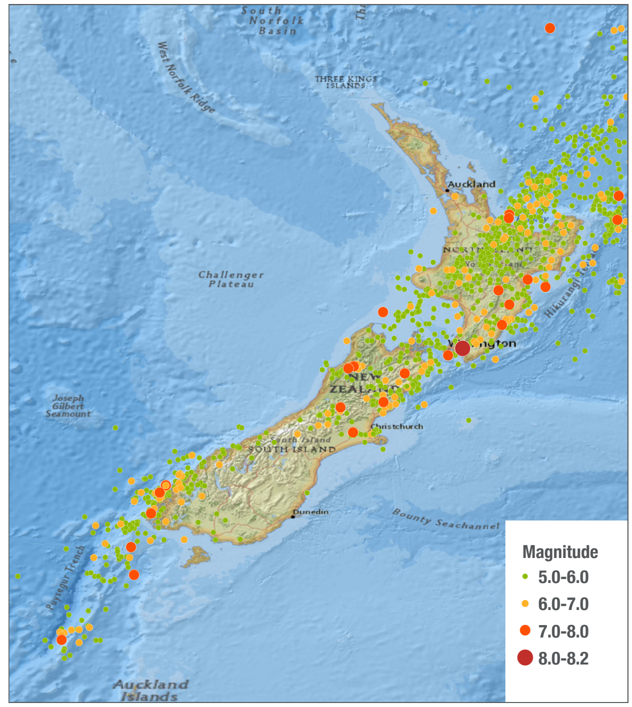
The AIR Earthquake Model for New Zealand

The 2010-2011 Canterbury Earthquake Sequence caused more than NZD 30 billion in insured losses. This swarm of events, along with the more recent 2016 Mw7.8 Kaikoura earthquake, changed the perception of the region's seismicity and revealed new data on faults and vulnerabilities. Providing the most up-to-date and comprehensive view of earthquake risk, the AIR Earthquake Model for New Zealand enables stakeholders to prepare for and mitigate potential future impacts with confidence.

AIR

The AIR Earthquake Model for New Zealand provides an integrated view of loss from ground shaking, liquefaction, landslide, tsunami, and fire following. Through the use of a time-dependent approach developed by AIR scientists for New Zealand, the model accounts for the impact of recent earthquake ruptures and the potential for multi-fault ruptures—yielding the most realistic view of seismic hazard available for New Zealand. In addition to seismic risk management, the AIR model can be used to satisfy regulatory requirements that base capital reserves on probabilistic loss estimates.



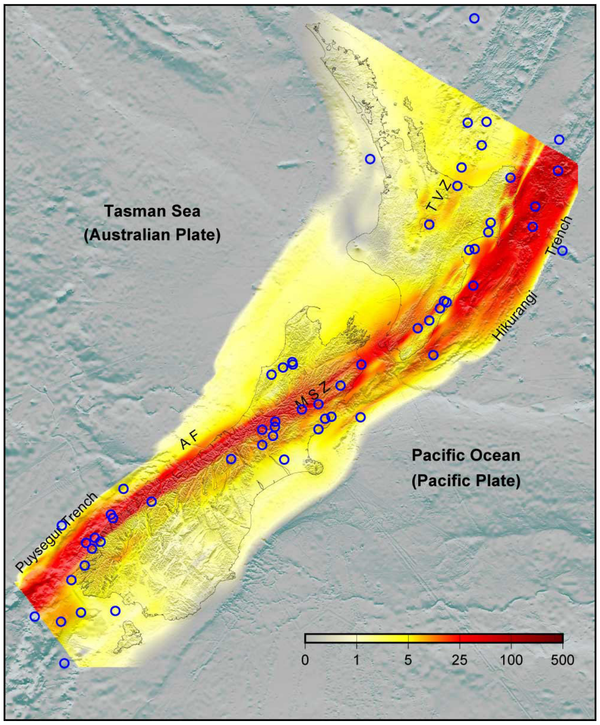
Historical seismicity in New Zealand by magnitude ($M_W \geq 5.0$).

Time-Dependency Modeling Yields Most Comprehensive View of Seismicity

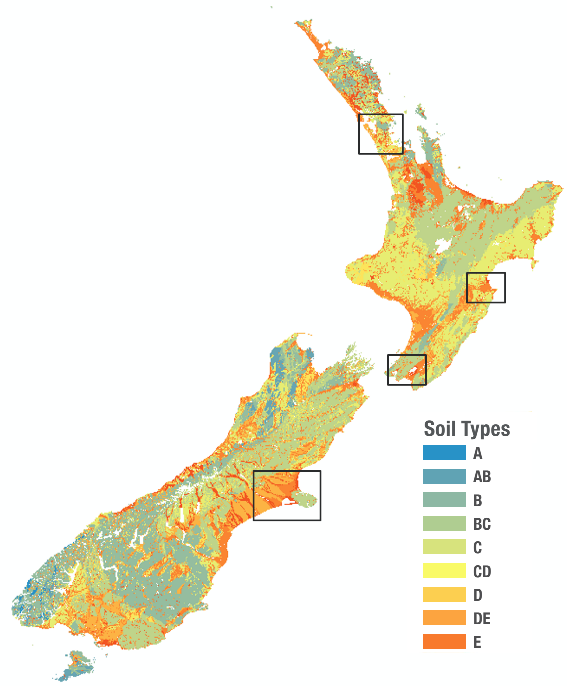
Because earthquakes are caused by the release of accumulated seismic energy, the most realistic seismic hazard models are time dependent. Most time-dependent models follow the elastic rebound theory, which states that an earthquake occurs when the yield strength of rock on a fault is exceeded by the stress building up, causing sudden movement and a release of stress. As the fault accumulates or releases stress, earthquake likelihood increases or decreases accordingly. The difficulty in applying this concept to forecasting large magnitude earthquakes on subduction zones, however, can be a lack of information about levels of stress buildup along different sections. The rupture magnitude can also vary considerably due to the complexity of fault geometry, with fault segments that may be fully locked, partially locked, or relaxed, and thus capable of producing earthquakes of different magnitudes with different probabilities.

> "I think AIR Worldwide has produced a comprehensive PSH model for NZ in a relatively short timeline. Many of the topics addressed in the model are items the NZ seismic hazard community would like to see addressed in the next national seismic hazard model (NSHM) update.
>
> -Prof. Mark Stirling, University of Otago,
> lead scientist of the 2010 NSHM of New Zealand.

AIR has employed an innovative approach to modeling time-dependent seismicity that augments historical and paleoseismic earthquake data with kinematic block modeling that reveals these complex patterns of locked and unlocked regions that may rupture. AIR's kinematic model employs more than 30 years of GPS data to determine the rate of strain accumulation (see figure), which is used in concert with historical data and geological fault slip rates to better estimate the frequency of large magnitude earthquakes.



Strain rate field (unit in 10^{-8} yr^{-1}) representing the distribution of seismic energy accumulation in the shallow crust. (Source: AIR) The blue circles represent large shallow historical earthquakes that have occurred since 1880. (Source: GeoNet)



High-resolution (250-meter) countrywide mapping of soil types for accurate assessment of risk from shaking, with higher resolution maps for major metropolitan areas. Site soil conditions are modeled at 50-meter resolution in most major cities and at 5-meter resolution in downtown Wellington. (Source: AIR)

High-Resolution Soil Maps Capture Local Shaking Intensity

Using the most detailed surficial geology maps available, together with microzonation studies, 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.

Ground motion prediction equations that are appropriate to each of the region's seismic settings—which include subduction, active crustal faults in the collision zone, crustal faults in the back-arc extension zone, and deep Benioff zones—are selected based on detailed evaluation of model performance against New Zealand historical strong ground motion data and are combined in a logic-tree approach to model the ground shaking intensity at each affected site.

> "T+T compliment AIR on development of the liquefaction model […] that is innovative and provides a good basis to […] predict the additional losses caused by liquefaction following an earthquake event.
>
> -Dr. Sjoerd van Ballegooy, Tonkin and Taylor Inc.

Modeling Complex Multi-Fault Rupture Scenarios

Complex multi-fault earthquakes—such as the 2016 Mw7.8 Kaikoura earthquake, which ruptured at least nine different faults simultaneously—can cause extensive damage. The model incorporates expanding global knowledge of these multi-fault rupture scenarios, including their potential to produce earthquakes with larger magnitudes than expected. AIR's unique view of seismicity, adapted from the UCERF3 framework, considers large multi-segment rupture scenarios to capture these complex quakes.

Megathrust Earthquake Potential

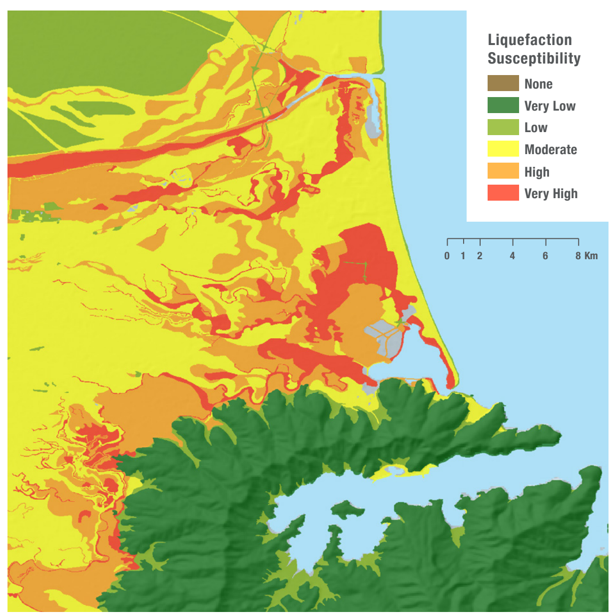
The 2011 Mw9.0 Tohoku, Japan, earthquake occurred in a subduction zone with no record of any previous megathrust earthquakes, prompting a reassessment of the risk in the similarly quiescent Hikurangi subduction zone off the east coast of New Zealand's North Island. While large subduction zone earthquakes in New Zealand are not infrequent, they have occurred in the south along the Puysegur subduction zone; the Hikurangi subduction zone has not experienced any megathrust earthquakes (Mw > 8) in the known history.

Incorporating the most recent studies on paleoseismic records for the Hikurangi subduction zone, along with kinematic modeling of slip deficit, the AIR New Zealand earthquake model helps insurers to accurately assess the potential for megathrust earthquakes in the Hikurangi Trench.

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 to suddenly tilt or even topple, and cause buried utility lines, pipelines, and ducts to rupture; it can make a significant contribution to earthquake-related losses. The February 2011 Mw6.2 Christchurch earthquake, which occurred on a previously unknown fault, revealed silty soils vulnerable to widespread liquefaction and land damage, severely impacting the city's central business district.

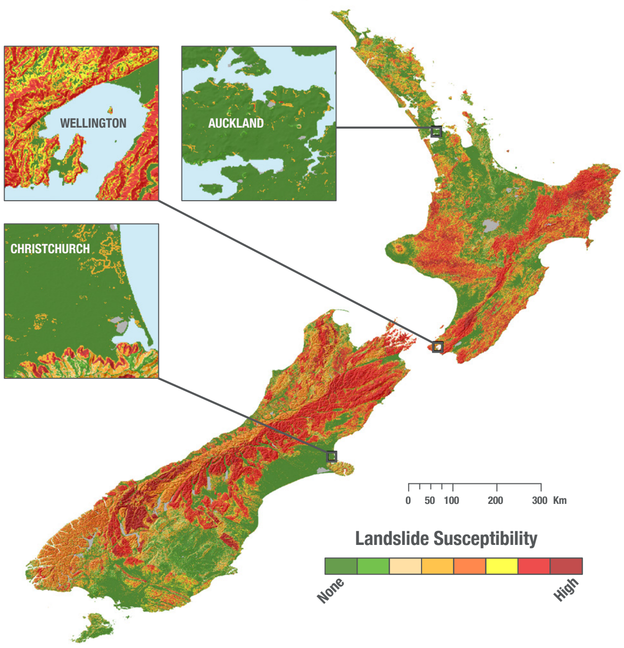
The AIR model incorporates detailed soil and groundwater data and site-specific studies with liquefaction damage surveys and claims data from recent New Zealand earthquakes, as well as information from around the world, to achieve a comprehensive view of liquefaction risk. The AIR model explicitly captures liquefaction risk, providing country-wide coverage modeled at 250-meter resolution, with a higher resolution of 30 meters in major metropolitan areas including Auckland, Wellington, Christchurch, and Napier-Hastings.



Modeled liquefaction susceptibility in the City of Christchurch showing widespread high-susceptibility areas. (Source: AIR)

Explicit Modeling of Earthquake-Triggered Landslide

The 2016 Mw7.8 Kaikoura earthquake, which ruptured over a 120-km stretch of interconnected fault segments on the South Island, triggered tens of thousands of landslides that blocked roads and disrupted transportation systems. New Zealand is a mountainous country with high potential for damage due to landslides. One particular region vulnerable to earthquake-triggered landslides is Wellington City and its suburbs at the southeastern tip of the Island. Landslide damage to power lines, pipelines, bridges, and roads can have far-reaching effects, even if homes and other buildings escape serious damage.



Landslide susceptibility for the entire country, with detailed views of Wellington, Christchurch, and Auckland.

The AIR Earthquake Model for New Zealand explicitly simulates earthquake-triggered landslides, incorporating a high-resolution digital elevation model, surficial geological conditions, and monthly precipitation to calculate landslide susceptibility. Using a slope stability model, landslide susceptibility is related to critical acceleration. For a modeled event, the ground shaking intensity is used in conjunction with the critical acceleration to estimate the ground deformation and resulting damage and loss due to landslides. Rockfalls and failure of retaining walls are considered implicitly in the model. The AIR model is calibrated based on observations after historical earthquakes in New Zealand, including the 2016 Kaikoura Earthquake.

Industry's First Probabilistic Tsunami Module for New Zealand Capturing Cross-Basin Sources

New Zealand is vulnerable to tsunamis generated by earthquakes offshore and across the Pacific basin. For example, the Mw9.5 1960 Chile earthquake—the most powerful earthquake ever recorded—generated a tsunami that caused significant runup along New Zealand's east coast. The AIR Earthquake Model for New Zealand is the industry's first to account for tsunamis generated from both local and trans-basin tsunamigenic sources. AIR uses a probabilistic approach to model tsunami occurrence, intensity, and damage. For each tsunamigenic earthquake in the catalog, AIR models the entire lifespan of the resulting tsunami waves to provide the peak tsunami intensity for a given location.

The AIR model also explicitly captures 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 as determined by the volume of cargo that is transported to/from major ports along the New Zealand coast.

Realistic Fire-Following Module Captures Ignition and Spread

The Hawke's Bay Mw7.4 earthquake and fire following that decimated downtown Napier in 1931 was New Zealand's deadliest natural disaster. Fire following earthquakes continue to pose a significant risk to New Zealand cities today. 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, as was the case in Napier.

> "The AIR Earthquake Model for New Zealand will be extremely useful for estimating earthquake loss of a spatially distributed existing building portfolio and hence a relevant decision-making tool.
>
> -Dr. Marta Giaretton, Dizhur Consulting.

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 availability of fire engines and water needed to contain the fire.

Damage Functions Provide a Comprehensive View of Vulnerability

The AIR Earthquake Model for New Zealand features unique sets of damage functions for modeling building, contents, and business interruption losses resulting from ground shaking, liquefaction, landslide, tsunami, and fire-following. These damage functions explicitly capture the relationships between the damaging aspects of each sub-peril and the vulnerability for a variety of exposure types. Additional fidelity is built into the damage functions for building structures accounting for the evolution of building codes.

Other highlights of the vulnerability module include:

- Support for 127 construction classes and 111 occupancy classes, with eight age bands and four height bands supported, as well as unknown damage functions for instances when exposure information (e.g., construction type, occupancy, or height) is unavailable
- Explicit support for motors, industrial facilities, infrastructure, builder's risk, and marine hull and cargo
- Support for damageable land which is covered by the Earthquake Commission (EQC)

Leveraging AIR's Detailed Industry Exposure Database for New Zealand

AIR has developed a high-resolution 1-km^2 industry exposure database (IED) that is based on the latest available information on risk counts, building characteristics, and construction costs from local sources, providing 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. Companies can also leverage the IED to better estimate the vulnerability of unknown exposure and disaggregate their exposure data to a highly detailed level, for improved loss estimates. It should be noted that the industry exposure database reflects the fact that there are no longer properties located in what is now classified as the residential red zone, an area impacted by the 2010 Darfield and 2011 Christchurch earthquakes.

A Comprehensive Approach to Model Validation

To ensure the most robust and scientifically rigorous view of risk, the AIR Earthquake Model for New Zealand was rebuilt from the ground up, with each model component independently validated against data from historical events specific to New Zealand as well as from around the world. For example, in the hazard component, the magnitude-frequency distribution of events in the stochastic catalog has been validated against historical earthquake rates. In addition, modeled ground motion intensity is in good agreement with recorded ground motion observations, and soil and susceptibility maps are validated using location-level geotechnical survey data. Similarly, modeled damage ratios have been validated against available observations and published reports for earthquakes in New Zealand. Exhaustive claims analysis was used for validating the model, including more than 635,000 recent claims totaling ~NZD 16.3B of incurred loss.

In addition to validating each model component individually, AIR has validated the model from the top down to ensure that model results are consistent with historical observations. Loss estimates produced by the AIR Earthquake Model for New Zealand compare well with loss data from historical earthquakes that have caused significant damage. The model has also undergone extensive peer review by a group of distinguished local and international experts. The hazard component was reviewed by Dr. Mark Stirling of University of Otago and Dr. Matt Gerstenberger of GNS; the vulnerability component was reviewed by Dr. Marta Giaretton of Dizhur Consulting; and the liquefaction module was reviewed by Dr. Sjoerd van Ballegooy of Tonkin and Taylor.

Model at a Glance

Modeled Perils	Earthquake ground shaking, liquefaction, landslide, tsunami, and fire following
Supported Geographic Resolution	Modeled zone, territorial authority, area unit, postal code, city name, or latitude and longitude; all exposures, except lat/long., can be disaggregated to 1-km resolution for more accurate result
Stochastic Catalog	Time-independent (TID) and time-dependent (TD) 10,000-year and 100,000-year stochastic catalogs; transient elevated localized seismicity events that can be turned on or off; 29 historical events, and 16 Extreme Disaster Scenarios
Supported Construction Classes, Occupancies, and Specialized Risks	— 127 construction classes and 111 occupancy classes are supported for shake and the four sub-perils, with eight age bands and four height bands supported — Supports damage to land, large industrial facilities, infrastructure, marine cargo and hull, and builder's risk, as well as business interruption — "Unknown" damage functions are available for instances 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; can be leveraged to disaggregate exposure data to a highly detailed level for improved loss estimates
Supported Policy Conditions	Supports a wide variety of location, policy, and reinsurance conditions specific to New Zealand

Model Highlights

- Explicitly models ground shaking, liquefaction, landslide, tsunami, and fire following to capture a comprehensive array of earthquake-triggered perils
- Captures the time-dependency of future earthquake events, accounting for the historical recurrence interval of earthquakes on known faults and the time since the last major rupture
- Provides the option to assess short-term elevated seismicity from recent quakes, including the Canterbury Earthquake Sequence and Kaikoura
- Includes complex multi-fault earthquake rupture scenarios and megathrust earthquake scenarios along the Hikurangi subduction zone
- The first probabilistic tsunami model to cover trans-ocean basin tsunami risk to New Zealand's low-lying coastal exposures from distant earthquakes, such as those off the western coast of South America
- Features peer-reviewed peril-specific damage functions reflecting regional building practices and the evolution of seismic codes
- Supports a variety of risk types, including damageable land, large industrial facilities, infrastructure, marine cargo and hull, and builder's risk, as well as business interruption

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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