On March 11, 2011, the Tohoku-oki earthquake struck Japan. Its magnitude was both unexpected and unprecedented in the region—and demonstrated that companies cannot rely solely on historical data when evaluating risk from great earthquakes. The AIR Earthquake Model for Japan provides the most up-to-date information to support risk management strategies that will effectively mitigate the impact of the next catastrophe.
The M9.0 Tohoku quake and ensuing tsunami caused USD 35 billion in insured loss. The event’s devastating aftermath led to a widespread sense of urgency to reexamine Japan’s seismicity and reassess the probability of another destructive temblor occurring nearby. The AIR Earthquake Model for Japan provides the most up-to-date information to support risk management strategies that will effectively mitigate the impact of the next catastrophe.

The AIR model provides a probabilistic approach for determining the likelihood of loss from earthquakes and their associated perils, including fire following, liquefaction, and tsunami. The model incorporates not only the results from AIR’s own extensive research, but findings from a wide variety of government and academic sources that best reflect the current understanding of Japan’s seismicity—as well as the latest insight into the vulnerability of local construction and specialty lines of business to earthquake perils. Extensive loss data from the Japanese insurance market were used to validate AIR model results.

The Most Comprehensive View of Seismic Hazard in the Market

Japan is one of the most seismically active regions in the world, and its complex tectonic setting is among the most studied. Yet despite Japan’s long and well-studied seismic history, the M9.0 Tohoku event was unexpected; it was not only the first subduction earthquake exceeding magnitude 8.5 in the Japan Trench since 1900, but was also the largest earthquake to strike Japan since record-keeping began in 1600. The transfer of seismic stresses that resulted from the Tohoku event had significant implications both for neighboring subduction zones and for onshore crustal faults—increasing the probability of rupture on some segments, and lessening it on others. In short, it changed seismic risk in Japan.

Following the Tohoku earthquake, AIR seismologists, Japan’s Headquarters for Earthquake Research Promotion (HERP), and many other members of the scientific community undertook a broad range of studies to better understand regional seismotectonics. For their part, AIR seismologists conducted research on the impact of the Tohoku earthquake on nearby seismic sources, including the segment of the Japan Trench located just off the Boso Peninsula. The Boso Segment has not experienced a significant rupture for several hundred years. However, because the Tohoku earthquake clearly proved that the lack of large earthquakes in the past is not reliable evidence that large earthquakes will not occur in the future, scientists no longer rule out the possibility that the Boso Segment may have accumulated enough energy to generate an earthquake of magnitude 7.5-8.6, an event that would devastate the Kanto Plain—and Tokyo.
Using regional and local GPS data, AIR seismologists developed a **kinematic block model** for the region around and including the Boso Segment to better understand and evaluate the earthquake potential for the Boso Segment. Kinematic block models are physically based models that provide information on the state of coupling (or locking) of subduction zones. The information obtained from kinematic models is especially useful in situations where there is lack of historical precedence to formulate recurrence rates for large magnitude earthquakes.

The kinematic block model shows locked areas within the Nankai Trough. Areas in red show where there is the greatest accumulation of seismic energy. (Source: AIR)

Based on results from exhaustive analysis by AIR seismologists and work published by the larger scientific community, the AIR model reflects the most up-to-date understanding of Japan’s seismic hazard. The findings from the AIR analysis complement the latest earthquake rupture probabilities from HERP, which are also incorporated in the model.

Prompted by the results of studies conducted after the Tohoku event by the Central Disaster Prevention Council to determine potential losses and damage for a set of worst case scenarios, AIR researchers also re-evaluated the seismicity of the Nankai Trough (see figure).

**MODELING GROUND MOTION AT HIGH RESOLUTION**

To determine the intensity of ground shaking at any given site nationwide, 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.
The Industry’s First Probabilistic Tsunami Modeling Capability

The AIR model, which includes many aspects of the widely used TUNAMI model, explicitly and probabilistically captures tsunami occurrence, intensity, and damage using a probabilistic numerical modeling technique. For each tsunamigenic earthquake in the catalog, the AIR model captures the entire life of the resulting tsunami—from genesis at the earthquake fault, to the initial uplift of water and its changing height and forward speed in the open sea, to its approach to and interaction with the coast, and, finally—unlike in other simulation models—throughout its entire inundation period.

A tsunami’s height and forward speed—the two major determinants of damage—are greatly affected by friction with the ocean floor. As a tsunami approaches the coastline, friction slows the wavefront and causes the tsunami to grow taller. Friction increases as the wave approaches shallow water near the coast, and the wave height and damage potential increase in turn. Once onshore, friction continues to slow the wave, but the absolute height to which the water reaches in some places may continue to increase as water is lifted by steep obstacles or terrain.

Capturing friction features is therefore critical to understanding potential tsunami damage and loss. The AIR model uses land cover data to specify friction characteristics and their effects on tsunami velocity and inundation.

CAPTURING JAPAN’S TSUNAMI DEFENSES

The tsunami component in the AIR model takes into account Japan’s extensive defense system by including the probabilistic failure of levees due to the hydrodynamic force of an ocean wave. The model also includes any additional damage caused by a levee breach. In addition, the damaging effects of debris impact are explicitly taken into account.

High resolution (50 meter) terrain and coastline data are used to capture onshore terrain heights and the depths of waterways, harbors, and ports.

Peer-Reviewed Fire Following Module

Several factors contribute to the risk of fire following an earthquake. Local ground shaking intensity 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. 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.

Fire ignitions are simulated based on ground motion, building density, and occupancy, using an ignition rate function developed from historical fire-following events in Japan. To model the subsequent spread of fires, AIR researchers have developed a multi-level approach. Fire spread is first analyzed at the city block level using a modeling technique that accounts for variations in building spacing and combustibility, ignition location, and wind conditions. Fire spread is then analyzed at a regional level, where fire propagation from one block to the next depends on the width of firebreaks and wind speed and direction. Fire suppression is based on fire engine movement and water availability.

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, which then suddenly tilt or even topple over. As the liquefied soil shifts, it can break buried utility lines. Pipelines and ducts can surface.
The AIR model explicitly captures liquefaction risk in Japan. Liquefaction severity depends on both the liquefied state of the soil and the amount of amplification that takes place due to soil conditions. Input data for the soil profiles in the AIR liquefaction module include maps of the country’s upper soil layer and maps of land formations—including depth to bedrock, which determines the susceptibility of soil to liquefaction.

Damage Functions Provide Robust Multi-Peril View of Seismic Risk

A damage function captures the relationship between a hazard and the vulnerability of affected structures. Based on engineering studies, post-disaster surveys (including Tohoku), and analyses of a large set of claims data, AIR engineers have developed peril-specific functions for 62 construction classes (15 of which are fire classes) and 117 occupancy classes (64 of which represent complex industrial facilities). Further highlights of the AIR model’s vulnerability module include:
- Extensive validation of damage functions against an unprecedented number of claims resulting from Tohoku, as well as claims across many historical earthquakes.
- Separate damage functions for shake, fire following, liquefaction, and tsunami
- Damage functions for all four modeled perils for buildings, contents, business interruption, marine cargo, inland transit (warehouses), railways, thermal power plants, automobiles, and aviation

A Component-Based Approach to Modeling Complex Industrial Facilities

In addition to the loss of life and property, the Tohoku earthquake also badly damaged nuclear and oil operations in the country. More than half of Japan’s 55 nuclear reactors were shut down following the earthquake, prompting officials to announce rolling power cuts and mandatory electricity savings that disrupted global supply chains.

“...The AIR [fire-following] model uses a variety of country-wide data sources on land use, building configuration and distribution data, wind speed and direction data, fire suppression data, including the location and number of fire engines, and ground motion data … The strength of the model is that it can estimate the risk of post-earthquake fire spread for the entire country of Japan using a sole risk scale.”

—Dr. Keisuke Himoto,
Kyoto University
The AIR model employs a robust, component-based approach to estimating losses to complex industrial facilities. Separate damage functions for more than 400 individual industrial components—including cooling towers, pipe racks, tanks, and transportation assets—are aggregated into facility-level damage functions using weights that reflect each component’s contribution to the total replacement value. This component-based approach is essential for reliable assessment of business interruption losses, which depend heavily on interactions among various components within an industrial facility.

Leveraging AIR’s Detailed Industry Exposure Database for Japan
AIR’s industry exposure database (IED) for Japan has a 1-km grid resolution and is based on the latest available information on risk counts, building characteristics, and construction costs from a wide variety of local sources. The benefits and uses of AIR’s IED are numerous. It provides a foundation for all modeled industry loss estimates. Risk transfer solutions, such as industry loss warranties that pay out based on industry losses, rely on the IED. Using AIR’s detailed modeling application, companies can also leverage the IED for Japan to disaggregate the exposure data in their own portfolios to a highly detailed level for improved loss estimates.

A Comprehensive Approach to Validation
The loss estimates produced by the AIR Earthquake Model for Japan have been validated against loss data from historical earthquakes, as well as nearly 4 million individual claims arising from the Tohoku earthquake. AIR’s comprehensive approach to validation confirms that overall losses are reasonable and that the final model output is consistent with basic physical expectations of the underlying hazard and unbiased when tested against historical and real-time information.

To ensure the most robust and scientifically rigorous model possible, validation is not limited to final model results. Each component is independently validated against multiple sources and data from historical events, including the abundant scientific data that the Tohoku event generated. The tsunami component, for example, was validated by comparing modeled tsunami events with more than 5,000 observations of tsunami generated by Tohoku and recorded by the Tohoku Earthquake Tsunami Joint Survey Group. Modeled ground motion agrees well with recorded ground motion fields. Modeled damage ratios were validated against actual observations and published reports.

AIR Model Supports a Broad Range of Japan-Specific Policy Conditions
Japan’s insurance market comprises a unique mix of policy types. The AIR model supports both single-location and multi-location first loss policies, reduced indemnity policies, and step payout policies that are commonly used by Japan’s mutual insurance companies. Users can take advantage of the detailed modeling capabilities for single risk analysis, portfolio management, and pricing of reinsurance submissions. Fire Following Earthquake and Earthquake Fire Expenses Insurance—an offering unique to Japan—are also explicitly modeled.
## Model at a Glance

<table>
<thead>
<tr>
<th>Modeled Perils</th>
<th>Ground shaking, fire following earthquake, liquefaction, and tsunami</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supported Geographic Resolution</td>
<td>Prefecture, JIS code area, user-provided geocodes (latitude, longitude), Yubin and Sonpo code</td>
</tr>
<tr>
<td>Stochastic Catalogs</td>
<td>Time-dependent and time-independent 10,000-year catalogs each contain more than 100,000 loss-causing simulated events.</td>
</tr>
</tbody>
</table>
| Supported Construction Classes, Occupancies, and Specialized Risks | — Separate earthquake, fire following, liquefaction, and tsunami damage functions for 22 construction classes, 15 of which are fire classes  
— 117 occupancy classes, of which 64 represent complex industrial facilities  
— The model supports a variety of specialized risks, including railways, marine cargo, marine hull, transit warehouse, and personal accident  
— Unknown Damage Function: When detailed exposure data (e.g., construction type or height) is unavailable, the model applies an “unknown” damage function that takes into account country-specific construction characteristics |
| Supported Policy Conditions | AIR’s detailed software system allows a wide variety of location, policy, and reinsurance conditions as well as Reduced Indemnity and First Loss. The complex policies that are commonly used in Japan, such as endowment or step policy functions, are also supported. |

## Model Highlights
- Includes two views of Japan earthquake risk: a standard (default) time-dependent catalog developed by AIR scientists, which is a weighted combination of alternative views, and a time-independent catalog. By providing two catalogs, AIR encourages clients to assess variability and uncertainty, which are fundamental to managing risk.
- Utilizes high-resolution soil maps developed by AIR to capture site amplification and liquefaction potential.
- Industry’s first probabilistic and dynamically deterministic numerical tsunami modeling component captures the life of a tsunami from rupture through the entire inundation period.
- Peer-reviewed fire following component implements a multi-level approach developed by AIR to simulate fire following risk first at city block level, then at regional level from fire ignition to spread to suppression.
- Liquefaction component covers all of Japan
- Supports a variety of specialized risks, including railways, marine cargo, marine hull, transit warehouse, and personal accident
- Each peril component is extensively validated against hazard, damage, and loss data from historical events, including nearly 4 million claims arising from Tohoku.
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.