AIR Earthquake Model for Japan

The 2011 M9.0 Tōhoku-oki megathrust earthquake and tsunami—which destroyed more than 120,000 buildings and damaged nearly 1 million more—provided an unprecedented amount of new data on seismic hazard and vulnerabilities in Japan, changing scientists' understanding of the region's seismic risk. The AIR Earthquake Model for Japan provides the most up-to-date and comprehensive view of this risk, enabling companies to prepare for and mitigate potential future impacts with confidence.

AIR

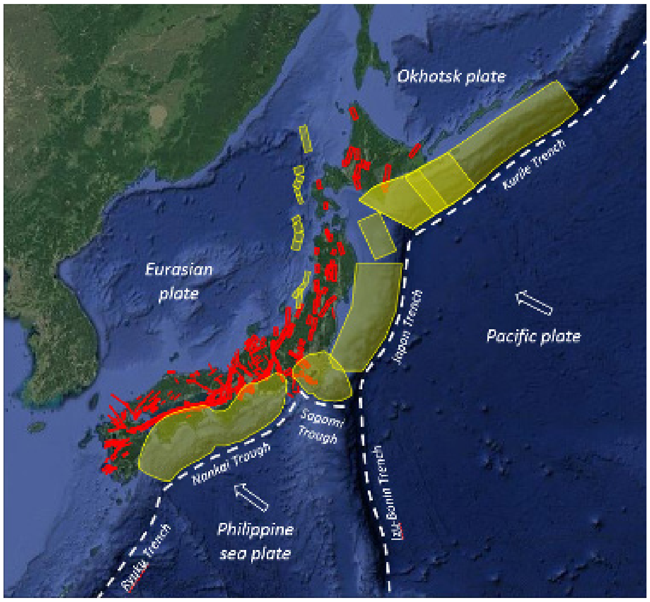
The AIR Earthquake Model for Japan provides an integrated view of loss from ground shaking, liquefaction, tsunami, and fire following. Through the use of a time-dependent approach developed by AIR scientists, the model accounts for the impact of recent earthquake ruptures as well as the potential for megathrust earthquakes and multi-fault ruptures—yielding the most realistic view of seismic hazard available for Japan. Incorporated with AIR researchers' insights into buildings' seismic response gained from damage observations, detailed claims data, and changes to design and construction practice, the model also provides the latest understanding of the vulnerability of the built environment.

The Most Up-to-Date and Comprehensive View of Seismic Hazard Available

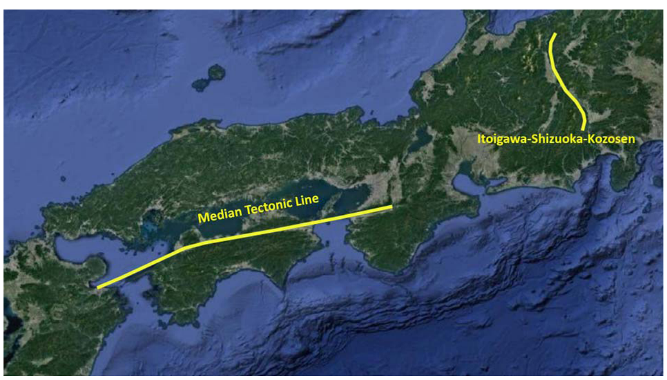
Japan lies in one of the most seismically active regions on the planet. The dominant subduction zones include the Japan Trench—the source of the Tohoku quake—formed by the convergence of the Pacific and Okhotsk plates in the north, and the Nankai Trough, formed by the Philippines and Amurian plates in the south. The Philippines and Okhotsk plates also converge at the Sagami Trough, causing devastating events such as the 1923 M7.9 Kanto earthquake. The Tohoku earthquake ruptured part of the subduction interface between the Pacific and Okhotsk plates, relieving stress in that region; however, the Nankai Trough has been locked with the Amurian Plate since the M8.0 Tonankai quake in 1944 and the M8.2 Nankai quake in 1946 and poses serious earthquake risk to south-central Japan.

The AIR Earthquake Model for Japan reflects the most up-to-date understanding of Japan's seismic hazard, including analysis by AIR seismologists and studies published by the larger scientific community on Tohoku and other recent earthquakes. The AIR model incorporates the Headquarters for Earthquake Research Promotion (HERP) 2019 national seismic hazard model with more than 500 active crustal faults, and subduction-related sources. AIR's unique, realistic view of Japan's seismicity considers a broader range of uncertainty for all earthquake sources using multiple stochastic models and time windows, including the potential for megathrust earthquakes along the Nankai Trough and Kuril Trench, in a time-dependent view of risk.

The model includes a time-dependent and a time-independent 10K catalog, a historical catalog of 66 events, four Extreme Disaster Scenarios (including a large Japan Trench scenario), one Lloyd's Realistic Disaster Scenario, and 15 disaster scenarios from the Japanese goverment.



Japan's tectonic setting, illustrating plate boundaries (in white), active crustal faults (in red) and large subduction interface sources (in yellow). Following Tohoku, rupturing scenarios along the Kuril Trench and Nankai Trough were revised to include M9.0-class earthquakes—with significant impacts to shake and tsunami risk. (Source: AIR; data source: HERP)



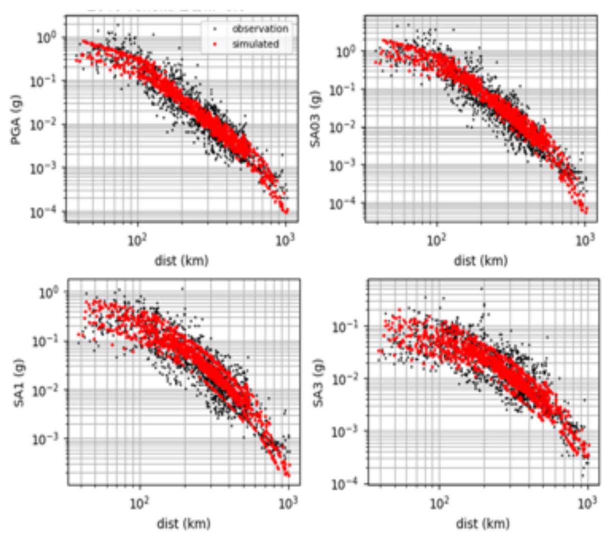
The AIR model captures the potential for large magnitude multi-segment rupture scenarios along the Median Tectonic Line and Itoigawa-Shizuoka-Kozosen faults. (Source: AIR)

TIME-DEPENDENCY MODELING YIELDS MOST COMPREHENSIVE VIEW OF SEISMICITY

The occurrence of large earthquakes on subduction zones and crustal faults is inherently time-dependent, considering the complex dynamics of local strain accumulation on fault geometry and the potential for release in a sudden rupture. The AIR view considers the buildup of strain on faults over time, in addition to historical earthquake data, to help re/insurers better understand the impact of Tohoku and other recent quakes and the potential for another megathrust earthquake.

Ground Motion Calculations Incorporate Latest Research and Data

Earthquakes impact buildings and infrastructures through the ground motions they create, so it is important to have a realistic understanding of the ground motions of earthquakes of different magnitudes occurring in different tectonic environments. The ground motion prediction equations (GMPEs) in AIR's model were developed using ground motion recordings from regional and global earthquakes, including more than 1,000 from Tohoku.

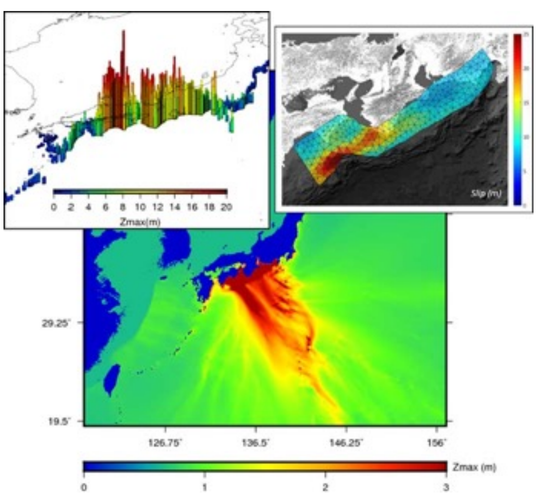


Observed (black) and simulated (red) ground motion intensities for the 2011 M9.0 Tohoku earthquake.

To calculate the ground motion of megathrust earthquake scenarios, AIR employed a state-of-the-art logic tree of GMPEs appropriate to each of the region's seismic settings. Developed using the latest studies and observation, the weighted logic tree considers epistemic uncertainty in ground motion predictions. In light of findings from the Tohoku earthquake, the AIR model considers saturation of long-period ground motion from subduction earthquakes at larger magnitudes. The impact of volcanic zones on short-period ground motion, with resultant additional decay due to inelastic attenuation, is also considered.

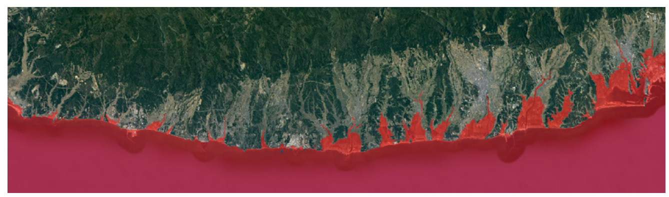
Probabilistic Tsunami Modeling

Following the Tohoku earthquake in 2011, estimates for large, full-interface rupturing scenarios along the Kuril Trench and Nankai Trough were revised to include M9.0-class earthquakes, which can generate massive tsunami waves that devastate entire coastlines. Relatively smaller, M7.0–8.0 tsunamigenic earthquakes can generate locally large tsunami waves that can cause significant destruction and losses, especially if the fault is close to the shoreline.



Maximum wave heights above mean sea level (Zmax) in meters around Japan and on land (left-inset) in southeastern Japan following a modeled 8.8 earthquake along the Nankai Trough (slip distribution shown in the right-inset). (Source AIR)

To estimate coastal flooding and inundation, AIR scientists numerically simulate the entire lifespan of tsunami waves, including their generation, propagation, and runup from all M>7.0 tsunamigenic earthquakes in AIR's stochastic earthquake catalogs, reflecting AIR's view on time-dependent and time-independent rupture probabilities for different sources. To measure subsidence and uplift, the model employs a triangular dislocation methodology that can follow fault geometries with high fidelity—including complex rupture scenarios along the Nankai Trough. The model incorporates the latest bathymetric and elevation data sets, and detailed information on defensive structures such as coastal levees, dikes, seawalls, and breakwaters—including those built in the aftermath of the Tohoku earthquake. The model also accounts for the effect(s) of astronomical tides and friction characteristics of land that impact the runup extent. Damage calculations explicitly capture the impacts of debris driven by the tsunami.



High-resolution digital terrain model captures Japan's coastal geometry to produce realistic inundation footprints. (Source: AIR)

Explicit Modeling of Liquefaction

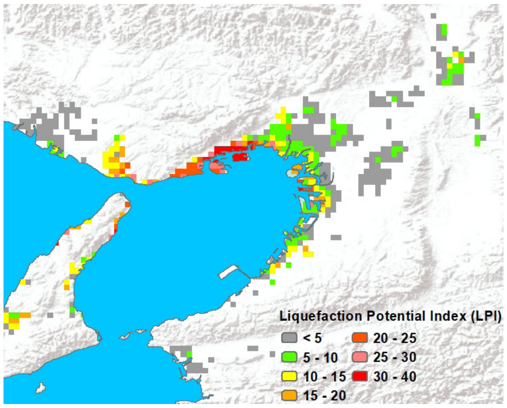
Liquefaction occurs when, as a result of violent shaking, water-saturated soils lose their strength and are unable to support the buildings above them. Liquefaction can cause buildings

HIGH RESOLUTION SOIL MAPS INFORM LOCAL SHAKING INTENSITY AND LIQUEFACTION RISK

The AIR model accounts for variations in soil type—including soft-shallow or deep-basin alluvial soils—that can dramatically alter the intensity and nature of ground shaking. Soil maps also serve to inform liquefaction risk. AIR employs geological and soil maps with resolution as high as 50 meters for the urban centers of Tokyo, Kobe, Kyoto, Osaka, Nagoya, Hiroshima, Fukuoka, Yokohama, and Sendai, and with resolution as high as 200 meters for the rest of Japan.

to suddenly tilt or even topple, and cause buried utility lines, pipelines, and ducts to rupture, making a significant contribution to earthquake-related losses.

The AIR model incorporates the latest research and lessons learned from damage surveys and claims data from recent Japan earthquakes, as well as from the 2010/2011 New Zealand earthquakes and others worldwide, to achieve a comprehensive view of liquefaction risk. The AIR model explicitly captures liquefaction risk that varies by geological zones.



AIR-modeled liquefaction potential index matches well with observed liquefaction-induced settlement in the 1995 Kobe earthquake. (Source: AIR)

Realistic Fire-Following Module Captures Ignition and Spread

Several factors contribute to the risk of fire following an earthquake. Local ground shaking intensity, in combination with regional building density, impacts in combination with regional building density impacts the number of initial fire ignitions, which are often caused by damage to electrical wiring, gas pipelines, and overturned household objects. Fire propagation from one block to the next depends on the width of firebreaks and wind speed and direction.

Earthquake damage to roads and water distribution pipelines may significantly hamper fire suppression efforts, and wind conditions at the time of the earthquake may cause relatively small fires to grow into a conflagration.

Developed from the latest studies of Japan's earthquake-triggered fires, fire ignitions are simulated based on local ground shaking intensity in combination with regional building density. Fire spread is then modeled at the city block level, using a technique that accounts for building spacing and combustibility, along with wind conditions. Fire suppression is based on modeled fire engine movement and water availability, given damage to local infrastructure.

Damage Functions Provide a Comprehensive View of Vulnerability

Based on engineering studies of many historical Japan earthquakes, including the Tohoku earthquake and tsunami, post-disaster surveys, and analyses of an extensive set of claims data, AIR engineers developed and calibrated peril-specific functions for 62 different construction classes and 117 occupancy classes in Japan.

These intensity-based damage functions directly translate calculated ground motion intensity into damage to buildings and property at each location with speed, transparency, and flexiblity. Secondary distributions quantify the uncertainties in building responses for a realistic representation of risk.

Further highlights of the AIR model's vulnerability module include:

- Peril-specific damage functions for shake, fire following, liquefaction, and tsunami
- Intensity-based vulnerability module that directly calculates loss estimations
- Secondary distributions that enable improved accuracy in modeling losses
- Temporal and spatial variation in vulnerability delineated based on building codes
- Detailed age and height bands that capture differences between engineered and non-engineered buildings
- Explicit support for large industrial facilities, railway, aviation, builder's risk, and marine hull
- Support for diverse marine, fine art, and specie lines of business, with 20 construction codes for assets

and 12 occupancy codes for storage conditions, enabling 107 explicitly modeled asset/storage combinations
- Personal accident model that estimates injury and death from shake, tsunami, and fire following
- Contents damage and business interruption (BI) modeling informed by analysis of claims from Tohoku and the 2010/2011 New Zealand earthquakes.
- Support for a broad range of Japan-specific policy conditions

Leveraging AIR's Detailed Industry Exposure Database for Japan

AIR's industry exposure database for Japan is a detailed collection of information on exposure data—including the occupancy and physical characteristics of structures, such as construction types and height classifications. AIR's industry exposure database is the foundation for all modeled industry loss estimates. It provides risk counts with replacement value breakdowns by line of business (LOB) and coverage, with take-up rates for shake, water perils, and fire following risk that reflect market conditions.

Companies can use our industry exposures to benchmark their own exposures, better estimate the vulnerability of unknown exposures, disaggregate exposures down to a detailed level (1 km^2), assess real-time losses, and more.

Comprehensive Approach to Validation

To produce realistic and robust model results, AIR builds its models from the ground up, validating each component independently against historical observations, employing multiple data sources. Modeled footprints were validated against actual observations and published reports. The tsunami component, for example, compares well with more than 5,000 observations of the tsunami generated by Tohoku and recorded by the Tohoku Earthquake Tsunami Joint Survey Group.

AIR also validates top down, comparing modeled losses to industry loss estimates and company data, including nearly 4 million individual claims arising from the Tohoku earthquake, as well as significant claims data from the Osaka and Kumamoto earthquakes and the 2010/11 New Zealand earthquakes. Model damage ratios were carefully validated against regional damage surveys. 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 is unbiased when tested against historical and real-time information.

Model at a Glance

Modeled Perils	Ground shaking, fire following earthquake, liquefaction, and tsunami
Supported Geographic Resolution	Latitude/longitude, JIS/ku/sonpo/yubin, and prefecture
Catalogs	— Time-dependent and time-independent 10,000-year stochastic catalogs — Historical catalog provides 66 events, including Tohuku, Kumamoto, and Osaka — 4 Extreme Disaster Scenarios (EDS); 1 Lloyd's Realistic Disaster Scenario (RDS), and 15 Japan government scenarios are also provided
Supported Construction Classes, Occupancies, and Specialized Risks	— Separate earthquake, fire following, liquefaction, and tsunami damage functions for 62 construction classes (including 15 fire codes) — Support for 4 height bands and 5 age bands for both non-engineered and engineered constructions — 117 occupancy classes, of which 64 are large industrial facilities — 107 modeled asset/storage code combinations support diverse marine lines, including marine cargo, inland transit, warehouse, fine art and specie, and builder's risk — Supports residential building and contents, large mutual, commercial/industrial, personal accident, and automobile — Supports aviation, marine hull, railways, automobiles, and large industrial facilities — When detailed exposure data (e.g., construction type or height) is unavailable, the model applies an Unknown Damage Function that takes into account region-specific construction characteristics
Supported Policy Conditions	Supports a wide variety of location, policy, and reinsurance conditions, including complex endowment or step policy functions, as well as Reduced Indemnity and First Loss.

Model Highlights

— Explicit modeling of shake, tsunami, fire, and liquefaction based on the latest studies
— Time-dependent stochastic catalog considers recent transfers of seismic stresses to help users better understand earthquake potential
— Captures seismic risk from complex faults, multi-fault rupture scenarios, and the potential for megathrust earthquakes along the Nankai Trough and Kuril Trench
— State-of-the-art logic tree of ground motion prediction equations considers saturation of long-period ground motion at larger magnitudes
— Highly accurate tsunami inundation calculations account for complex coastal geometries and flood defenses
— Peril-specific vulnerabilty functions directly translate event intensities into realistic potential damage to buildings and property
— Detailed age and height bands capture vulnerability differences between engineered and non-engineered structures
— Japan industry exposure database reflects recent replacement values and policy conditions for insured and insurable risks
— Comprehensively validated against historical earthquake data, damage footprints, observations, and claims data

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, supply chain disruptions, 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. For more information about Verisk, a leading data analytics provider serving customers in insurance, energy and specialized markets, and financial services, please visit www.verisk.com.

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