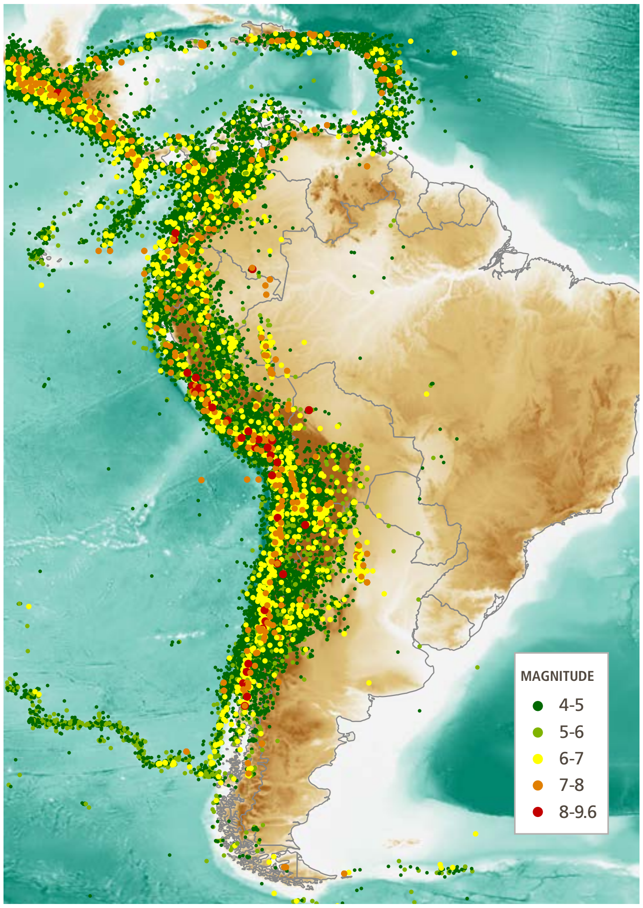
AIR Earthquake Models for South America

Chile | Colombia | Ecuador | Perú | Venezuela

The western coast of South America is one of the most seismically active regions of the world. The 1960 M9.6 Valdivia, 1967 M6.5 Caracas, 1987 M7.1 Napo, 1999 M6.2 Armenia, 2007 M8.0 Pisco, and 2010 M8.8 Maule temblors underscore the major threat that earthquakes pose. The AIR Earthquake Models for South America provide the most up-to-date information to support earthquake risk mitigation strategies in Chile, Colombia, Ecuador, Perú, and Venezuela.

AIR WORLDWIDE®



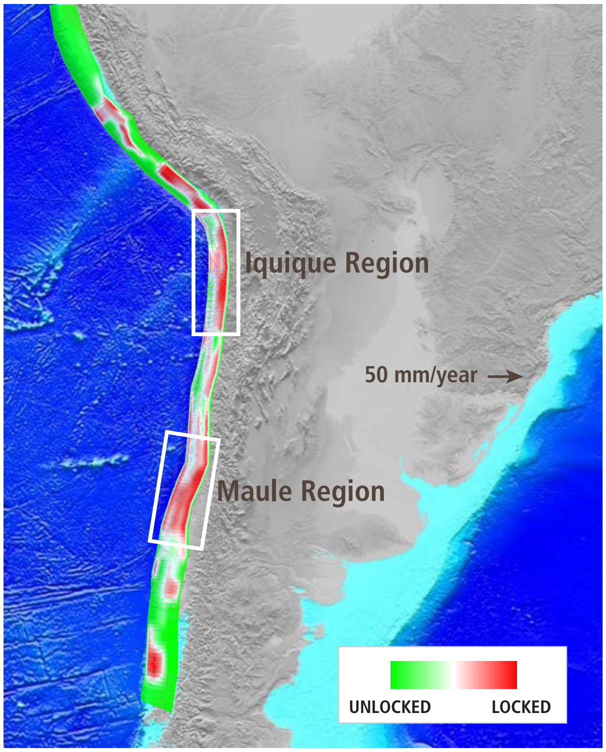
Earthquakes of M4.0 and greater in the South American region. (Source: AIR)

The AIR Earthquake Models for South America are the first catastrophe models for the region to provide an integrated view of loss from ground shaking, tsunami, and liquefaction. Through the use of a novel, time-dependent approach developed by AIR scientists for South America, the AIR models account for the impact of recent earthquake ruptures and the potential for partial rupture of subduction zones—yielding the most realistic view of seismic hazard available for Chile, Colombia, Ecuador, Perú, and Venezuela. In addition to seismic risk management, the AIR models can be used to satisfy regulatory requirements that base capital reserves on probabilistic loss estimates.

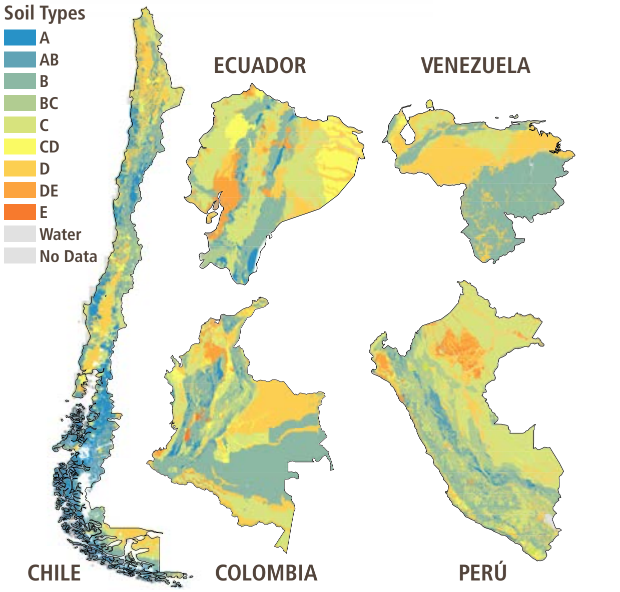
> *…AIR's South America earthquake models represent a relevant and innovative contribution to better evaluation of hazard and risk related to earthquake processes along South America, as well as a significant contribution to improving the classic methodological approach.*
>
> Dr. Diana Comte, Departamento de Geología y Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile
> Dr. Daniel Carrizo, Departamento de Geología y Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile

NOVEL TIME-DEPENDENCY MODELING YIELDS MOST COMPREHENSIVE VIEW OF HAZARD

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 hypothesis*, which states that after a major rupture, the likelihood of another large earthquake on that fault is reduced. As the fault accumulates strain, earthquake likelihood increases. The difficulty in applying this concept to forecasting large earthquakes on subduction zones—such as the Nazca subduction zone that is a major driver of seismic hazard in Chile, Colombia, Ecuador, and Perú—is that rupture areas often overlap and rupture magnitude can vary considerably. This produces a very complex pattern of overlapping segments that may be fully locked, partially locked, or relaxed, and thus capable of producing earthquakes of different magnitudes with different probabilities.



The AIR models account for the accumulation of seismic energy that results in fault locking, as is shown here (in red) for the Nazca subduction zone prior to the 2010 Maule and 2014 Iquique earthquakes, which released this accumulated stress. (Source: AIR)



Detailed soil maps are a critical data source for the models' hazard component. (Source: AIR)

AIR has employed an innovative approach to modeling time-dependent seismicity that augments historical earthquake data with more than 20 years of GPS data to develop a *kinematic block model*. The kinematic block captures these complex, alternating patterns of locked and unlocked regions that may discharge only a portion of their accumulated stress. The result is a more realistic view of seismic hazard. The kinematic block model reveals, for example, the strain accumulation at the sites of the 2010 Maule and 2014 Iquique earthquakes before those ruptures—strain that was subsequently released when the ruptures occurred, resulting in a reduction of regional seismic hazard.

HIGH RESOLUTION SOIL MAPS CAPTURE SHAKING INTENSITY

Using the most detailed surficial geological maps that are available for Chile, Colombia, Ecuador, Perú, and Venezuela, together with seismic microzonation studies, the AIR models account for variations in soil type that can dramatically alter the intensity and nature of ground shaking.

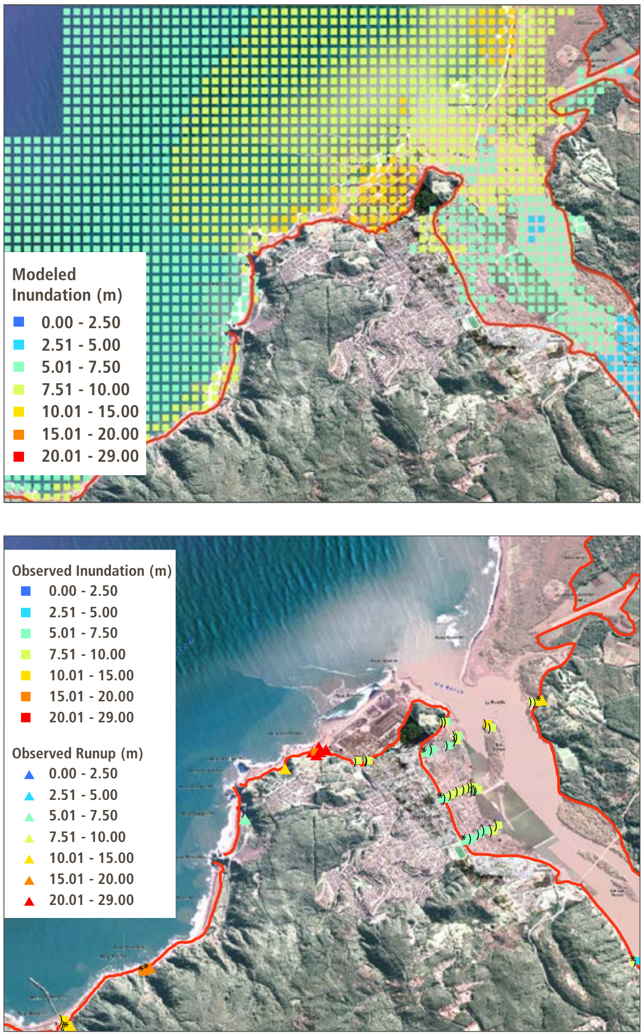
Ground motion prediction equations that are appropriate to each of the region's seismic settings—which include subduction, stable continental, and active crustal fault zones—are used in a logic-tree approach to model the ground shaking at each affected site.

A FULLY PROBABILISTIC TSUNAMI MODEL FOR SOUTH AMERICA'S PACIFIC COAST

The Nazca subduction zone can generate devastating tsunamis that pose great risk to life and property. The largest instrumentally recorded earthquake, the 1960 M9.6 Valdivia event, generated a tsunami that battered the Chilean coastline and locations as distant as Hawaii and Japan. More recently, a tsunami triggered by the powerful M8.8 Maule earthquake in 2010 devastated hundreds of kilometers of South America's Pacific coast.

The AIR models explicitly capture tsunami occurrence, intensity, and damage using a fully probabilistic approach. For each tsunamigenic earthquake in the catalog, the models capture the entire lifespan of the resulting tsunami—from the initial uplift of water and its changing height and forward speed in the open ocean, to its interaction with the coast and, finally, its onshore inundation.

The AIR models also capture the effect on properties of debris borne by tsunami waves. Tsunami-prone regions of the coast are characterized as zones of light, moderate, or heavy debris determined from satellite imagery. The resulting damage is a function of building construction type, occupancy, and height, as well as the tsunami's forward velocity and inundation depth. AIR's tsunami model has been extensively validated against reported inundation depths, damage observations, and financial losses from historical tsunamis, including losses from the 2010 Maule event.



The observed and modeled inundation extent of the 2010 Maule tsunami near the city of Constitución (shown by location of colored squares and red line in top and bottom panels, respectively) and the observed and modeled inundation depth (illustrated by the color of the squares in the top and bottom panels, respectively) show good agreement. (Source: AIR)

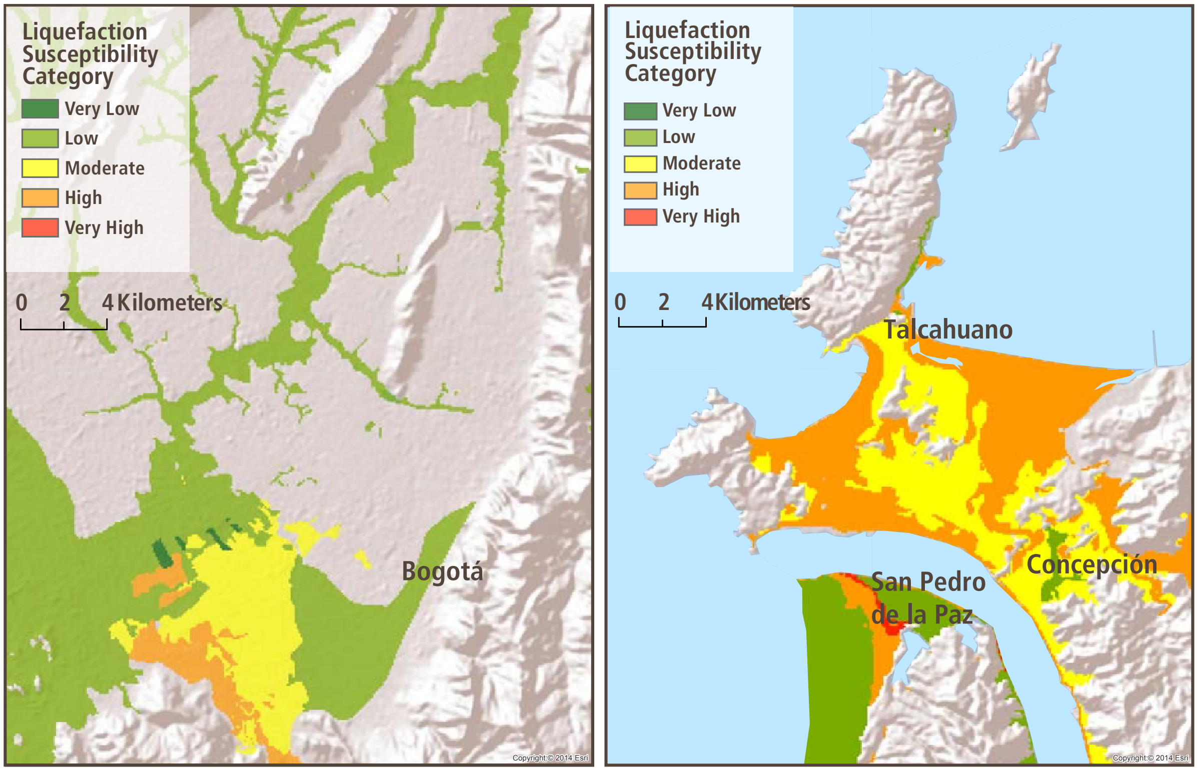
EXPLICIT MODELING OF LIQUEFACTION

When violent ground shaking causes water-saturated soils to lose their strength, buildings can suddenly tilt or even topple. Buried utility lines, pipelines, and ducts can rupture.

Because liquefaction is strongly correlated with soil type and water depth, detailed topographic, soil, and groundwater data are required to produce a comprehensive picture of liquefaction risk. Liquefaction risk is explicitly captured in the AIR Earthquake Models for South America where high-resolution soil and groundwater depth data are available.

WHERE LIQUEFACTION RISK IS MODELED

COUNTRY	MODELED REGION
CHILE	Santiago Metropolitan Region, Viña del Mar, Antofagasta, Valparaíso, Temuco, Concepción, Rancagua, Arica, Iquique, Talcahuano, Coquimbo, La Serena, Valdivia, Quilpué, Copiapó, Curicó, Hualpén, San Antonio, Chiguayante, and San Pedro de la Paz
COLOMBIA	Bogotá, Medellin, Cali, Barranquilla, Cartagena, Bucaramanga, Ibagué, Soledad, Pereira, Santa Marta, Soacha, Pasto, Montería, Villavicencio, Manizales, Bello, Valledupar, Neiva, Buenaventura, Palmira, Armenia, Popayan, Floridablanca, Sincelejo, Itagüí, and Tumaco
ECUADOR	Quito and Guayaquil
PERÚ	Entire country
VENEZUELA	Caracas



Parts of Bogotá, Colombia (left panel) and Concepción, Chile (right panel) are notably susceptible to earthquake-triggered liquefaction. (Source: AIR)

AIR Damage Survey after the 2010 Maule Earthquake Informed Damage Function Development

In the aftermath of the M8.8 Maule earthquake in 2010, AIR engineers conducted a damage survey in several regions of central and southern Chile. The team's observations, together with the information gained from meetings with industry experts, local engineers, and governmental and humanitarian organizations, provided invaluable information that was leveraged during development of the AIR models.

While Chile's code-compliant building stock generally performed well, structural damage to some of these buildings revealed possible weaknesses. In particular, shear walls sustained considerable damage due to a lack of boundary elements and sufficient confinements—perhaps not surprising in light of the fact that after the 1985 Valparaiso earthquake, reinforced concrete design codes in Chile relaxed some provisions for wall boundary elements and confinement detailing. Following the 2010 Maule earthquake, the 2011 Chilean seismic code included a minor update that incorporated lessons learned from the Maule event, and increased the stringency of some provisions for wall boundary elements and confinement detailing. The AIR Earthquake Model for Chile reflects these changes, incorporating increased vulnerability of high-rise shear wall structures built between 1985 and 2011, and an age band that captures the 2011 seismic code update.

DAMAGE FUNCTIONS PROVIDE A ROBUST MULTI-PERIL VIEW OF VULNERABILITY

In developing the models' damage functions, AIR conducted a comprehensive evaluation of the evolution of building codes and partnered with scientists and engineers from Chile, Colombia, Ecuador, Perú, and Venezuela to gain further insight on local construction practices.

The models feature damage functions for shake, tsunami, and liquefaction for 106 construction classes and 115 occupancy classes. These damage functions fully capture the relationship between each hazard and the vulnerability of affected structures.

Regional Vulnerabilities Reflect Local Expert Knowledge

The models' regional building vulnerability assumptions are informed by local experts and the latest developments. For example, AIR's assessment of building vulnerability in Ecuador accounts for the full enforcement of 2011 building codes, which is planned for 2015.

Further highlights of the vulnerability modules of the AIR Earthquake Models for South America include:

- Damage functions generated using nonlinear dynamic analysis (NDA), together with component-level fragilities, to establish relationships between building damage ratios and ground motion parameters
- Detailed age bands that are fully consistent with the evolution of building codes in each modeled country, and incorporate knowledge from local experts
- Height bands that include a "tall" building designation for buildings of 26+ stories
- For buildings with unknown attributes—such as building height or year built—damage ratios are calculated as a weighted average of the damage ratio for buildings of known attributes
- Damage functions for complex industrial facilities, infrastructure, builder's risk, marine hull, and marine cargo are included for the shake and tsunami perils

This building in Maipú, greater Santiago, partially collapsed due to shear wall failure caused by the 2010 Maule quake. (Source: AIR)

AIR's damage functions for the South America earthquake models have been thoroughly validated against damage data—such as reported mean damage ratios (MDR) for a range of construction types—from historical earthquakes, including the 2010 Maule, Chile, event and the 2007 Pisco, Perú, event.

LEVERAGING AIR'S DETAILED INDUSTRY EXPOSURE DATABASES

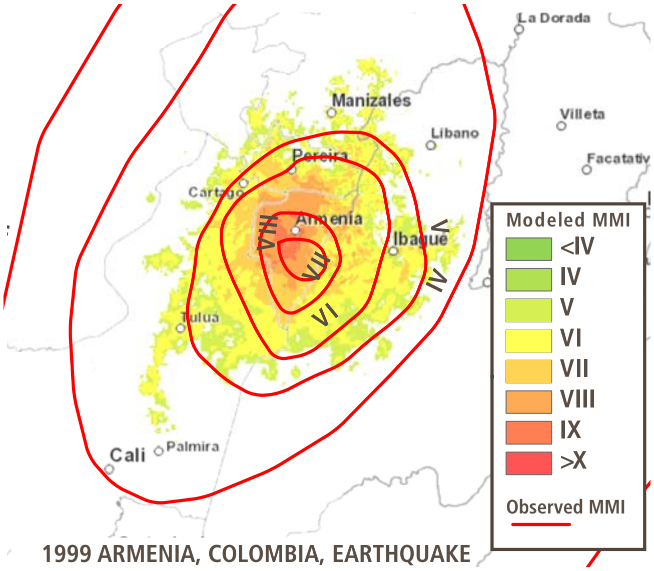
AIR's industry exposure databases (IEDs) for Chile, Colombia, Ecuador, Perú, and Venezuela consist of the latest available information on risk counts, building characteristics, and construction costs, at a 1-km spatial resolution. Developed using a wide variety of local sources, the IEDs capture the characteristics of properties at a high level of detail.

AIR's modeled mean damage ratios (MDR) comport with reported mean damage ratios from historical events. For example, the AIR modeled MDR (filled squares) agree well with the observed MDR (filled circles; the top half represents the upper bound MDR while the bottom half represents the lower bound MDR) inflicted by the 2010 Maule earthquake on high-rise reinforced concrete shear wall structures in the Viña del Mar region (Modeled MDR, Source: AIR; Observed MDR, Source: Carpenter et al. 2011, Kato et al. 2010)

The benefits and uses of AIR's IEDs are numerous: They provide 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; and based on industry exposure weights by line of business, aggregate CRESTA exposures are automatically disaggregated to a 1-km grid during analysis.

THOROUGH VALIDATION OF ALL MODEL COMPONENTS AND LOSS ESTIMATES

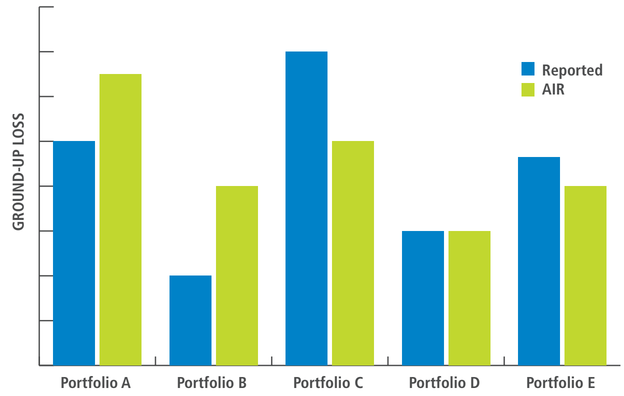
To ensure the most robust and scientifically rigorous results possible, the AIR models have been built from the ground up, with each model component independently validated against multiple sources and data from historical events around the world. For example, the magnitude–frequency distribution of events in the stochastic catalog has been validated against historical earthquake rates and published kinematic modeling results. In addition, modeled ground motion agrees well with recorded ground motion fields for earthquakes.



Modeled ground motion footprints for historical events are a good fit for observed ground motion footprints. (Source: AIR)

Similarly, modeled damage ratios have been validated against available observations and published reports for earthquakes in each of the modeled countries. In addition, AIR damage functions have been validated against damage functions obtained from local or global published studies.

In addition to validating each model component individually, AIR has validated the models from the top down to ensure that final model results make sense. Modeled loss estimates show good agreement with observed losses from the available claims data.



AIR loss estimates compare well to observed losses from claims data. (Source: AIR)

The Models Have Undergone Extensive Peer Review by Distinguished Local and International Experts

Hazard

- Dr. Diana Comte, Departamento de Geología y Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile
- Dr. Carlos A. Vargas, Profesor Asociado en Departamento de Geociencias, Universidad Nacional de Colombia
- Dr. Daniel Carrizo, Departamento de Geología y Geofísica, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile

Vulnerability

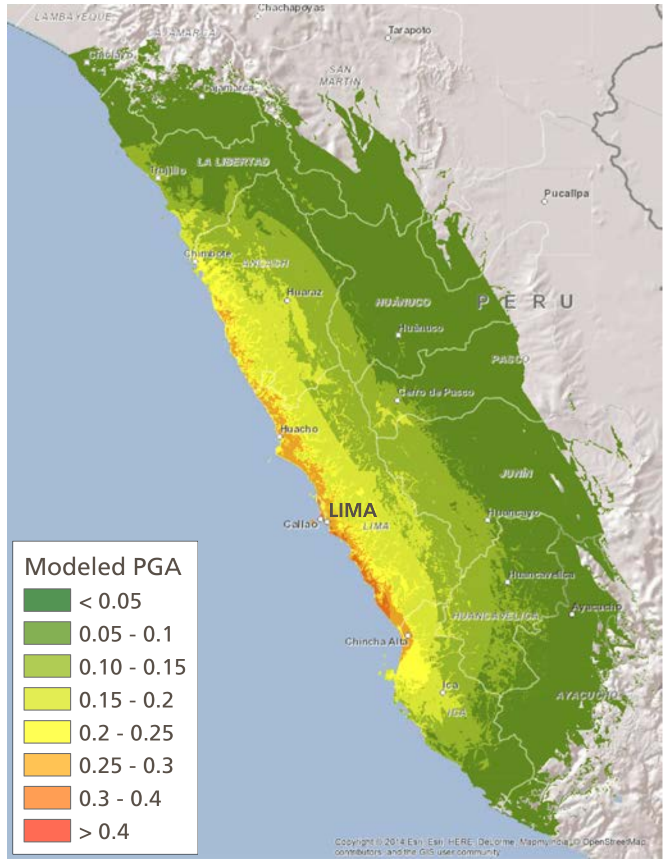
- Prof. Juan Carlos de la Llera Martin, Pontificia Universidad Católica de Chile
- Prof. Luis Yamin, Universidad de Los Andes, Colombia
- Prof. Fabricio Yepez, Universidad San Franscisco de Quito
- Prof. Jorge Olarte Navarro, Universidad Nacional de Ingenieria, Perú
- Prof. Jose Grases, Universidad Central de Venezuela

ANALYZE HISTORICAL EVENTS

The footprints of many historical events are available for the AIR Earthquake Models for South America. You can analyze your accumulations of exposure against ground motion footprints, such as the one in the figure, using the Geospatial Analytics Module in Touchstone®. You can also modify the damage ratio Touchstone applies to the properties located within each peak ground acceleration band to customize your view of risk. Furthermore, you can calculate a location's distance from the closest fault line using the Geospatial Analytics Module.

SUPPORT FOR COMPLIANCE WITH CAPITAL REQUIREMENTS

To protect the strong growth of South America's insurance markets, regulators are moving to establish model-based capital requirements more reflective of the actual risk faced by the region than reserves suggested by standard formulae. For example, the Superintendencia de Banca y Seguros (SBS) of Perú requires domestic insurers to use catastrophe models for risk assessment. Regulators in Chile and Colombia are also revising their requirements, in light of Europe's Solvency II. The AIR models can be used to manage risk and satisfy regulatory requirements that base capital reserves on probabilistic loss estimates, helping companies improve their financial positioning to survive the next major earthquake.



Modeled ground motion footprints, such as the one shown here for the earthquake that struck the Lima, Perú, region in 1746, are available in Touchstone's Geospatial Analytics Module. (Source: AIR)

> *"AIR's vulnerability framework is an excellent method of estimating the seismic vulnerability of a portfolio specific to the insurance industry in a simple and practical way."*
>
> Dr. Jorge Olarte Navarro,
> Facultad de Ingeniería Civil,
> Universidad Nacional de Ingenieria, Perú

MODELS AT A GLANCE

MODELED PERILS	Earthquake ground shaking, tsunami, and liquefaction
STOCHASTIC CATALOG	All five modeled countries share a 10,000-year stochastic catalog of simulated earthquakes. Ninety-nine historical events are available for loss analysis. Each of the five countries has two Extreme Disaster Scenarios (EDS).
SUPPORTED CONSTRUCTION CLASSES AND OCCUPANCIES	– 106 construction classes and 115 occupancy classes are supported for shake, tsunami, and liquefaction – Complex industrial facilities, which are represented by 62 occupancy classes, are supported for shake and tsunami
INDUSTRY EXPOSURE DATABASES	– Contain risk counts, building characteristics, and construction costs, at a 1-km spatial resolution – Provide a foundation for all modeled industry loss estimates
SUPPORTED POLICY CONDITIONS	AIR's detailed software system supports a wide variety of location, policy, and reinsurance conditions that are specific to each modeled country.

HIGHLIGHTS OF THE MODELS

- Explicitly model ground shaking, tsunami, and liquefaction
- All five countries covered by the AIR South America earthquake models share a 10,000-year stochastic catalog, facilitating modeling of portfolios that cross borders
- Incorporate the most up-to-date analyses of historical seismicity in the South American region through the integration of local and global earthquake catalogs
- Employ kinematic modeling, active faults, and historical earthquake data to produce a comprehensive, time-dependent view of seismic hazard using a novel approach developed by AIR expressly for the South American region
- Use high-resolution soil maps to capture site amplification and liquefaction potential
- Feature a tsunami module that captures the propagation of a tsunami from its origin through the entire inundation period
- Feature extensively validated peril-specific damage functions for shake, tsunami, and liquefaction
- Benefit from AIR's collaboration with local researchers during model development, and from a thorough peer review of all model components

ABOUT AIR WORLDWIDE

AIR Worldwide (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 90 countries. More than 400 insurance, reinsurance, financial, corporate, and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, detailed site-specific wind and seismic engineering analyses, and agricultural risk management. AIR, a Verisk Analytics (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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