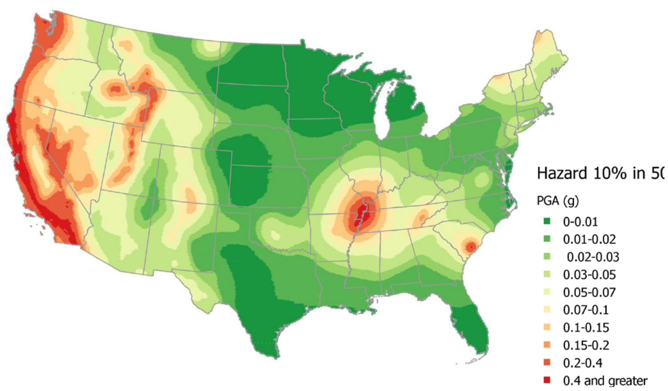
Induced Seismicity Module Captures Effects of Human Activity on the Natural Environment

The stable, continental region of the Central United States has seen an uptick in earthquakes due to induced seismicity (seismic events resulting from human activity). To quantify the risk of damage due to induced earthquakes, the model includes a stochastic induced seismicity module, which can be turned on and off. Focused on Arkansas, Colorado, Kansas, New Mexico, Oklahoma, and Texas—states where enhanced oil recovery, wastewater injection, or other practices associated with oil and natural gas production occur—AIR's induced seismicity catalog integrates research conducted by AIR scientists with data and scientific opinion from the USGS 2016 One-Year Seismic Hazard Forecast. The AIR model employs ground motion prediction equations (GMPEs) for the Central and Eastern United States as well as recent research on the ground motion behavior of induced earthquakes.



Cumulative M3.0 or larger earthquakes in the Central United States, 1973-2016. The curve and inset epicenter map show the increase in seismicity (red points) in the years since 2009, the point at which wastewater injection rates and volumes increased in the oil and gas industry, inducing earthquakes in the region. (Source: USGS)

The hazard component of the AIR Earthquake Model for the United States is consistent with the 2014 USGS National Seismic Hazard Maps, with the addition of time-dependency for California and the Cascadia subduction zone. Using the latest earthquake hazard data from the USGS, the third Uniform California Earthquake Rupture Forecast (UCERF3) developed by WGCEP, and other seismic data that characterized the regional site conditions, AIR scientists have created the most comprehensive model of U.S. seismic hazard available.



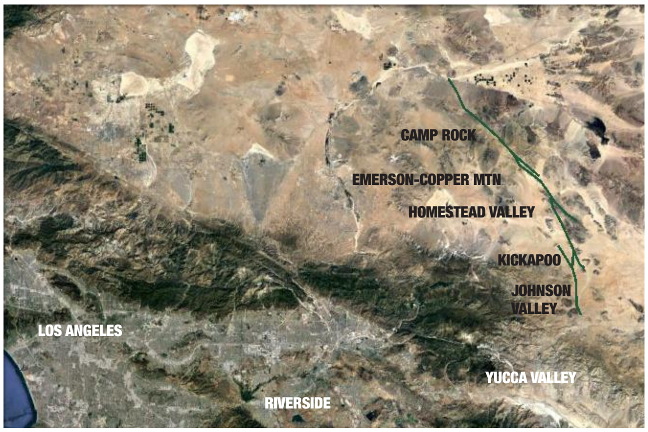
Peak ground acceleration (PGA) from all seismic sources modeled in the AIR stochastic catalog, including background seismicity, faults, and the Cascadia Subduction Zone. AIR models are validated against 2014 USGS National Seismic Hazard Maps. (Source: AIR)

Ground Motion Prediction Equations Compute Local Intensity

The suites of ground motion prediction equations (GMPEs) implemented in the U.S. earthquake model reflect the wide range of tectonic settings within the United States, including stable continental, active crustal, interface subduction zone, and deep in-slab. In calculating the local intensity of ground motion, the model takes into account the effects of site amplification that occur during intense shaking at locations with underlying soft-shallow or deep-basin alluvial soils. Shallow-site–condition databases were constructed using the most recent and highest resolution surficial geological maps and a database of borehole and shear-wave velocity measurements.

Modeling Multi-Fault, Multi-Segment, Cascading Earthquakes

Observations suggest that earthquakes are not confined to individual faults. The most-recent large California earthquakes—1999 M7.2 Hector Mine and 2010 M7.2 El Mayor-Cucapah—jumped from one fault to another as multifault ruptures. The U.S. earthquake model considers cascading scenarios in which two or more faults or fault segments are triggered simultaneously, incorporating the latest view of the UCERF3 model, which considers long cascades that can cause large magnitude fault ruptures, including those impacting both Northern and Southern California.



The main shock of the 1992 M7.3 Landers earthquake in the Southern California Mojave Desert ruptured five separate fault segments (identified in black) in sequence on a jigsaw rupture 50 miles (80 km) long, demonstrating that an earthquake can load stress onto neighboring faults. (Source: AIR and NOAA)

Multi-Level Fire Following Module

In the United States, standard home and renters insurance policies cover fire, resulting in insurance companies taking on significant exposure to risk from fire following an earthquake. The local ground shaking intensity, in combination with regional building density, impacts the number of fires ignited by damage to electrical wiring, gas pipelines, and overturned household objects. Earthquake damage to roads and water distribution pipelines can significantly hamper fire suppression efforts.

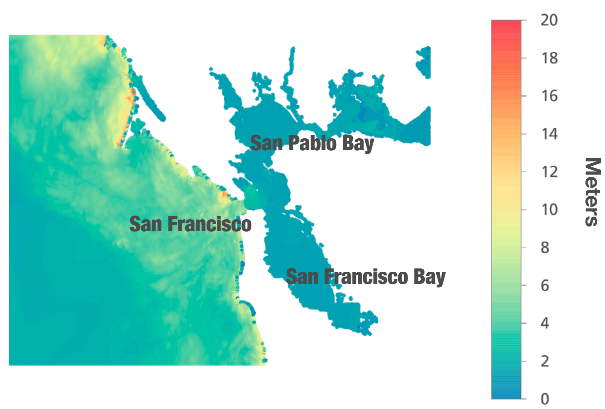
In the AIR model, fire ignitions are simulated based on ground motion, and fire spread is modeled at the city block level, using a technique that accounts for building spacing and combustibility, ignition location, and wind conditions. Fire suppression is based on fire engine movement and water availability.

The Industry's First Probabilistic Tsunami Module for the U.S. West Coast

The Cascadia and Alaska-Aleutian subduction zones can generate devastating tsunamis that pose great risk to life and property. The Great Alaska Earthquake of 1964 produced a tsunami that destroyed houses, cars, and boats along the Washington, Oregon, and California coasts, causing tens of millions of dollars in damage at the time.

AIR uses a probablistic approach to model tsunami occurrence, intensity, and damage. For each tsunamigenic earthquake in the catalog, the AIR model captures the entire lifespan of the resulting tsunami.

The AIR model also determines the effect of debris borne by tsunami waves on property. Tsunami-prone regions of the coast are characterized as zones of light, moderate, or heavy debris (determined from the industry exposure database), with the resulting damage a function of construction type.

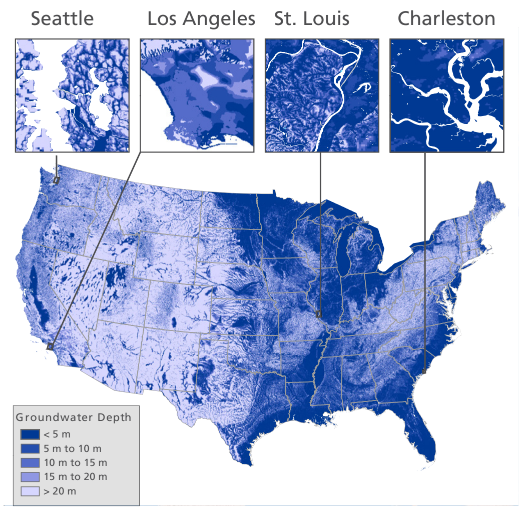


An AIR simulation of tsunami flow depth in the San Francisco area for a 10,000-year return period event reveals the greatest impact along the shore north of the mouth of San Francisco Bay and along Point Reyes. (Source: AIR)

Explicit Modeling of Liquefaction

Liquefaction occurs when loose, saturated soils lose strength and act as a viscous fluid due to intense shaking during an earthquake. Liquefaction can cause ground and foundation settlement that can damage buildings, port facilities, bridges, roads, automobiles, and pipelines.

The enhanced liquefaction module provides high-resolution (about 30 m) coverage for 36 major metropolitan areas and moderate-resolution (about 90 m) coverage for 13 states located in high seismic zones of the contiguous United States, including California and the Pacific Northwest, Utah, the New Madrid Seismic Zone, and South Carolina. AIR has incorporated thousands of local liquefaction studies, as well as lessons learned in New Zealand and Japan, to achieve a comprehensive picture of liquefaction risk.



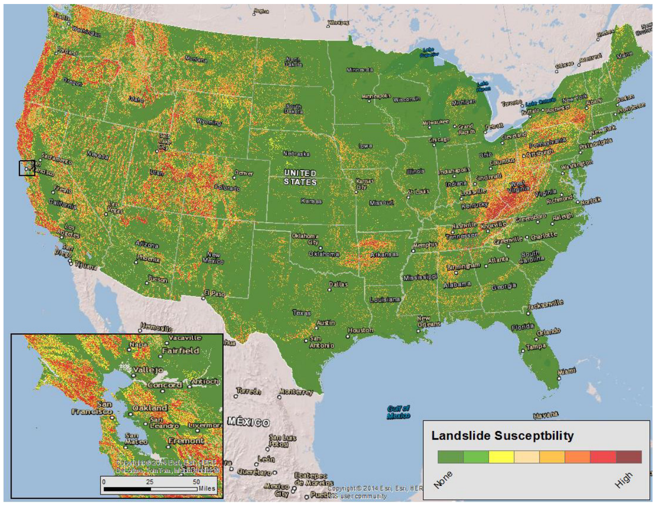
Groundwater depth maps incorporate data from multiple sources for liquefaction modeling. (Source: AIR)

Groundwater depths—an important variable affecting liquefaction potential—are provided by maps from multiple sources. These sources include maps explicitly developed to capture shallow groundwater, based on observations and filled-in data gaps using a model that considers climate, terrain, and water bodies.

Explicit Modeling of Earthquake-Triggered Landslides

In the mountainous regions of the United States, buildings and infrastructure are vulnerable to damage from earthquake-triggered landslides. Landslide damage to power lines, pipelines, bridges, and roads can have far-reaching effects, even if structures escape serious damage.

AIR's U.S. earthquake model explicitly simulates earthquake-triggered landslides. With high-resolution digital elevation landslide susceptibility using a slope stability model relating critical acceleration and permanent ground displacement. Modeled ground shaking intensity and seasonal water saturation are then coupled with landslide susceptibility to estimate damage and loss.



Landslide susceptibility for the contiguous United States. (Source: AIR)

Sprinkler Leakage

The model assesses damage to commercial, industrial, and residential buildings and their contents from fire sprinkler pipe leakage resulting from earthquake ground shaking. Damage functions explicitly account for building construction, occupancy, height, year built, and location. Users can turn on or off sprinkler damage assessment for each risk modeled.

Vulnerability Peer Review

The vulnerability module's building code–based, vulnerability assessment framework and methodology have been peer reviewed by experts familiar with portfolio risk modeling and building vulnerability, as well as with countrywide building codes and design practices.

> "The overall vulnerability assessment framework is a reasonable approach to a very difficult problem—quantification of building damage due to earthquake ground motions for all of the many different types of buildings that exist in the United States. The framework is a sophisticated combination of several different state-of-the-art technologies that address regional differences and evolution of seismic codes and design practices in the assessment of building vulnerability."

Charles Kircher, Ph.D., PE
Principal, Charles Kircher & Associates

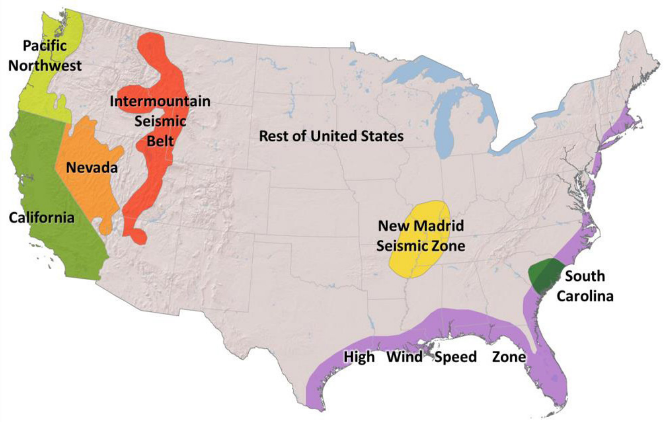
> "The AIR Vulnerability Assessment Framework addresses the challenging problem of assessing the entire U.S. building stock in a manner that can be used to analyze spatially distributed risks and expected losses under a seismic event. The Framework recognizes the complexity of design code development over time and within different regions."

Eric Hines, Ph.D., PE
Principal, LeMessurier Consultants
Professor, Tufts University

Comprehensive Damage Functions Provide a Robust Multi-Peril View of Vulnerability

The AIR Earthquake Model for the United States features unique sets of damage functions for modeling building, contents, and business interruption losses resulting from ground shaking, fire following, tsunami, liquefaction, landslide, and sprinkler leakage. These damage functions explicitly capture the relationships between the damaging aspects of each peril-specific hazard and the vulnerability of the exposure. Damage functions account for the evolution of building codes, as well as regional code adoption and enforcement practices. The model supports 127 construction classes and 111 occupancy classes.

A building designed to withstand high wind loads will also exhibit improved seismic performance because high winds can exert significant lateral forces and displacements, not unlike the horizontal forces exerted by an earthquake. Accordingly, the model considers the impact of both seismic and wind design provisions on building vulnerability. The history of building code adoption and the degree to which these requirements are enforced have been thoroughly investigated through an independent review of past studies and by leveraging the Building Code Effectiveness Grading Schedule (BCEGS®) developed by ISO®.

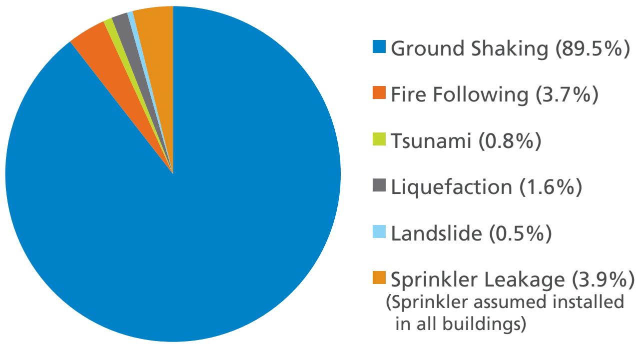


Vulnerability of wood frame construction in the U.S. earthquake model is based on construction requirements and practices in eight zones, dictated by seismicity and wind speed. (Source: AIR)

Additional highlights of the vulnerability module include:

- Damage estimation for conventional buildings, manufactured homes, auto, large industrial facilities, infrastructure, and marine hull and marine cargo for ground shaking, as well as for fire following, tsunami, liquefaction, landslide, and sprinkler leakage
- Loss estimation for structures (coverage A and B), contents (coverage C), and business interruption (coverage D or time element)
- A building-code-based vulnerability assessment framework that allows consistent assessment of structures based on in-depth study of evolving design criteria over time in various regions of the contiguous United States
- For engineered buildings, explicit modeling of spatial and temporal variations of seismic hazard, design forces, and ductility requirements
- Modeling of high-value homes (“high net-worth residential properties”) and distinct consideration for the vulnerability of tall buildings (26 stories or higher)
- Explicit differentiation between the vulnerability of one- and two-story wood frame dwellings
- Estimation of casualties and worker’s compensation due to ground shaking, fire following, and tsunami

AIR EARTHQUAKE MODEL FOR THE UNITED STATES

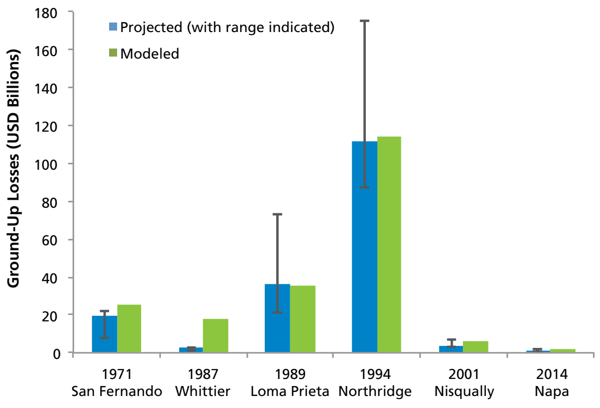


Contribution of sub-perils to industry gross average annual loss (AAL) for the entire United States. (Source: AIR)

Independently Validated Against Multiple Sources

AIR validated each component of the model individually and against multiple credible sources of data. For modeled seismicity and ground motion, AIR validated against historical catalogs—at the industry level, as well as by geographic region—and against observed ground motion data in accordance with USGS models. Damage functions for various construction types were scrutinized by an independent external expert and validated using claims data, post-earthquake damage data, shake table tests, and published research.

As a final test, AIR validated modeled ground-up losses against company claims data and reported industry losses for residential, commercial, and industrial assets using the range of losses, rather than a single loss number, to ensure robustness and reliability. The graph compares modeled losses with projected losses for several events in the states of California and Washington.



Modeled ground-up losses for selected historical earthquakes compare well with the projected range of ground-up losses (from various sources, trended to 2015 dollars). (Source: AIR)

Model at a Glance

Modeled Perils	Earthquake ground shaking and fire following, tsunami, liquefaction, landslide, and sprinkler leakage sub-perils
Stochastic Catalogs	Time-dependent (TD) and time-independent (TID) 10,000-year stochastic catalogs seamlessly integrated with the AIR Earthquake Model for Canada; TD and TID 50,000-year catalogs; TD and TID 100,000-year catalogs, optimized from 1-million-year-plus catalogs; induced seismicity module that can be turned on or off; historical event set with 118 events, 59 extreme disaster scenarios, and 9 realistic disaster scenarios
Supported Construction Classes and Occupancies	— 127 construction classes and 111 occupancy classes (62 for large industrial facilities), supported for shake, fire following, tsunami, liquefaction, landslide, and sprinkler leakage sub-perils — Unknown damage functions when exposure information (e.g., construction type, occupancy, year built, or height) is unavailable
Industry Exposure Database	Provides a foundation for all modeled industry loss estimates
Supported Policy Conditions	Separate industry loss file profiles included with CATRADER® contain different assumptions with respect to California residential earthquake policy conditions as follows: — **Mini-Policy**. Assumes California Earthquake Authority (CEA) mini-policy conditions for all California residential properties — **Non-Mini Policy**. Assumes that all of the earthquake policies in California are non-mini policies — **Hybrid**. Assumes a California residential mix of 2/3 mini-policy and 1/3 non-mini policy

Model Highlights

— Explicitly models the full range of earthquake-triggered perils, ground shaking plus fire following, tsunami, liquefaction, landslide, and sprinkler leakage
— Seamlessly integrated with the AIR Earthquake Model for Canada, facilitating modeling of cross-border risks
— Provides an induced seismicity catalog for earthquakes caused by human activity
— Offers multi-fault, multi-segment, cascading earthquake modeling capability
— Features peer-reviewed peril-specific damage functions reflecting regional building practices and the evolution of seismic codes
— Gives special consideration to the vulnerability of high-value homes due to larger gross areas and more-vulnerable interiors, and explicitly differentiates between one- and two-story homes
— Supports the builder's risk, large industrial facilities, direct and contingent business interruption, and worker's compensation lines of business

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 attacks, globally. Insurance, reinsurance, financial, corporate, and government clients rely on AIR's advanced science, software, and consulting services for catastrophe risk management, insurance-linked securities, 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.

AIR
A Verisk Business