Preview of the New AIR South America Earthquake Models

AIR

THE NEW AIR EARTHQUAKE MODELS FOR SOUTH AMERICA

Chile | Colombia | Ecuador | Peru | Venezuela

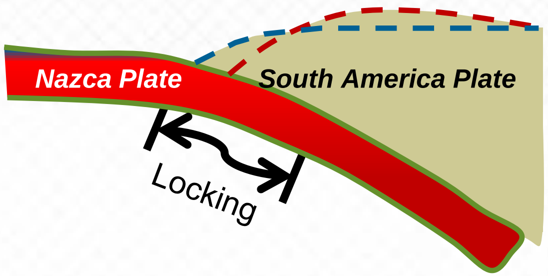
Agenda

- New Hazard Modeling: Data & Methods
- New Vulnerability Modeling: Data & Methods
- Model Validation: Component-Level & Loss Estimation
- Software: New Features for South America

New Hazard Modeling

Mesut Turel

South America Is One of the Most Seismically Active Regions of the World



2010 Maule Earthquake

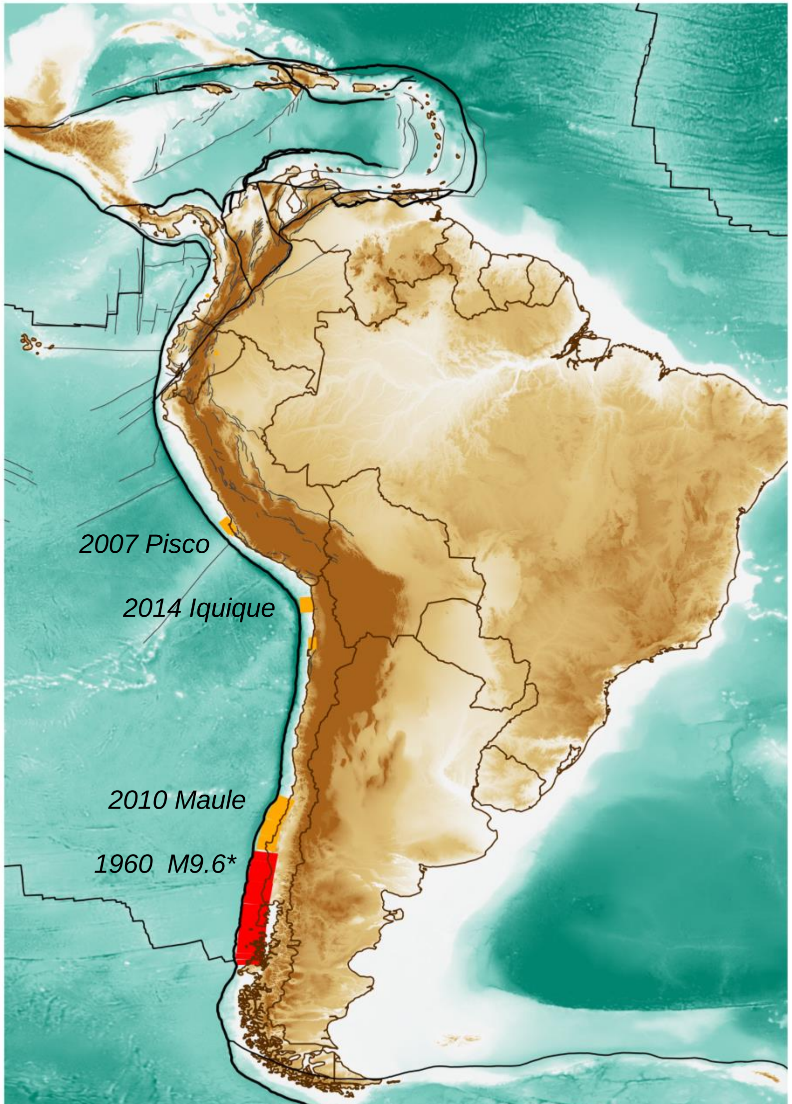
1960 M9.6 Earthquake

Length: 1000 km

Width: 100 – 150 km

Maximum Uplift: ~ 5.7 m

Maximum Subsidence: ~ 2.3 m



** Largest recorded earthquake worldwide*

The AIR Earthquake Models for South America Is Receiving a Comprehensive Update

AIR Earthquake Models for South America

- Industry Exposure Database
- Catalog Seismicity
  Time-Dependent Model
- Intensity Modeling
  GMPEs
  Soil Maps
- Liquefaction Risk
- Tsunami Risk on the Pacific Coast
- New Seismic Design Codes
- New Risk Types
  Industry Facilities, Infrastructure, Builder's Risk
- New Shake Damage Function Methodology

Stochastic Event Generation Requires Latest Data Sources and Knowledge

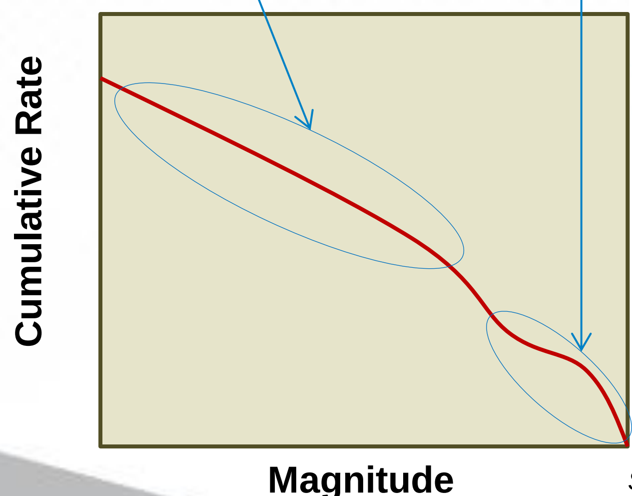
- Historical earthquakes, fault parameters, and GPS data constrain the magnitude-rate in a seismic source zone

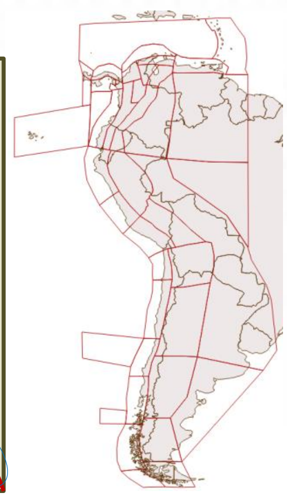
- Historical earthquake catalog data
- Fault slip rates
- GPS strain rates

Seismic moment rate (Seismic budget)

Driven by
- **Historical earthquake catalog for M≥4 from 1471 - 2014**

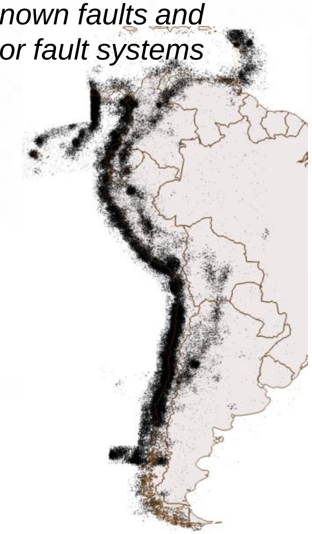
Driven by:
- **Historical catalog**
- **Fault slip rates**
- **GPS data**



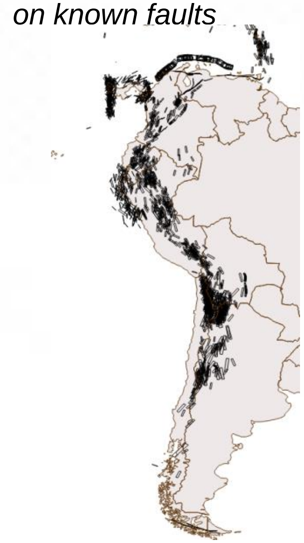


Seismic Source Zone Model

Background seismicity on unknown faults and major fault systems



Characteristic earthquakes on known faults



The History of Past Events Is of Great Importance for Characterizing the Seismic Hazard

- Extensive evaluation of data sources including work of the *Global Earthquake Model* GEM

International Seismological Centre

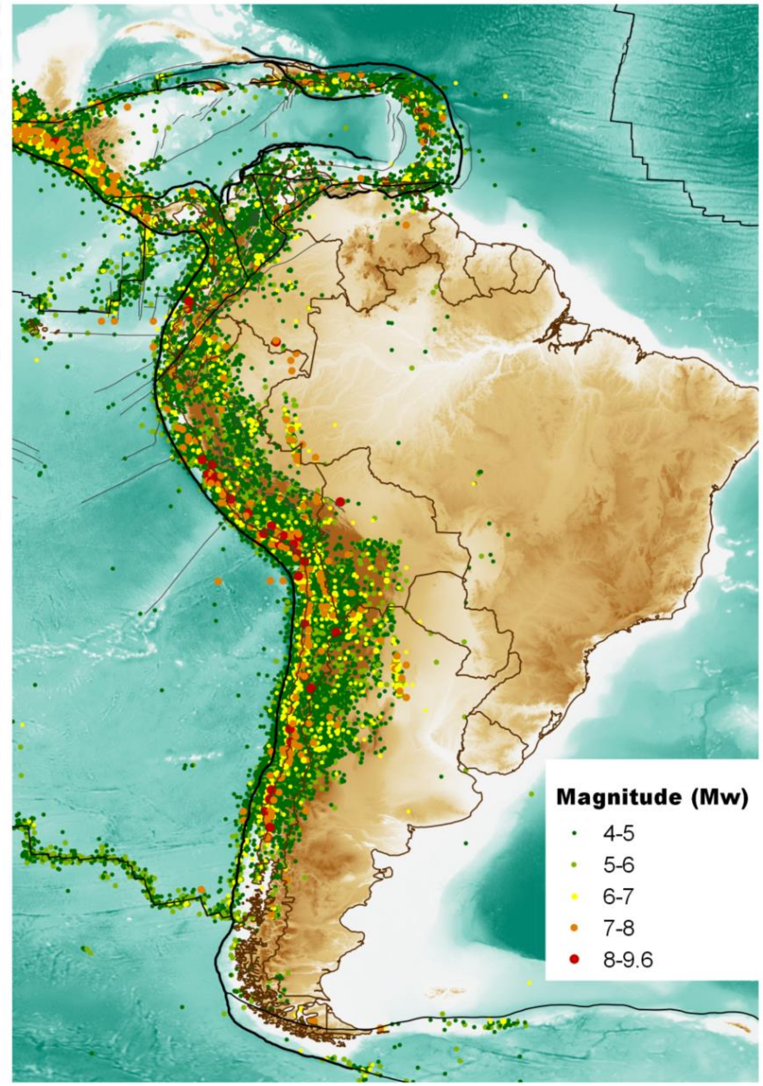
Global CMT

USGS science for a changing world

RSNC Red Sismológica Nacional de Colombia

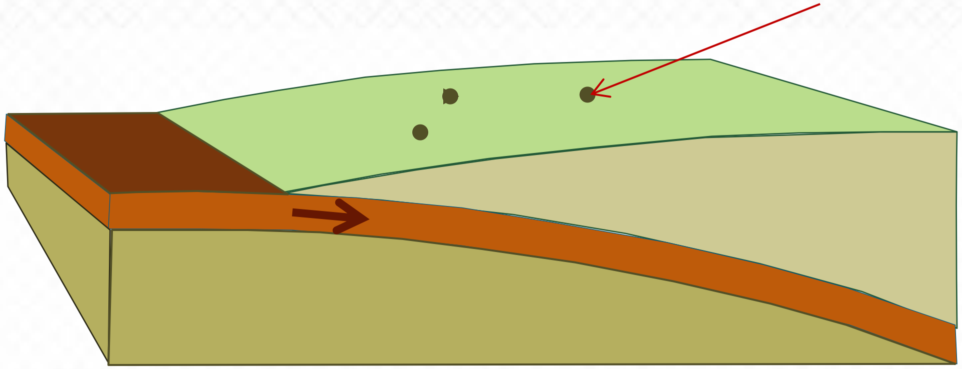
IG Instituto Geofísico EPN

- Homogenization of data to moment magnitude (Mw) scale
- Compilation of unified, comprehensive catalog of 47k events Mw≥4 from 1471 to 2014 based on a catalog quality and magnitude scale

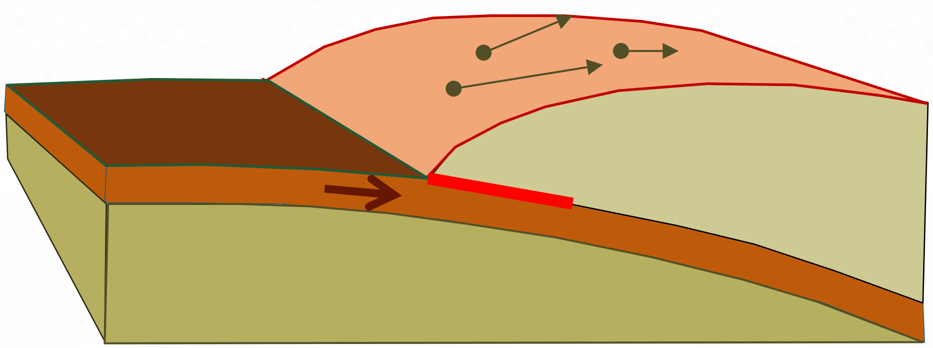


Characterizing Subduction Zone Locking and Deformation

GPS Stations

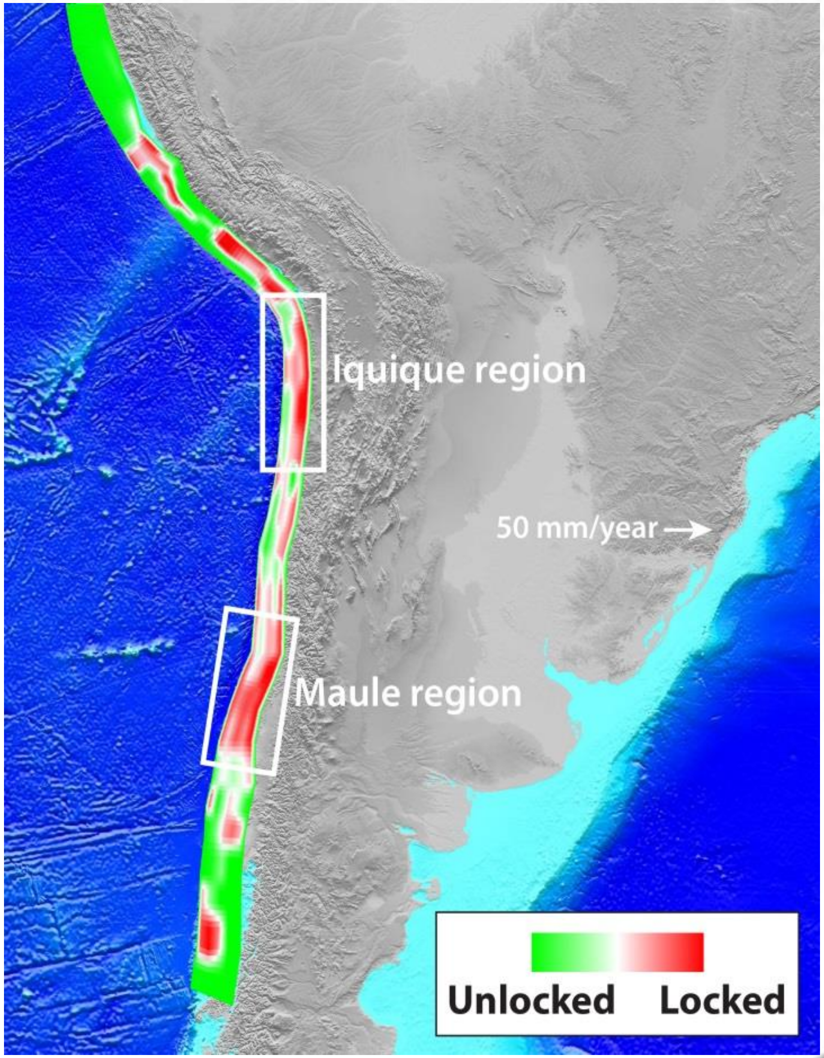


Creeping Subduction Zone

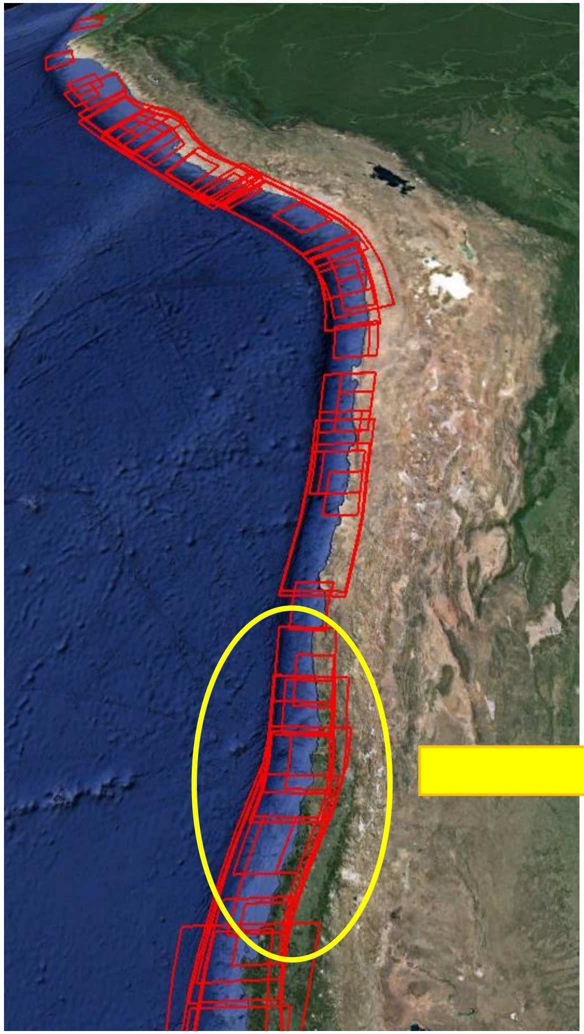


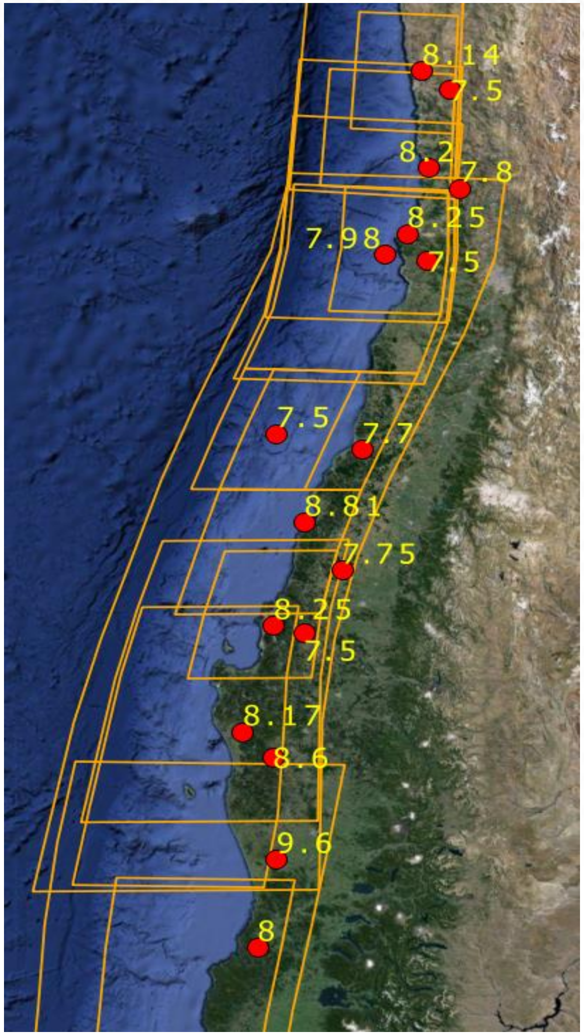
Locked Subduction Zone

Subduction Zone Locking Pre-2010 Maule



There Is a Need for Multi-Mode Time-Dependent Rupture Probability Models for Subduction Zones



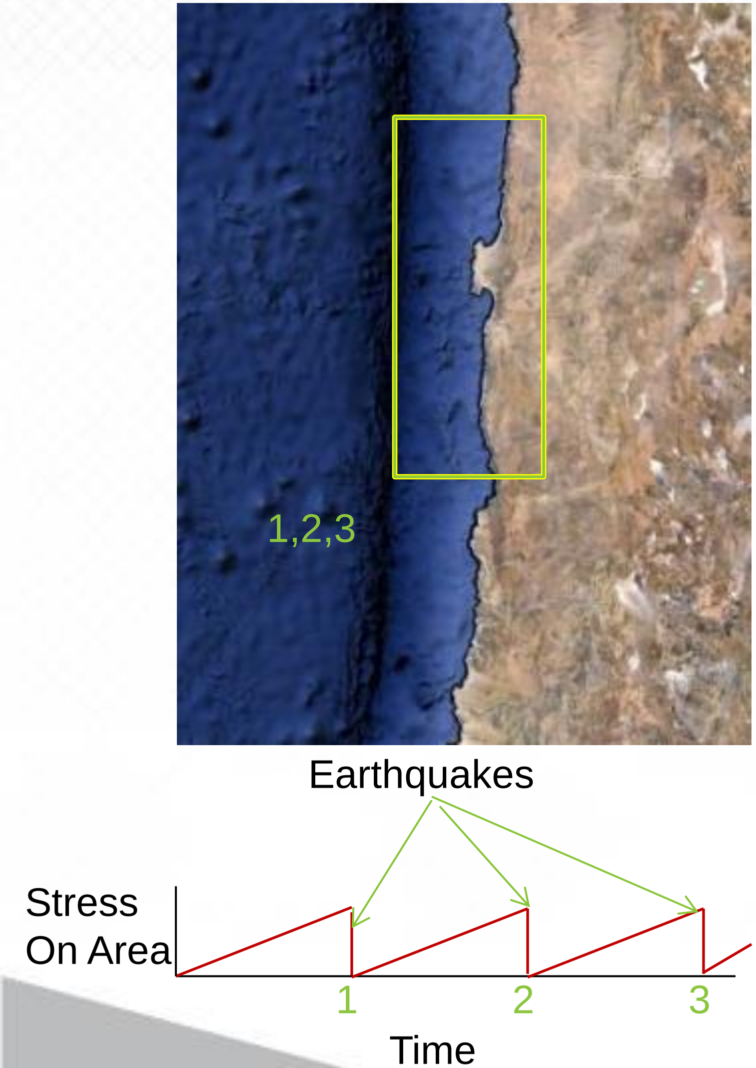


Historical Earthquake Rupture Areas

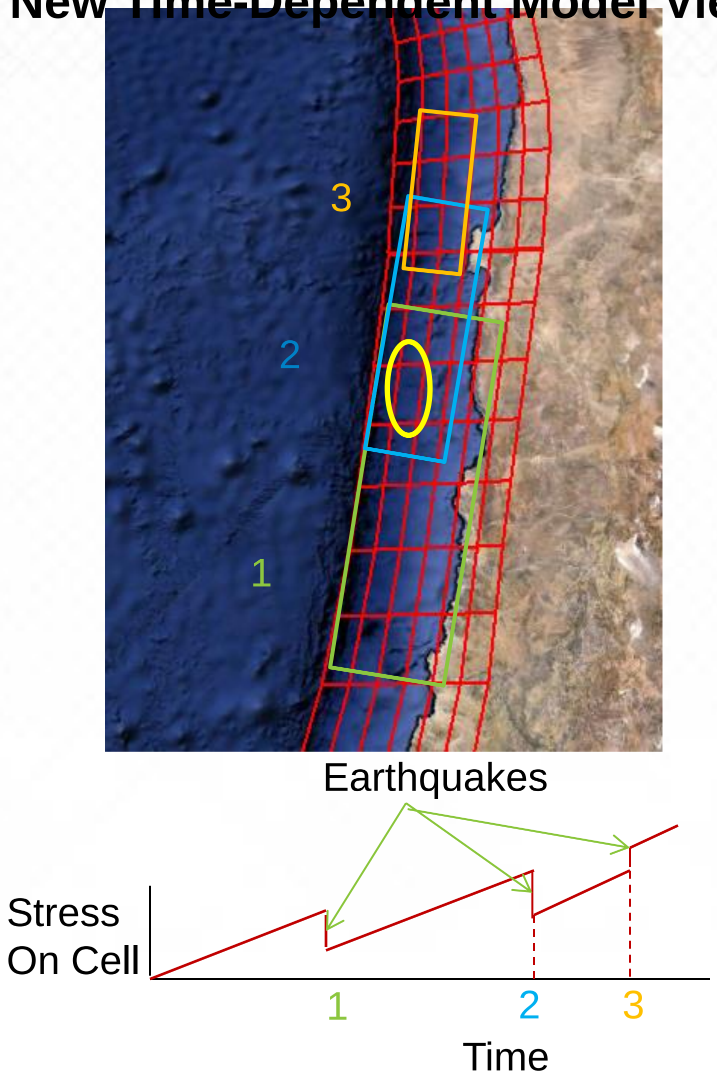
Historical Epicenters

Standard Versus New Approach to Time-Dependent Modeling

Stochastic Renewal Model View



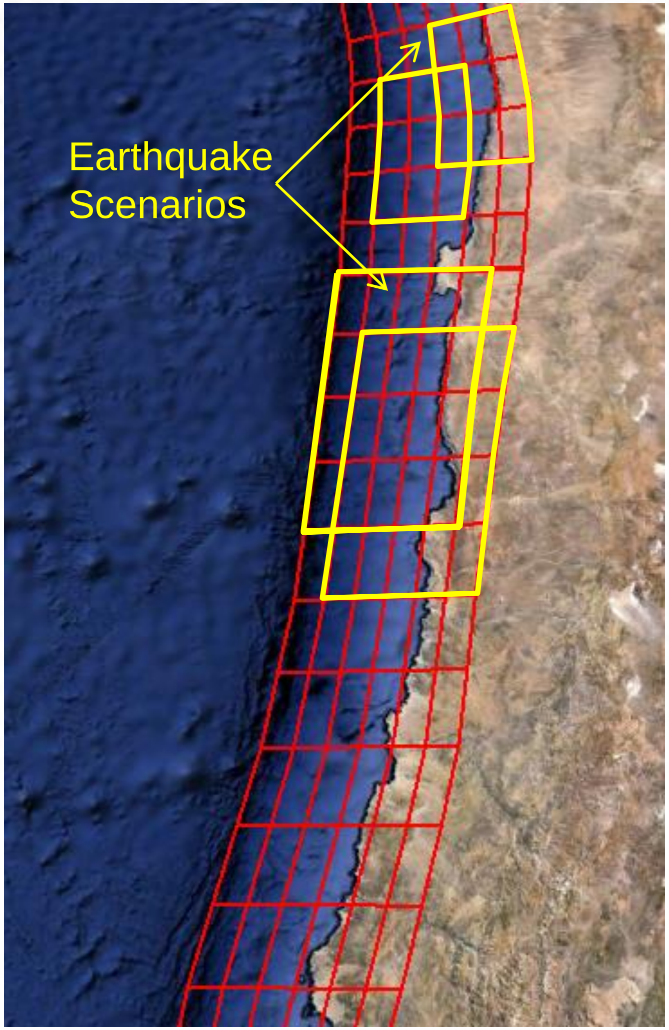
New Time-Dependent Model View



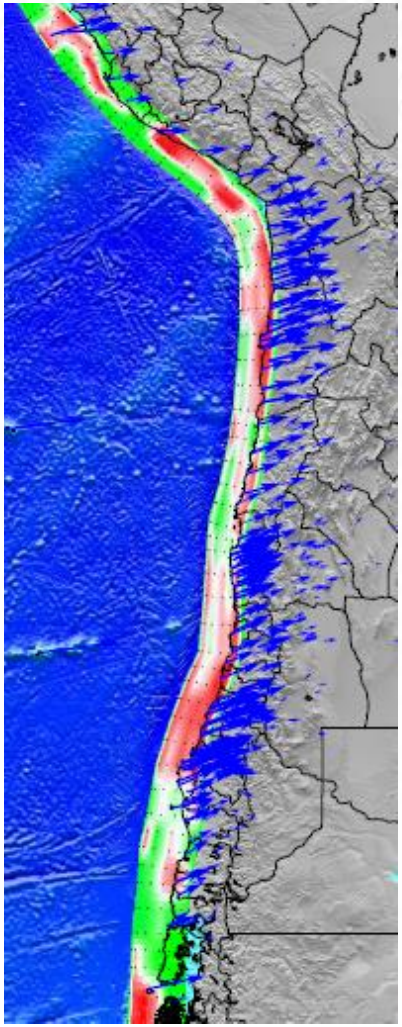
Advantages of the AIR Time-Dependent Rupture Probability Model

Likelihoods of earthquakes are quantified using physical data:

- State of locking on the subduction interface
- Impact of historical earthquakes

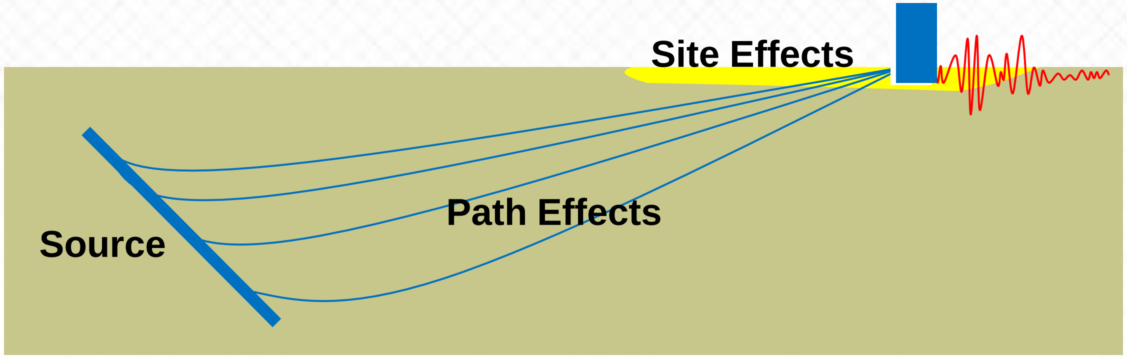


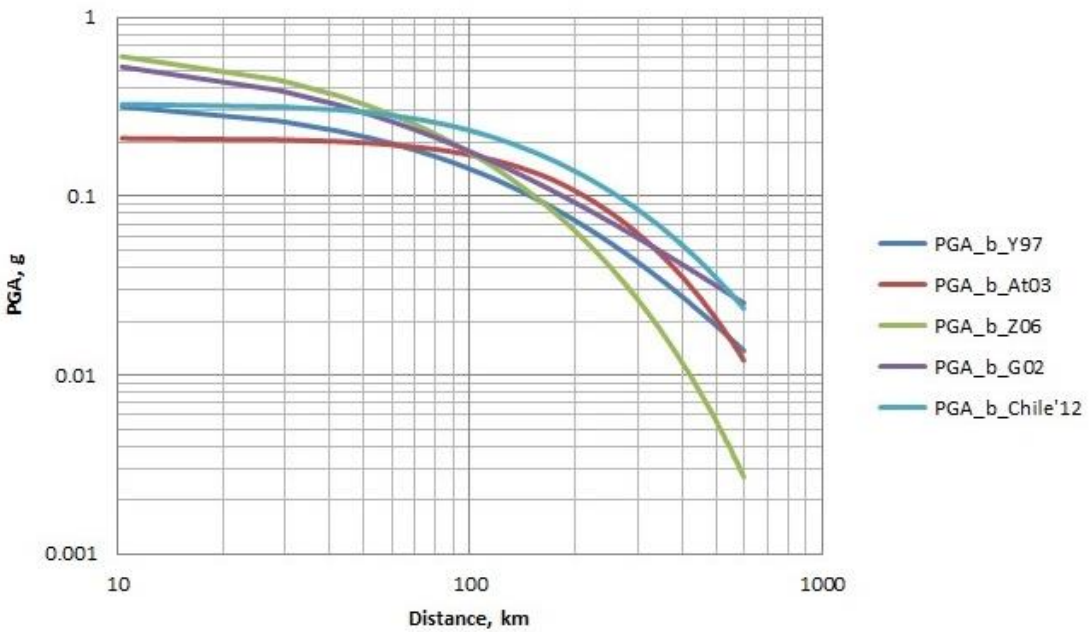
AIR time-dependent model can capture complex rupture dynamics

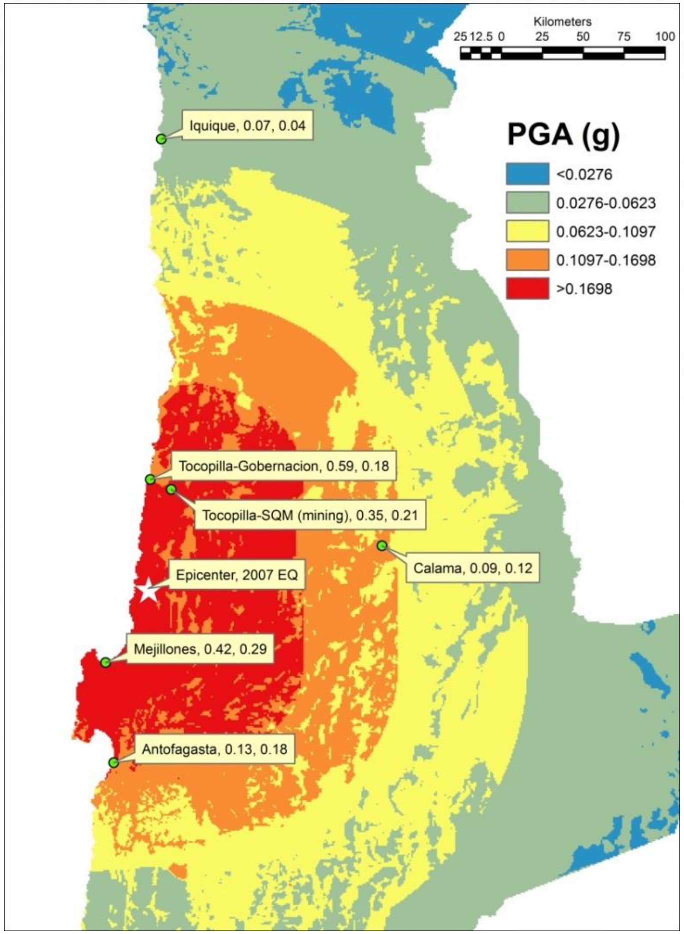


State of locking from kinematic modeling

Ground Motion Prediction Equations (GMPEs) Are Updated Using Latest Research







2007 Tocopilla Modeled PGA

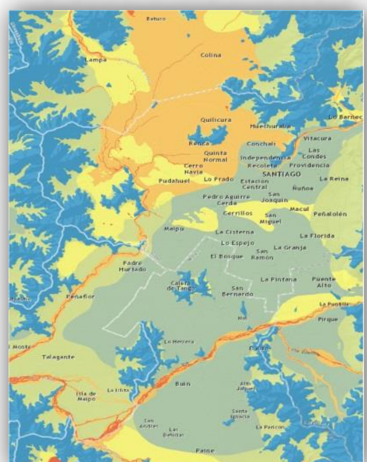
Most Recent Geological Maps and Microzonation Studies Are Used To Create Soil Maps

SERNAGEOMIN
Ministerio de Minería
Gobierno de Chile

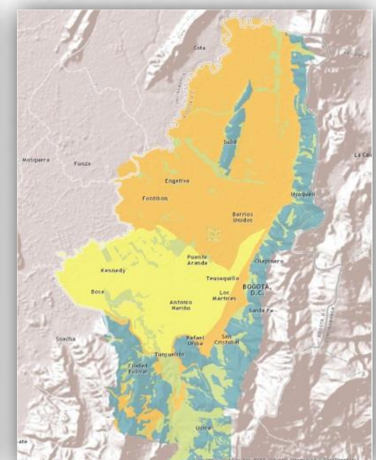
SERVICIO GEOLÓGICO COLOMBIANO

funvisis
Fundación Venezolana de INVESTIGACIONES SISMOLÓGICAS

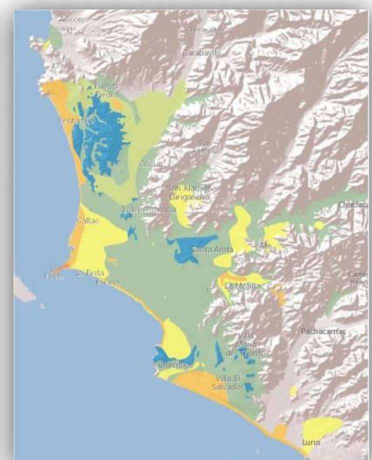
INGEMMET



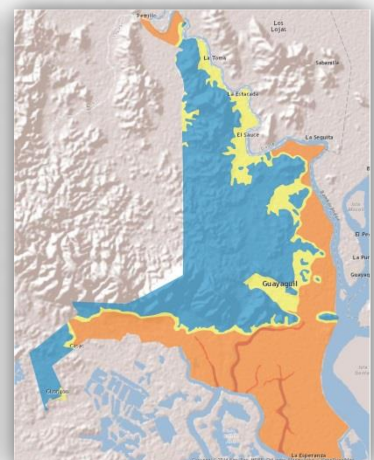
Santiago



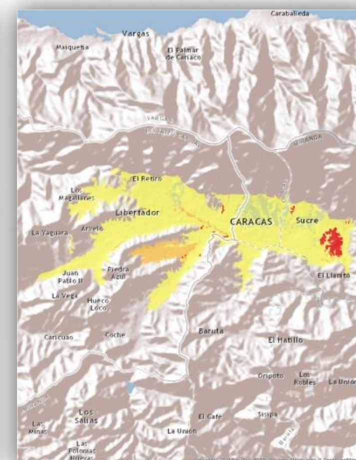
Bogota



Lima



Guayaquil

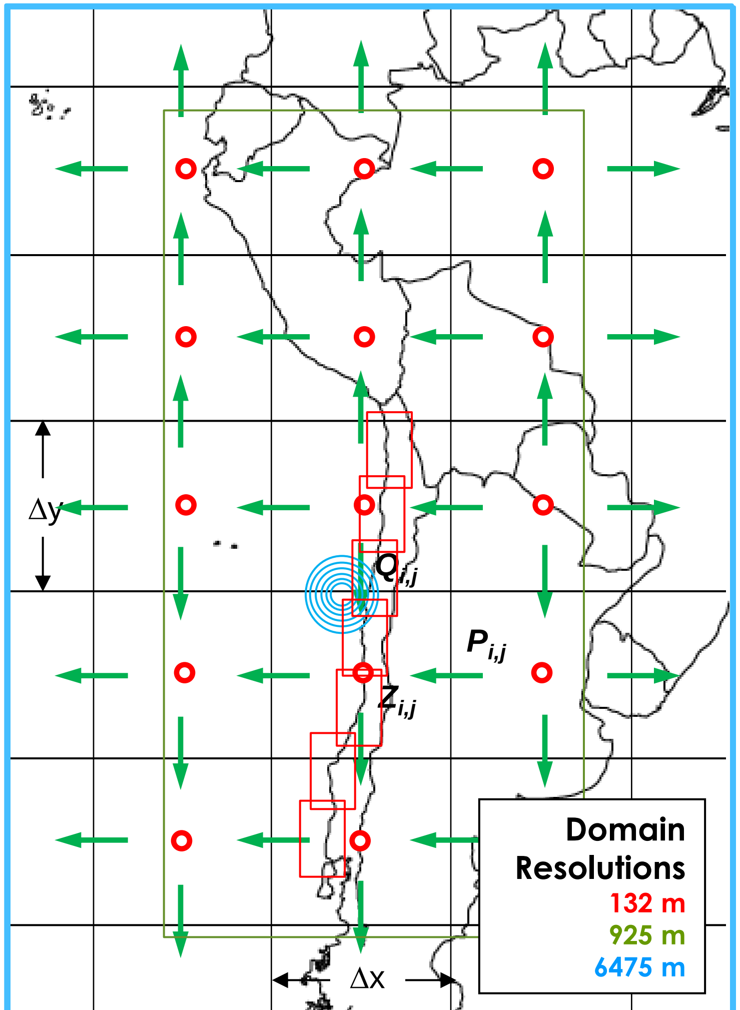


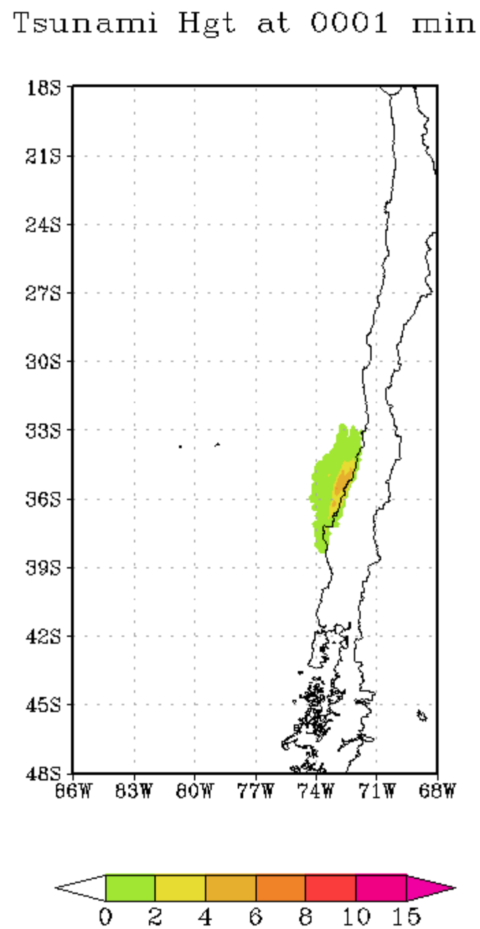
Caracas

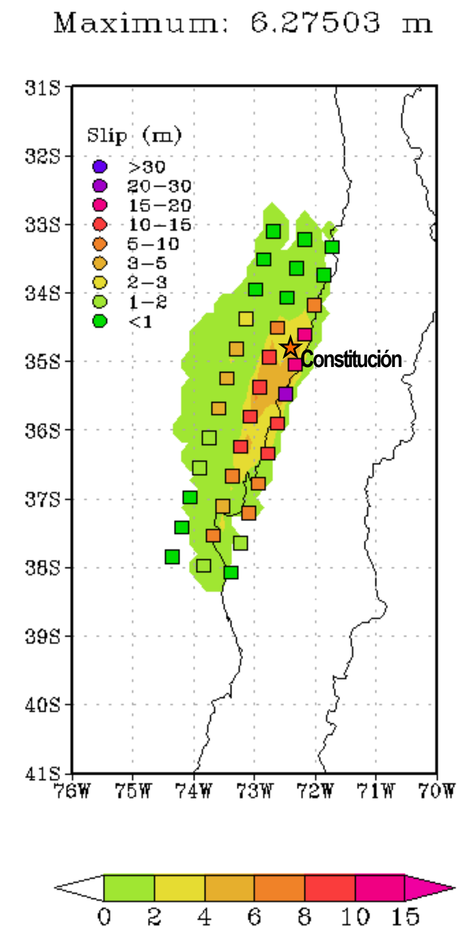
The Need for a Tsunami Model Was Greatly Felt After the Destructive 2010 Maule Earthquake

Numerical Modeling Best Captures Tsunami Complexities

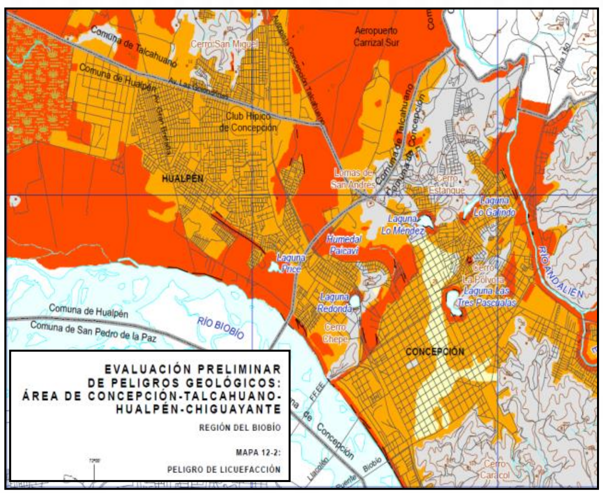
schematic domain configuration for an event



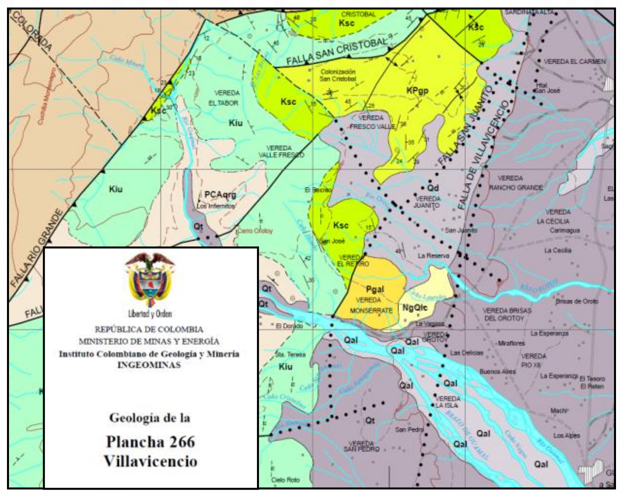




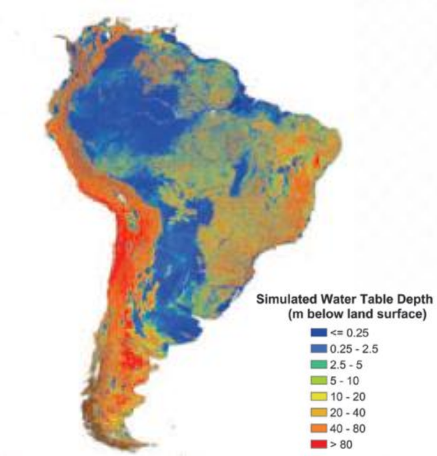
Liquefaction Risk Is Modeled Explicitly



Liquefaction Hazard Maps



Surficial Geology Maps



Groundwater Depth Maps

New Vulnerability Modeling

Vulnerability Update Uses State-of-the-Art Engineering and Data for Damage Estimation

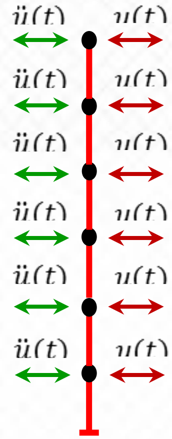
Risk Type	Shake	Tsunami	Liquefaction
Building/Content/BI	✓	New	New
Industrial Facilities	New	New	New
Infrastructure	New	New	New
Builder’s Risk	New	New	New
Auto	✓	New	New

✓ Existing model

- New methodology for shake damage estimation
- Building code–based vulnerability classification for each country

The Updated Damage Functions Are Generated Through Extensive Engineering Analyses

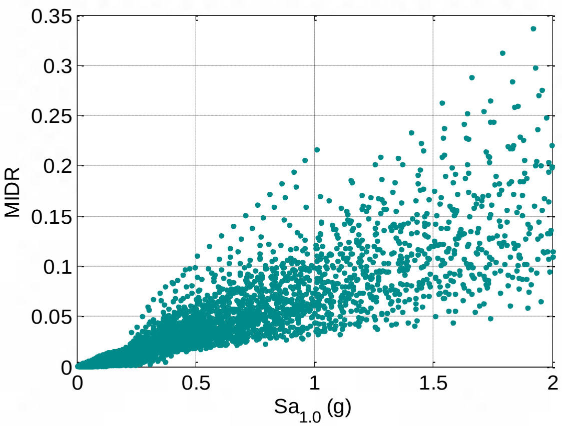
Representative Building



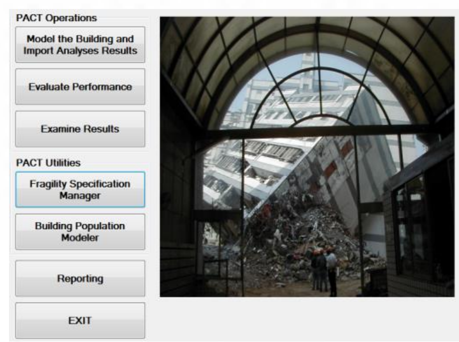
Numerical Models

Subjected to **6900** Ground Motion Records from Earthquakes Worldwide

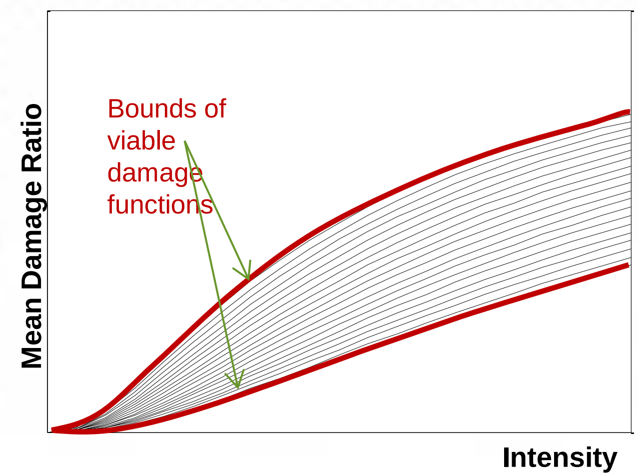
Nonlinear Dynamic Analysis



Building Response vs. Ground Motion



Estimate Losses Based on Building Response Using PACT – FEMA P-58

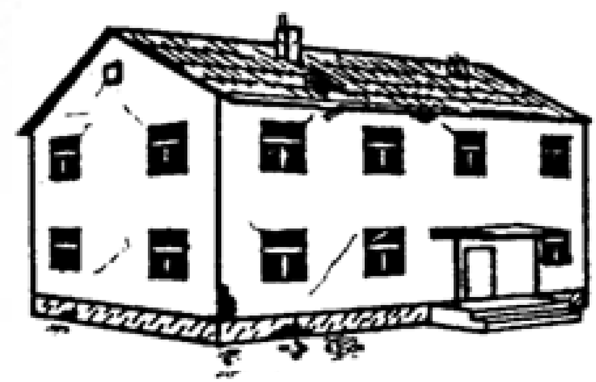


Damage Ratio vs. Ground Motion

Stringency of Seismic Design Code Is an Implicit Measure of Seismic Resistance in Vulnerability Assessment

Seismic Code Levels to Classify Vulnerability in AIR Model

Vul. Class (code level)		**Description**
Pre		Without seismic consideration, mostly refers to non-engineered buildings
Low	I	With minimal seismic consideration
	II	
Moderate	I	With moderate seismic consideration
	II	
	III	
High	I	With stringent seismic consideration
	II	
	III	
Special	I	With very stringent seismic consideration
	II	
	II	
	IV	



AIR Analysis of Building Code Evolution in Colombia Was Reviewed by Local Experts

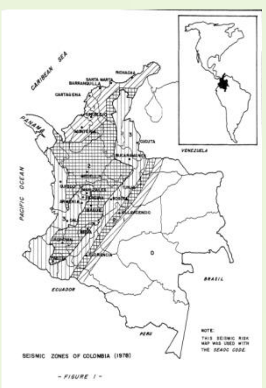
1960 — 1970 — 1980 — 1990 — 2000 — 2010

1967
M6.8
Huila Earthquake

1983
M5.6
Popayan Earthquake

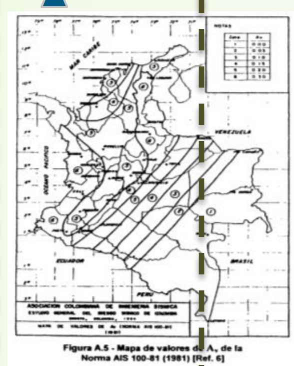
1999
M6.2
Armenia Earthquake

SEAOC Translation - 1974
First seismic zonation map

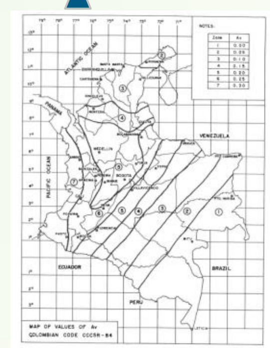


ATC-3-06 Translation - 1979

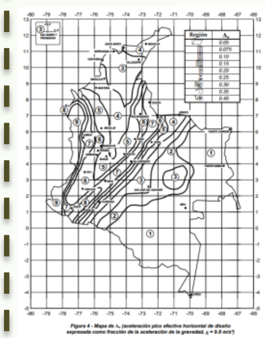
AIS 100 81 - 1981
First Colombian Code



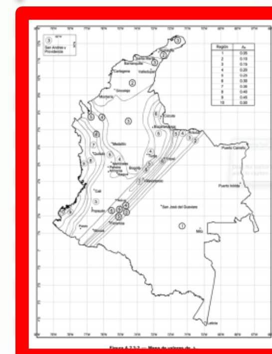
CCCSR-84 - 1984
noncompliance legal penalties included



NSR 98 - 1998
Advances the incorporation of the soil's effects.

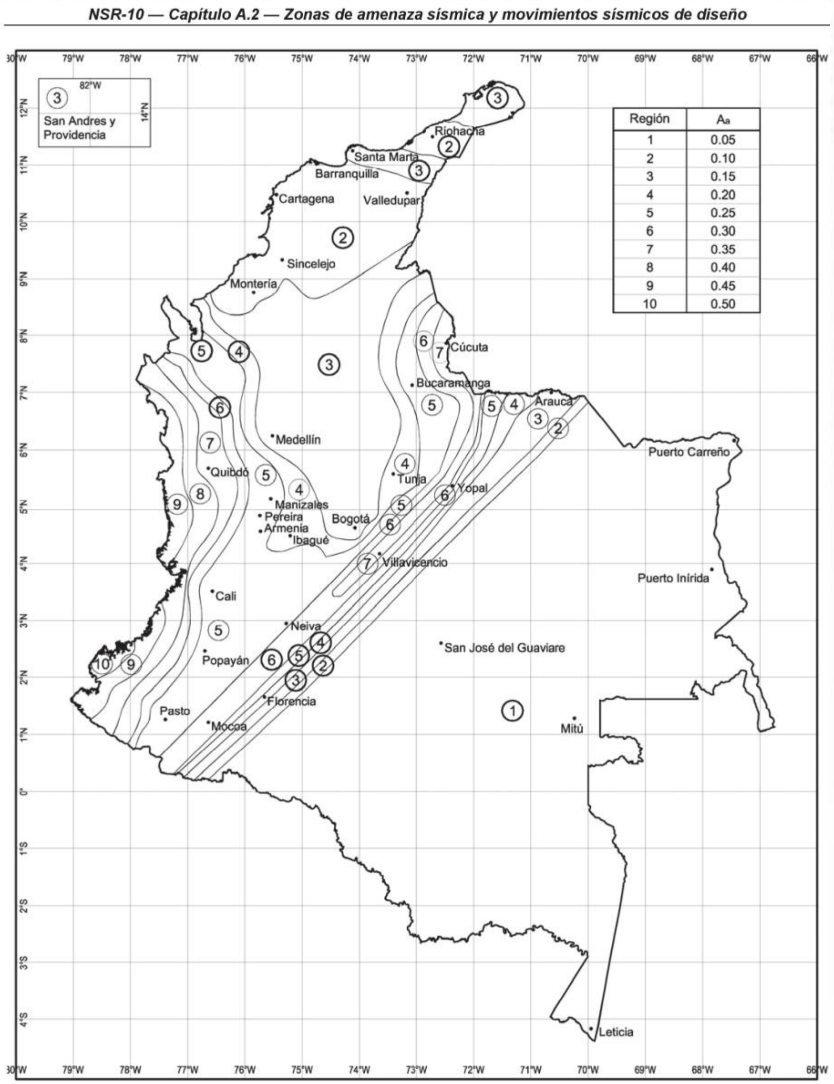


NSR 10 - 2010
More detailed construction class and soil specification

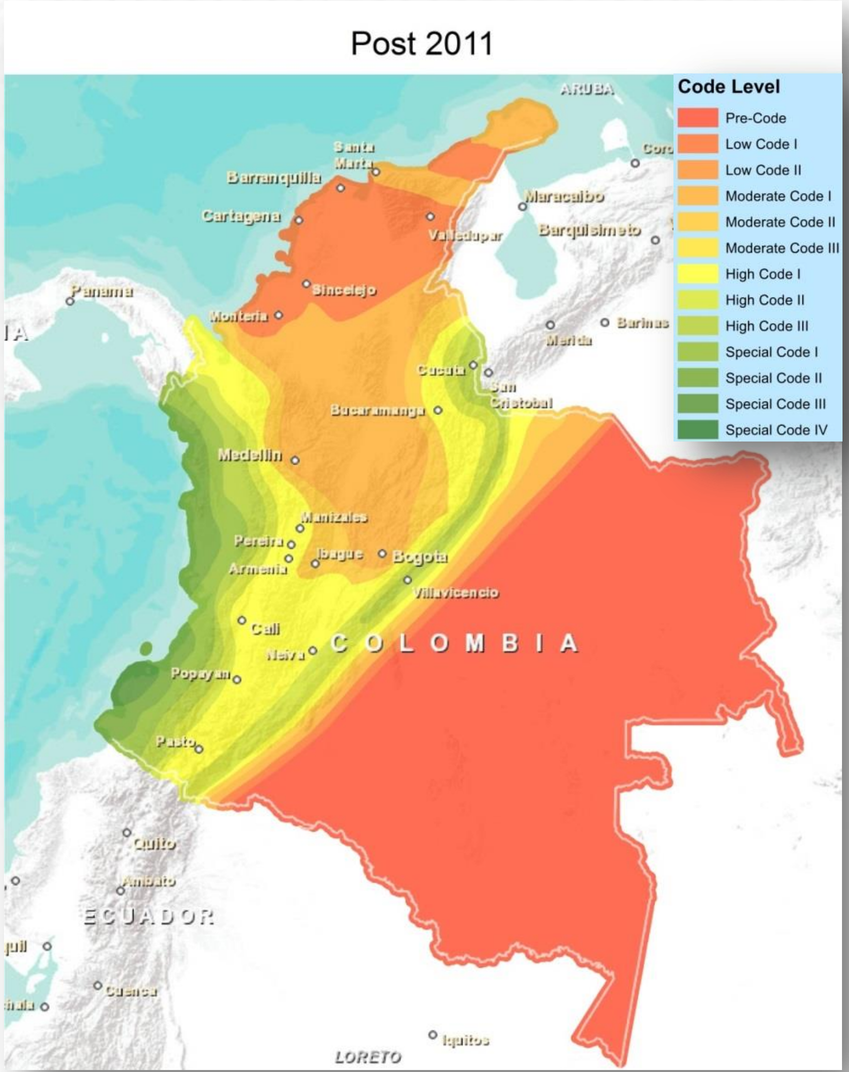


Pre 1974 | 1975-1979 | 1980 -1984 | 1985 -1998 | 1999 -2010 | Post 2011

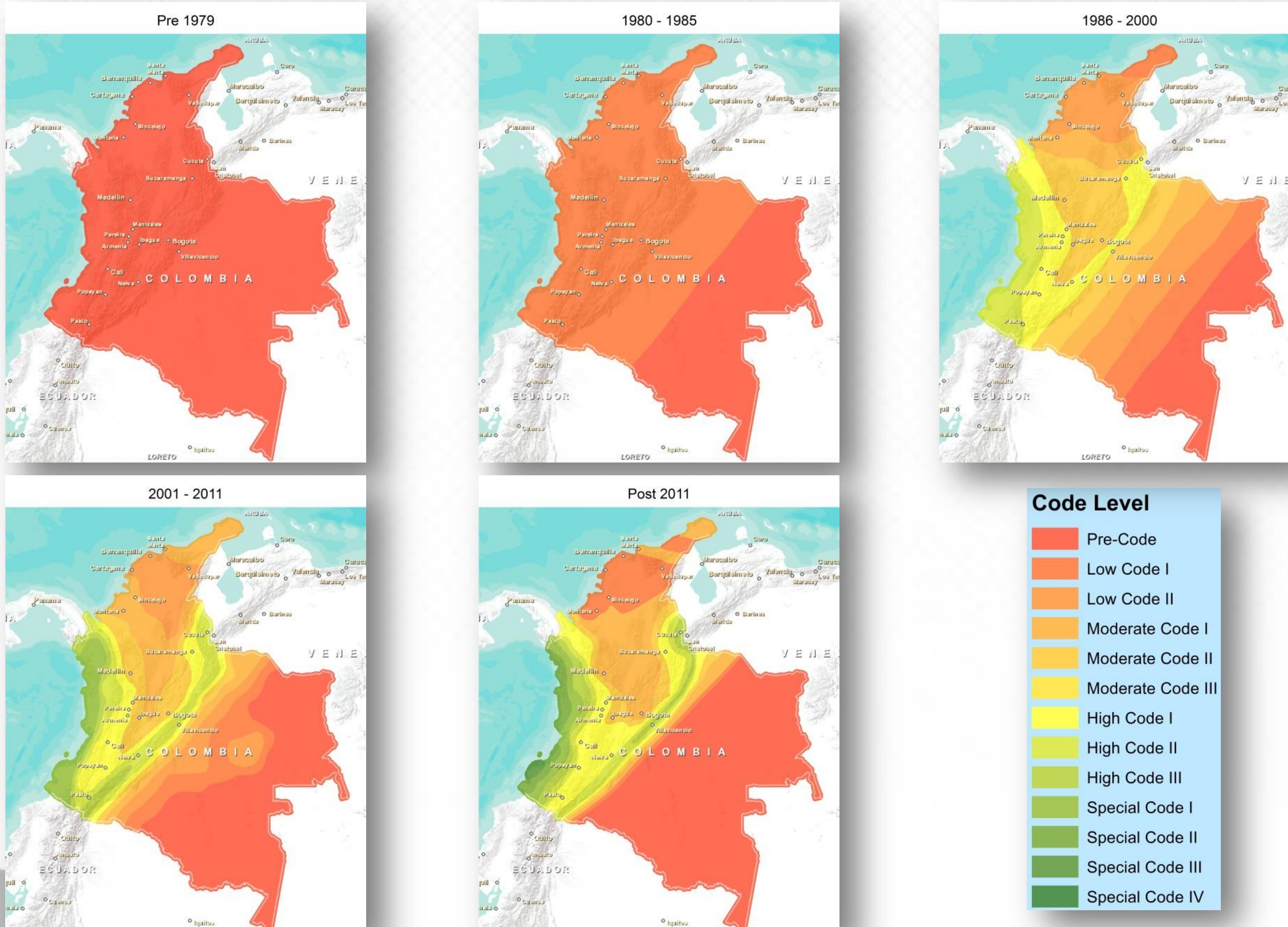
Regional Variation in Vulnerability Is Considered Using Seismic Design Zonation



Región	Aa
1	0.05
2	0.10
3	0.15
4	0.20
5	0.25
6	0.30
7	0.35
8	0.40
9	0.45
10	0.50



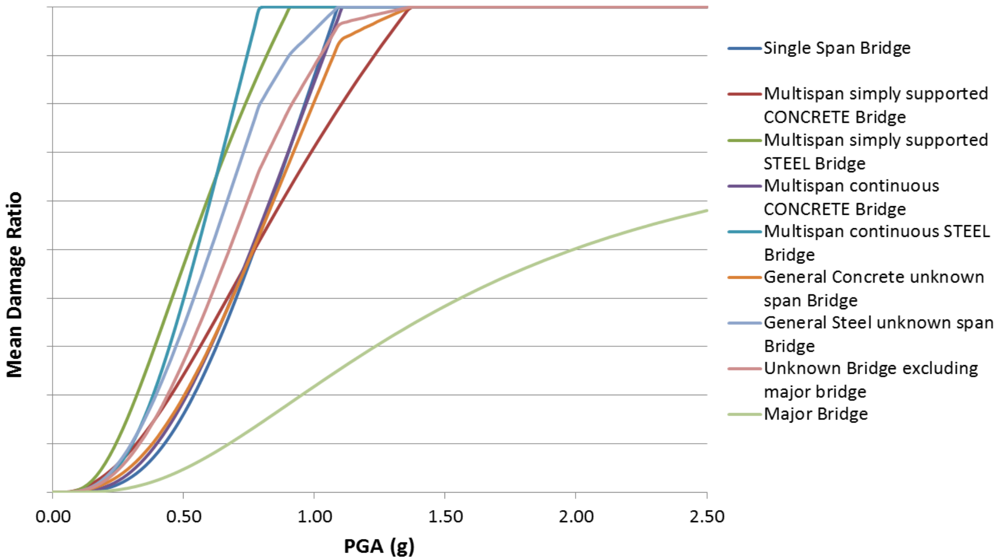
AIR Model Captures the Temporal and Spatial Variation of Vulnerability by Incorporating the Code Evolution



Complex Industrial Facilities Are Modeled Using Dedicated, Component-Based Damage Functions

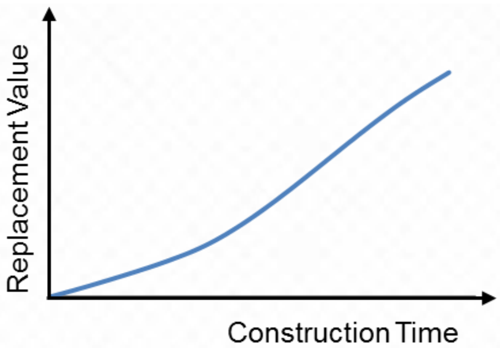
- Power Plants
- Water Systems
- Gas Processing Systems
- General Building/ Construction Contractors
- Heavy Fabrication and Assembly
- Light Fabrication and Assembly
- Food and Drug Processing
- Chemical Processing
- Metal and Mineral Processing
- High Technology
- Mining
- Oil Refineries

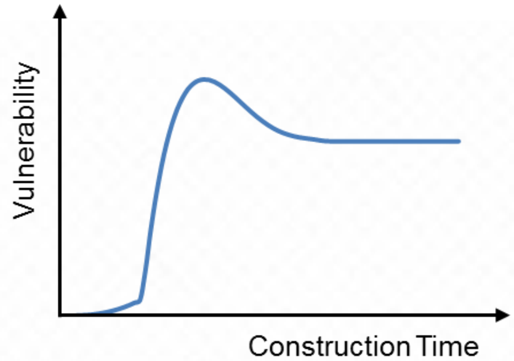
The Updated Models Support Infrastructure Systems with an Improved Set of Vulnerability Functions

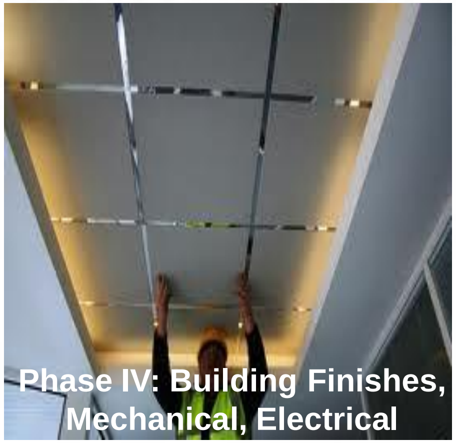


The Updated Model Supports the Builder’s Risk Line of Business

Risk for buildings under construction is characterized by time-variability of vulnerability and replacement







Construction time is broken down to four distinct phases

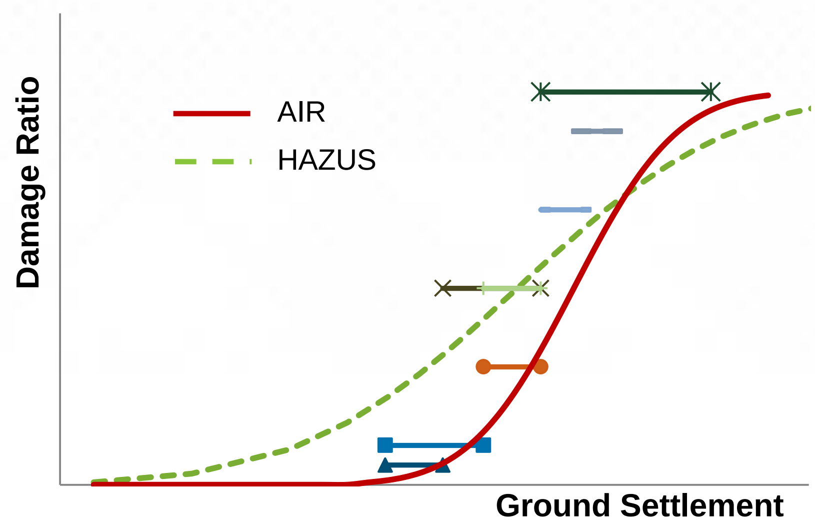
Ground Settlement Is the Salient Parameter in Estimating Liquefaction Damage

Empirical relationships provide an estimate of ground displacement using the ground motion parameters and soil properties

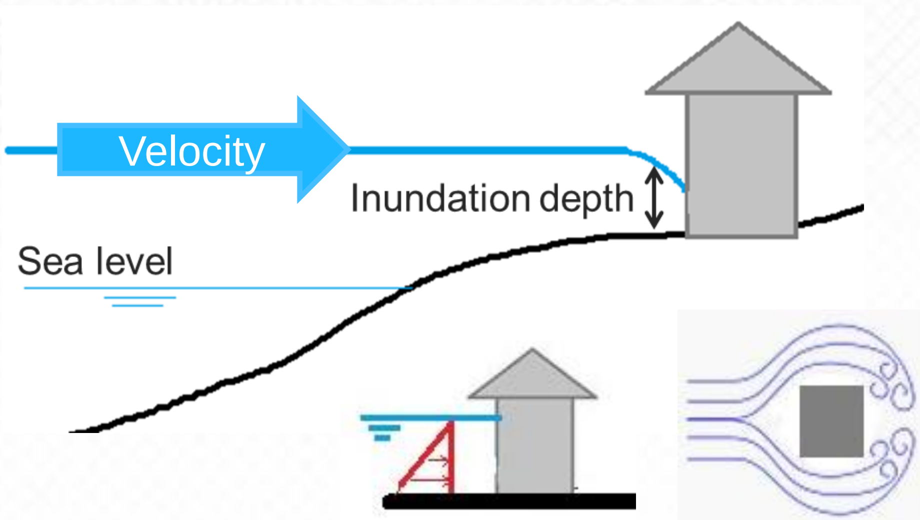
Settlement

AIR damage survey of Christchurch 2011

AIR damage functions are developed by leveraging existing studies and using observational data from Japan and New Zealand earthquakes



AIR Tsunami Vulnerability Model Accounts for Three Damage Determinants



Hydrostatic force

Drag force

AIR tsunami model accounts for:

- Inundation depth d
- Flow velocity v
- Debris factor

Equivalent inundation

$$d + v^2/2g$$

San Antonio, 2010 Maule Earthquake

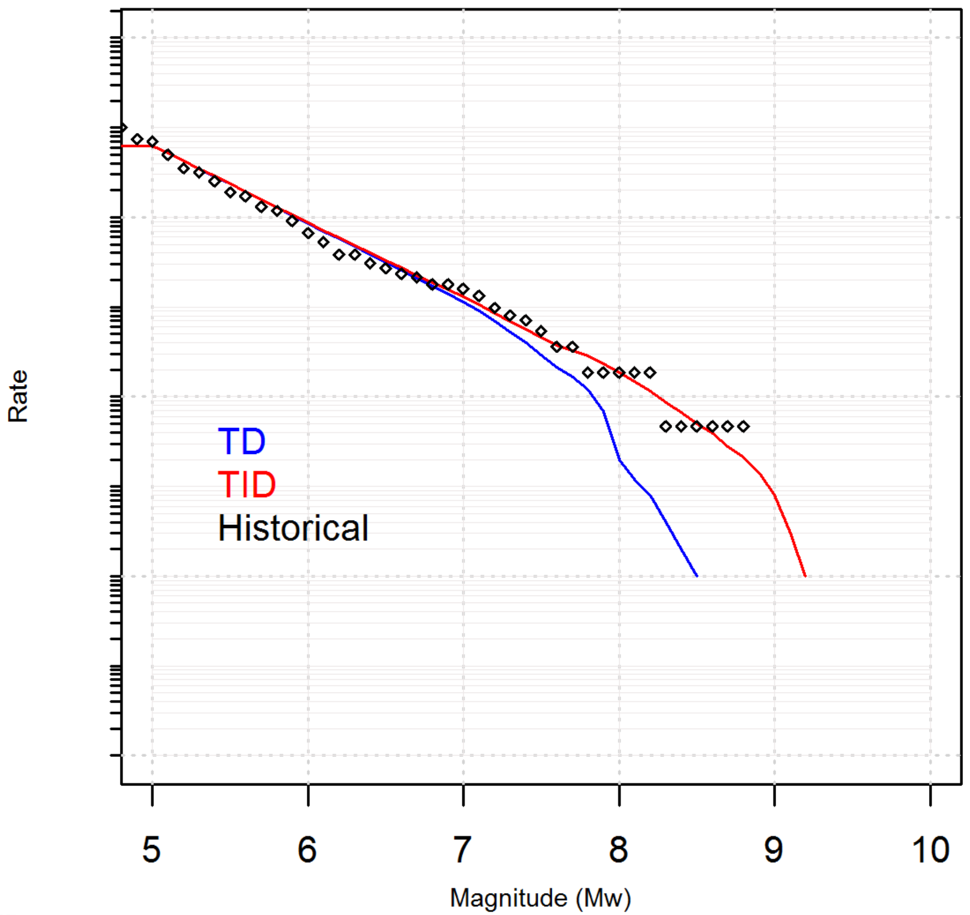
Port debris observed after 2010 Maule Earthquake

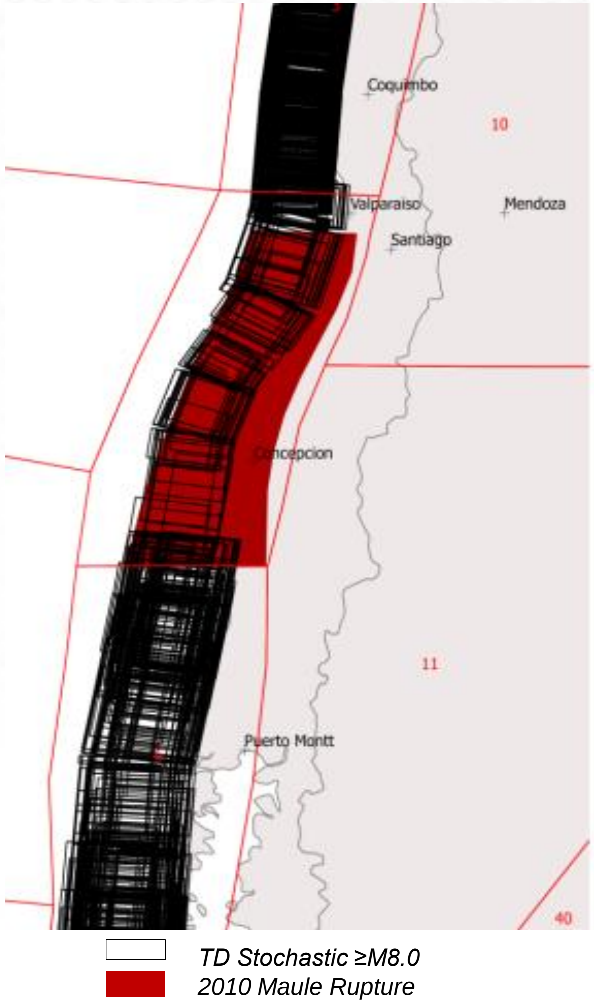
Validation and Software

Mark Szretter

Time-Dependency of AIR's Catalog Should Validate With the Energy-Release Observed in Maule 2010 Event

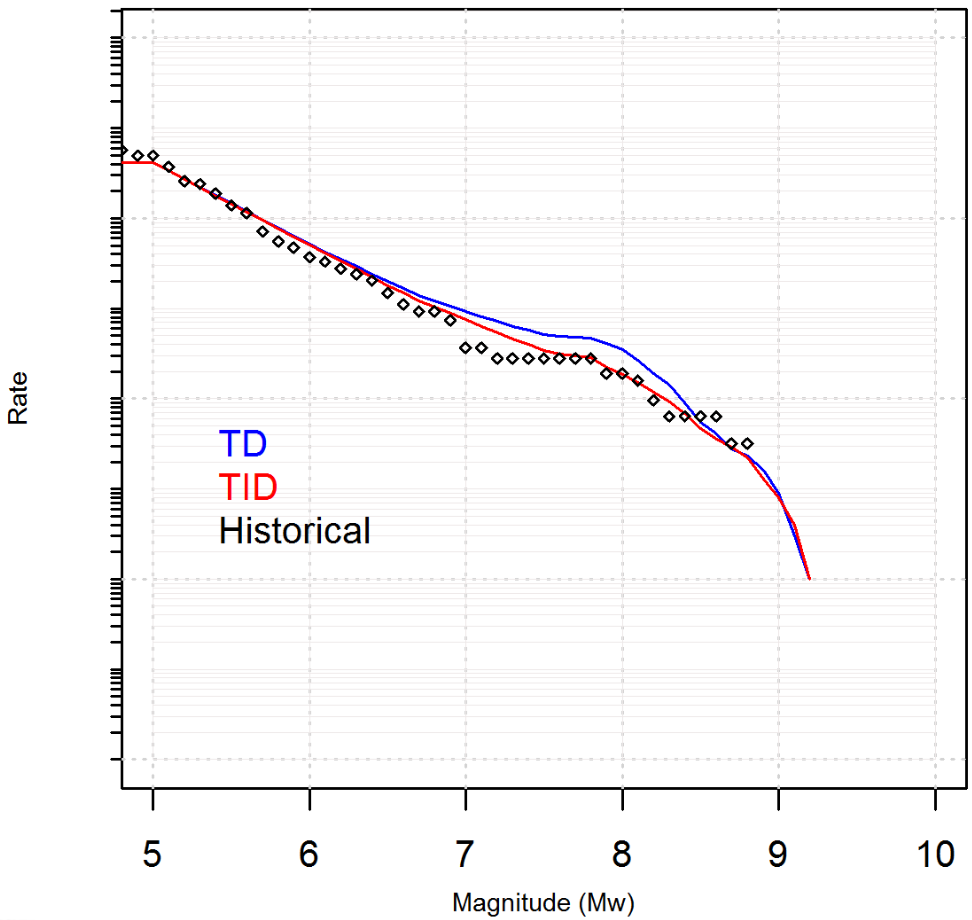
Magnitude-Frequency Plot: Region of the 2010 Maule Earthquake

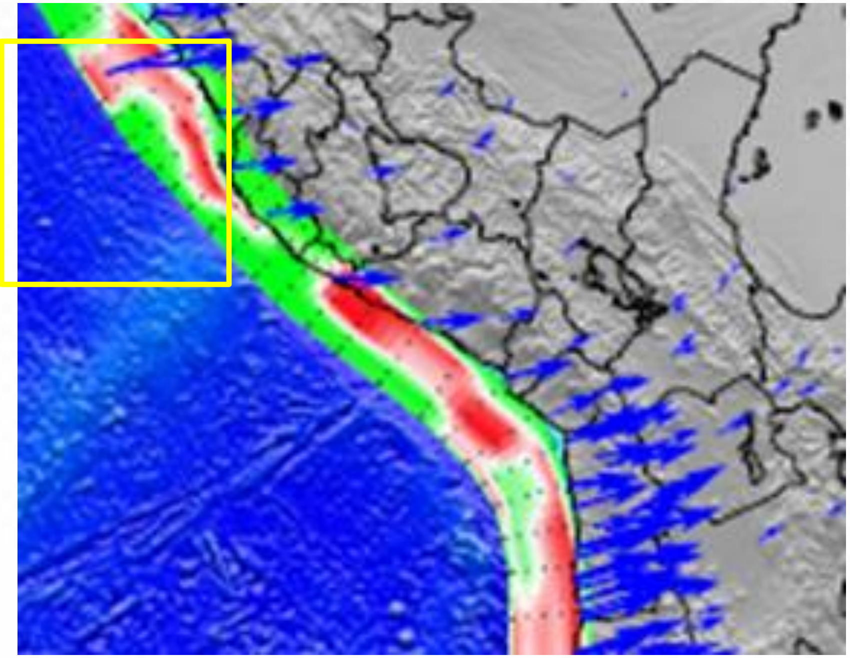




Time-Dependency of AIR's Catalog Should Validate With the Absence of 'Great' Event in Peru Since 1746

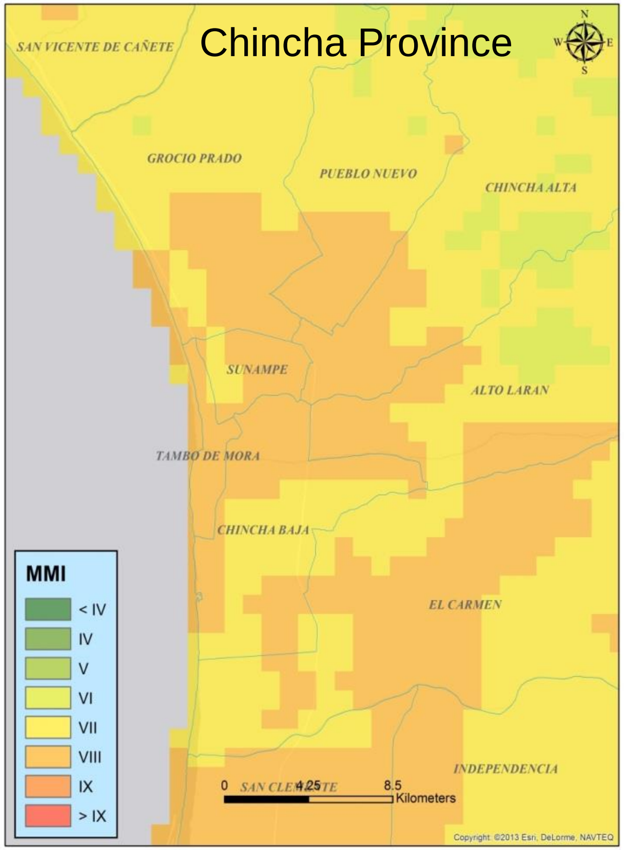
Magnitude-Frequency Plot: Region Near Lima, Peru

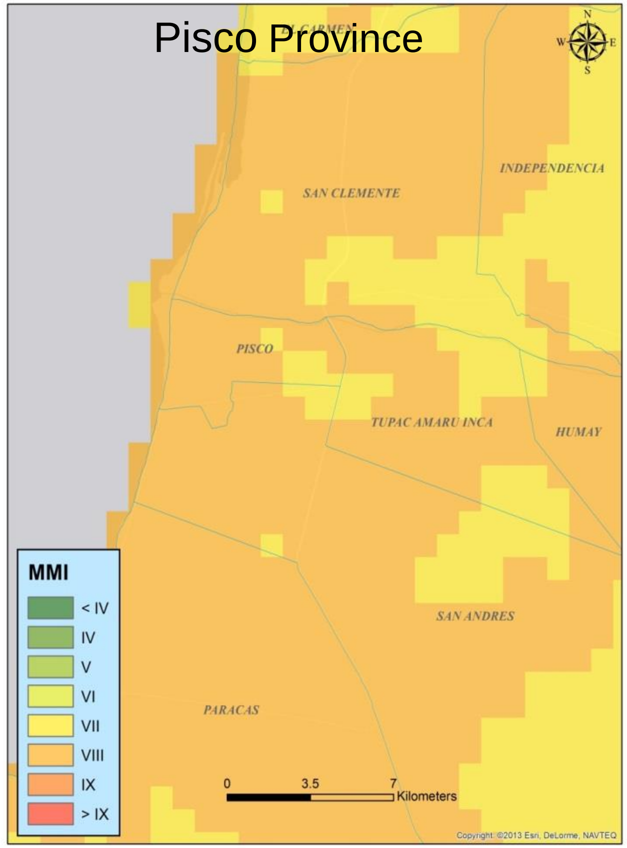


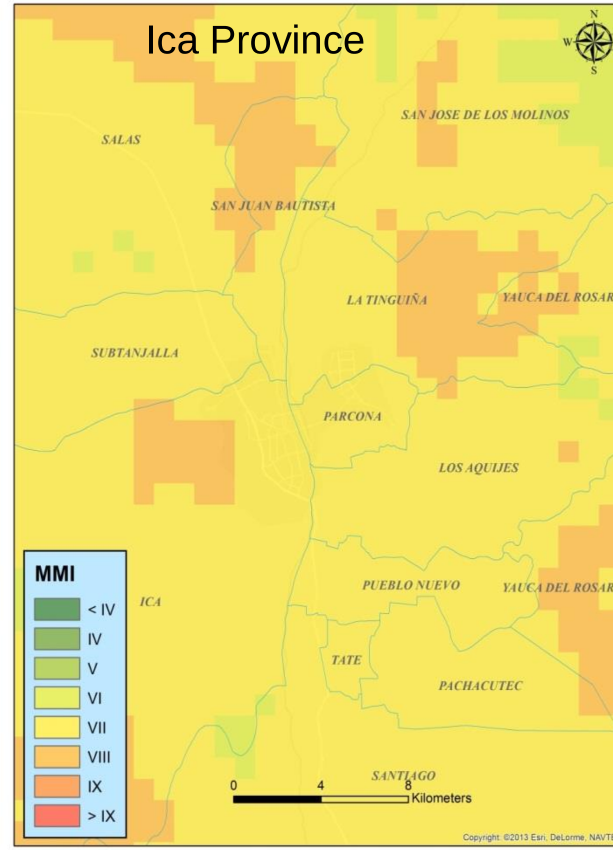


Locked (red) subduction zone
In the region around Lima, Peru (designated area in yellow)

Modeled Ground Motion Intensities Match Observations in the Major Affected Provinces in the 2007 Pisco Event







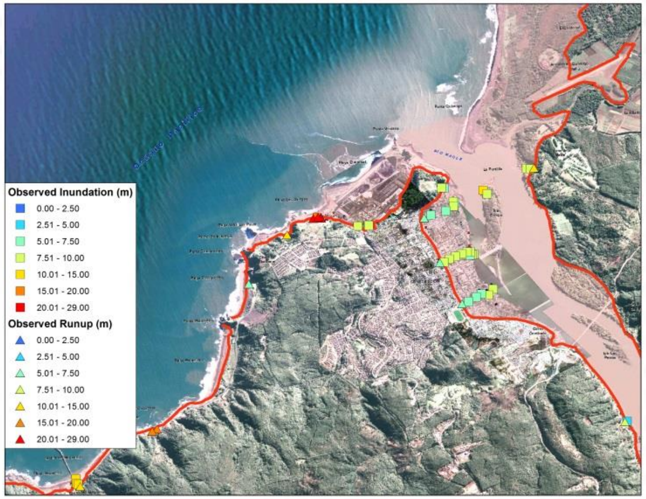
Location	Reported MMI	Modeled MMI
Chincha Alta	7.5	7
Tambo de Mora	7	7.5
Chincha Baja	7.5	7.5

Location	Reported MMI	Modeled MMI
San Clemente	7.5	8
Pisco	8	8
San Andres	7.5	7.5
Paracas	7.5	7.5

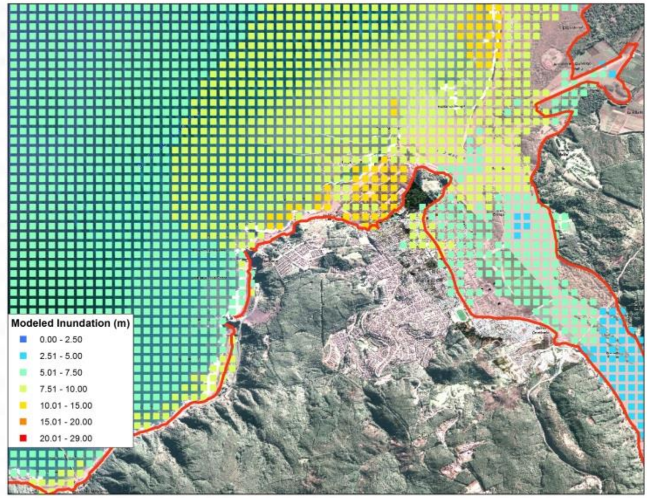
Location	Reported MMI	Modeled MMI
Ica	7	7
Santiago	7	7
Tate	6.5	7

AIR Carefully Validated Tsunami Extents and Maximum Heights Against Historic Event Data

2010 Maule Tsunami - City of Constitución

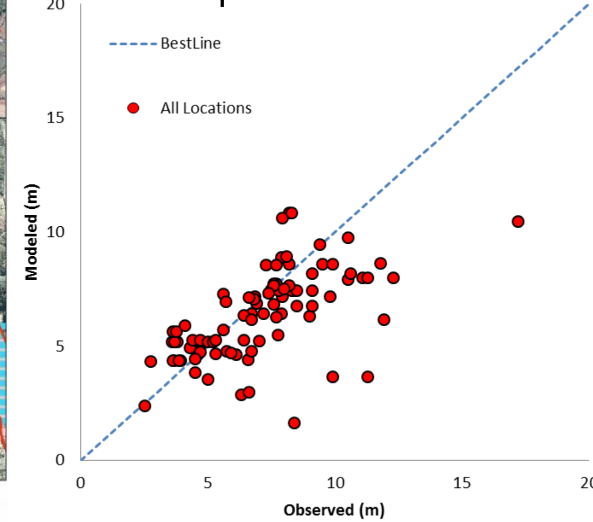


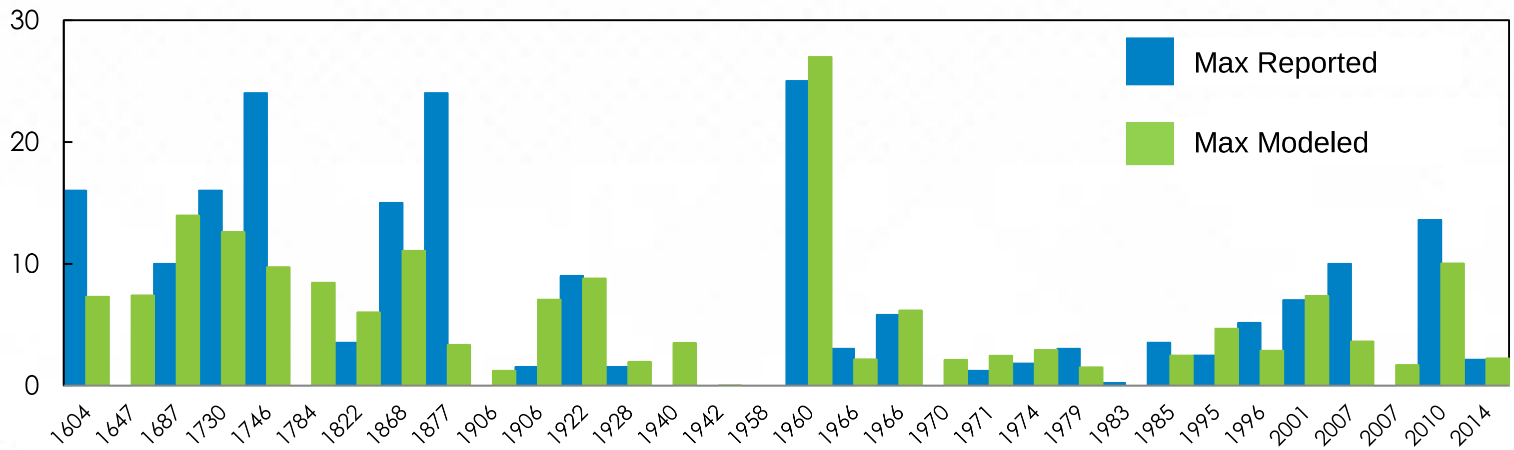
Observed Extent



AIR Model Extent

Maule 2010 Observed Depths vs. Modeled





Max. Inundation Validation for Tsunami Historical Events

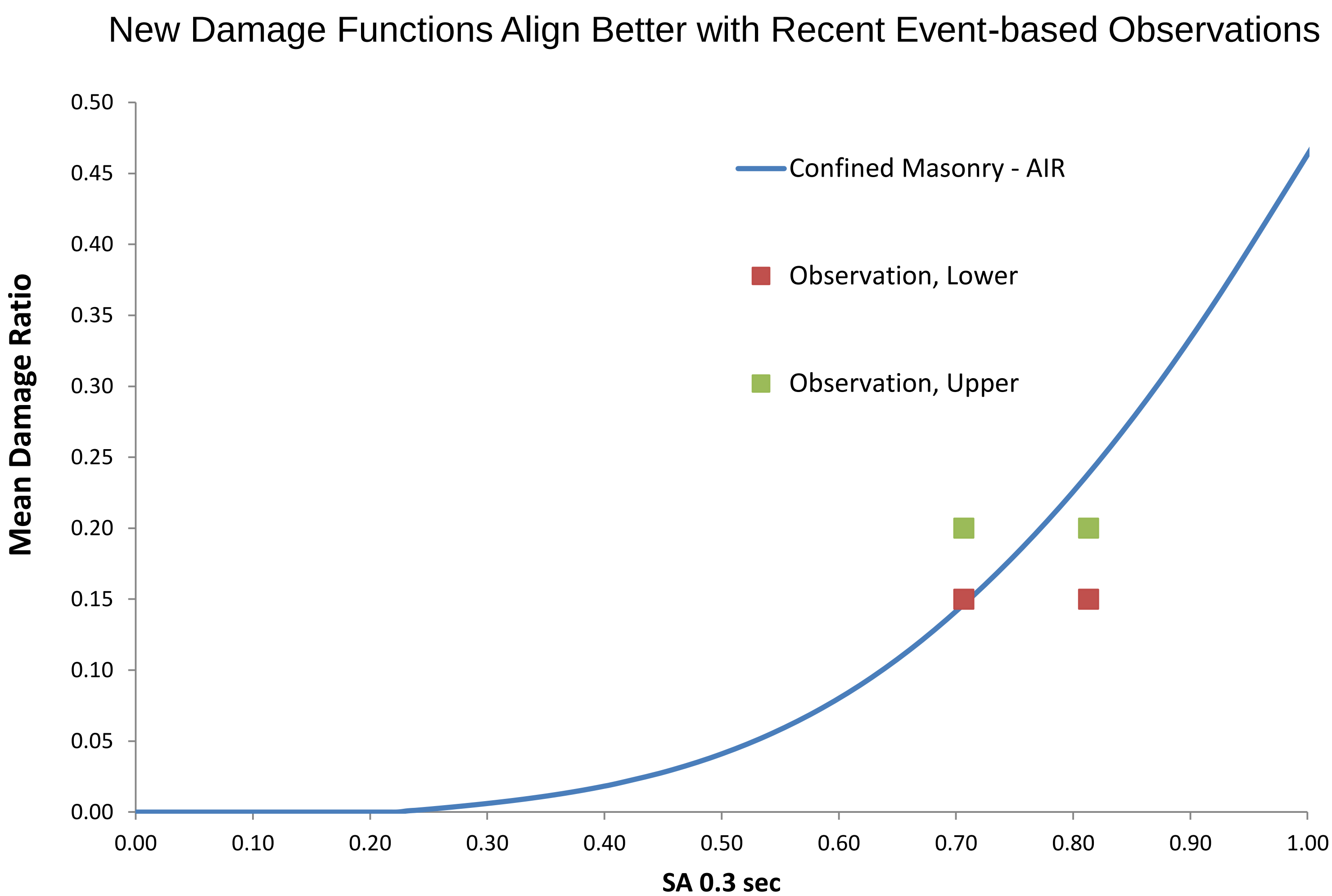
AIR Participated in a South American Seismology Summit and Collaborated with Local Experts

- 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 of South American Construction Revised and Validated Against Recent Event Observations and Local Studies



AIR Considers Multiple Data Sources for Validation Including Local Expertise and Global Best Practices

Prof. Luis Yamín
Universidad de Los Andes, COLOMBIA

Prof. Fabricio Yépez
Universidad San Francisco de Quito, ECUADOR

Prof. Juan Carlos de la Llera Martin
Pontificia Universidad Católica de CHILE

Prof. José Grases
Universidad Central de VENEZUELA

Prof. Jorge Olarte
Universidad Nacional de Ingenieria, PERU

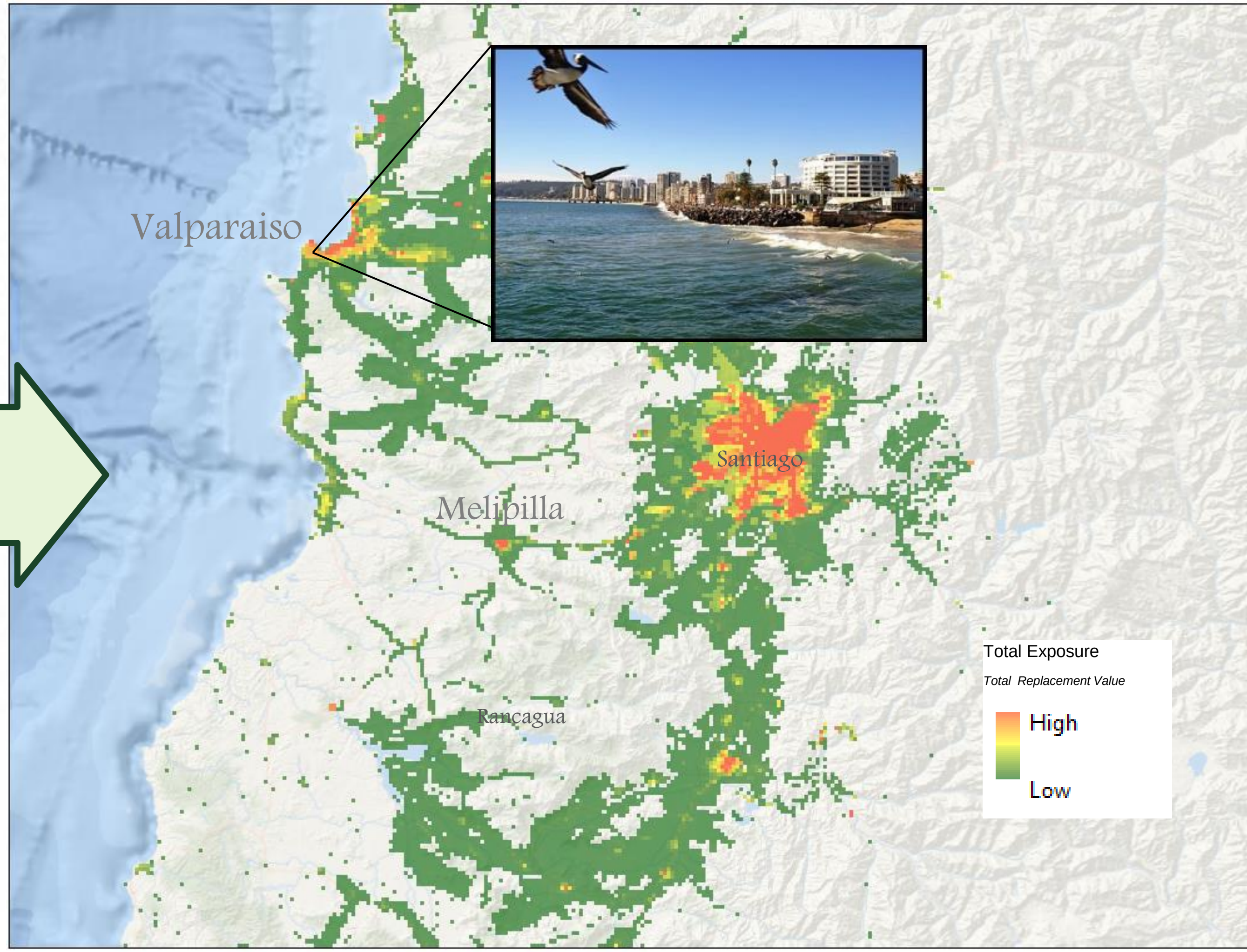
New 1Km Resolution Industry Exposure Databases Allows AIR to Better Validate Model Loss Estimates

Exposure Data Collection

Risk Counts
- Population & Economic Censuses
- Housing Surveys

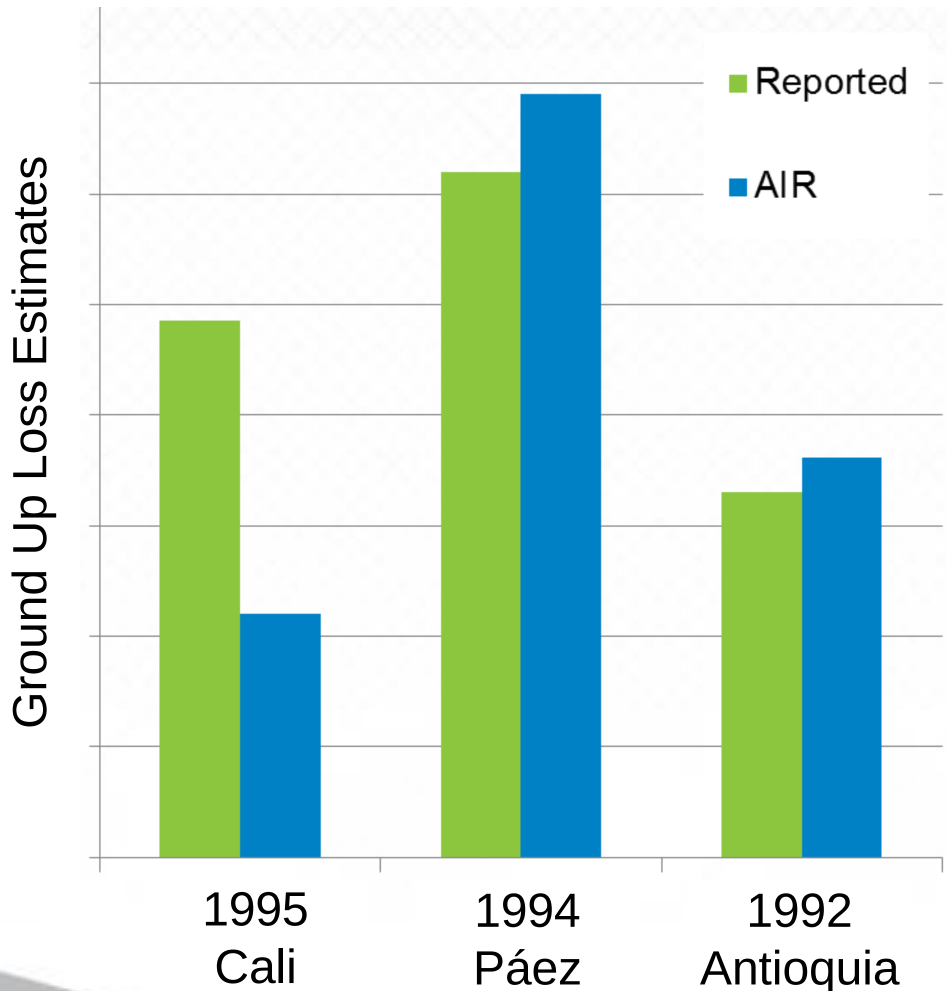
Risk Attributes
- Occupancy
- Construction & Height
- Floor Area

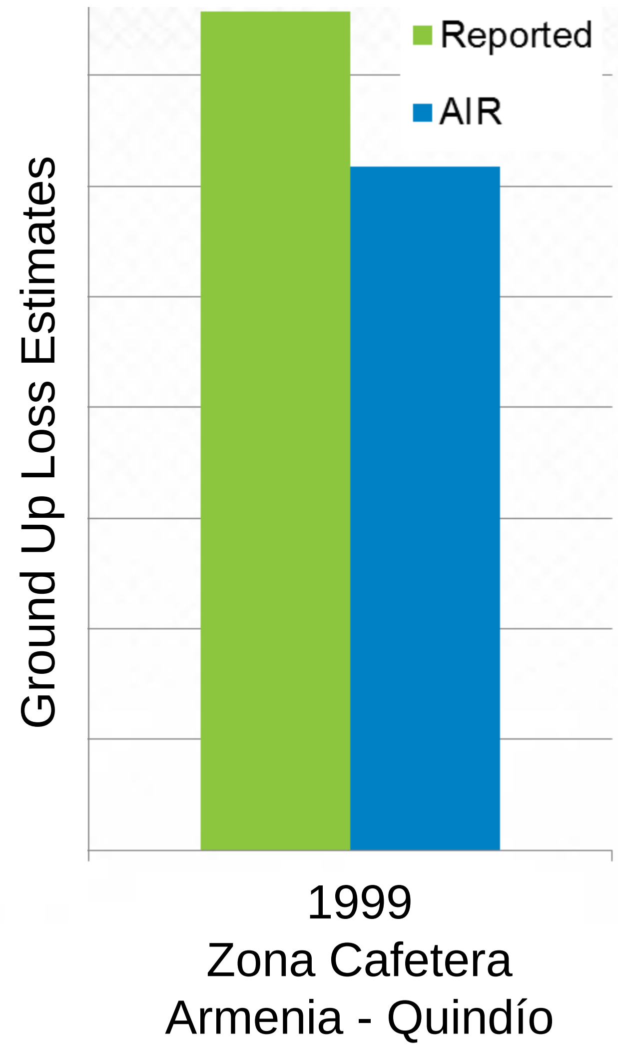
Construction Costs
- Costing Manuals
- Construction Indexes



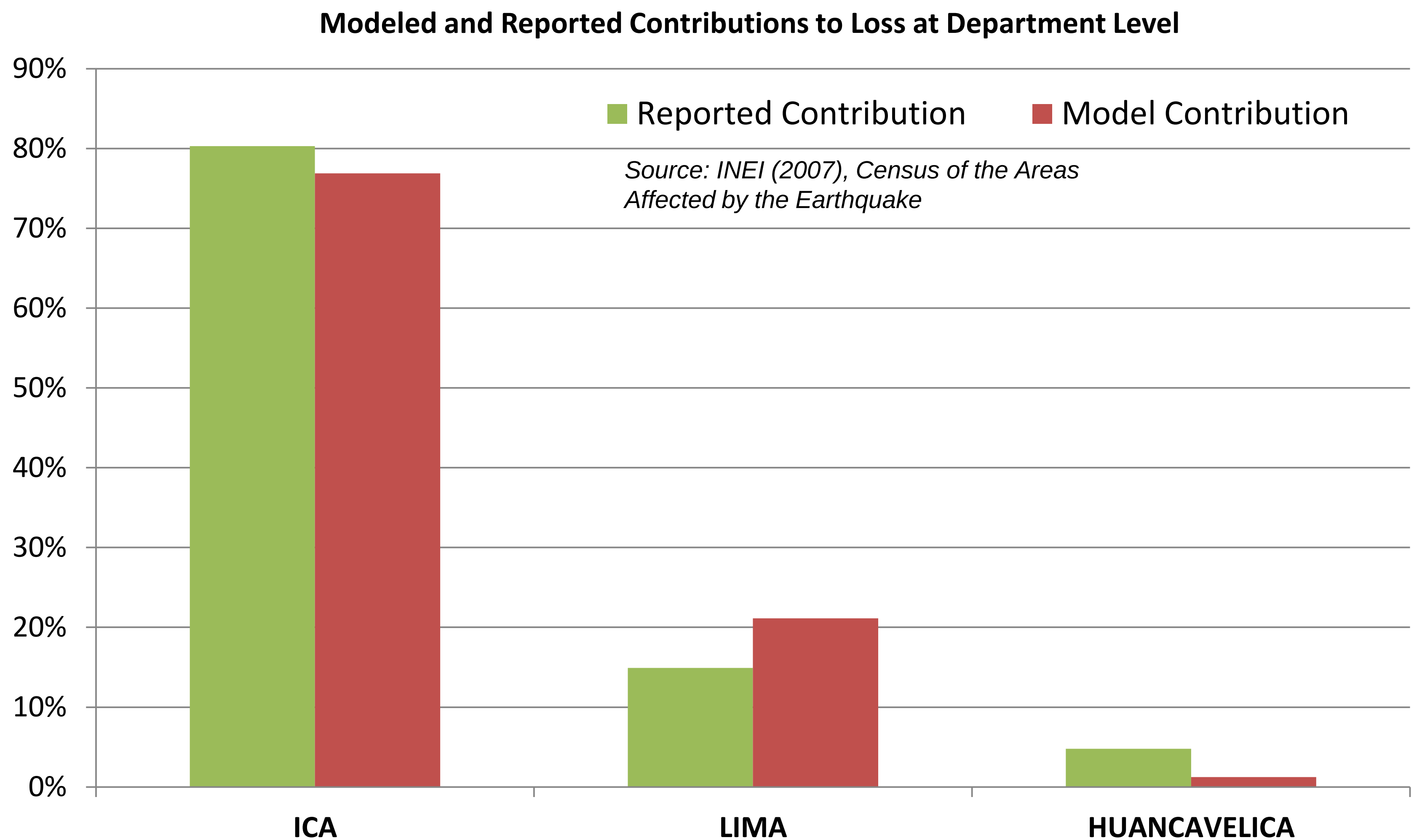
Historic Event Losses for Significant Earthquake Events Provide Important Guide Points for Validation

Economic Losses for Colombian Earthquake Events 1990-Present



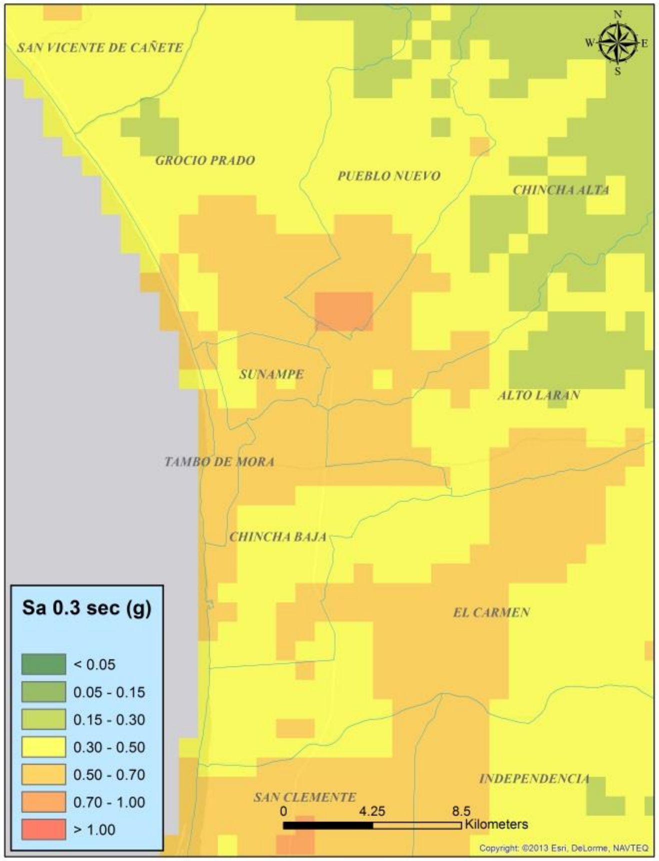


Model's Loss Distribution by Region Matches the Regional Losses from Reports – 2007 Pisco



Model Correctly Reproduces the Pisco Earthquake Observed Loss Ratios at the Province Level – Chincha, Peru

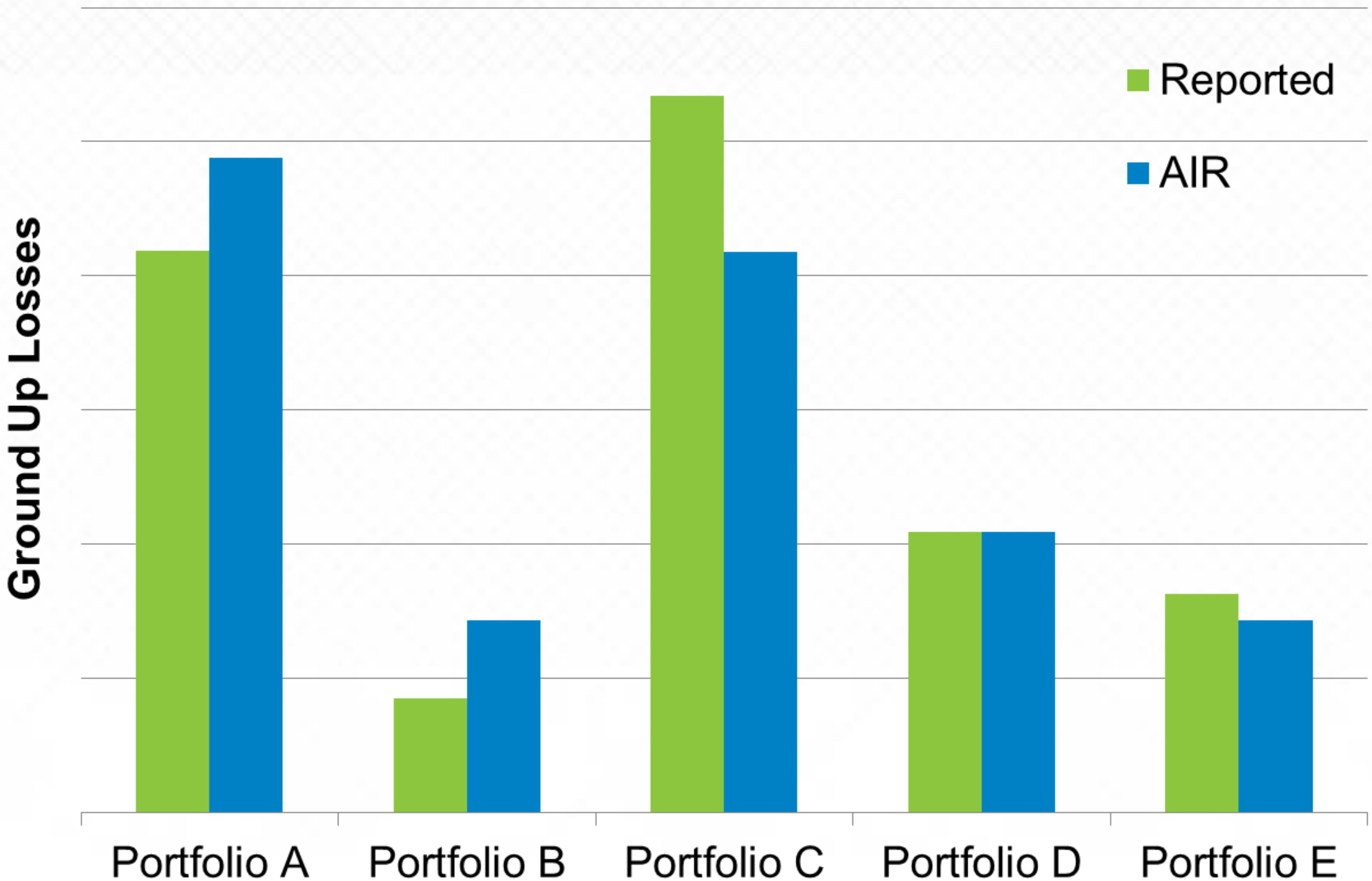
Modeled Ground Chincha Province
Motion *Spectral Acceleration Sa 0.3 sec (g)



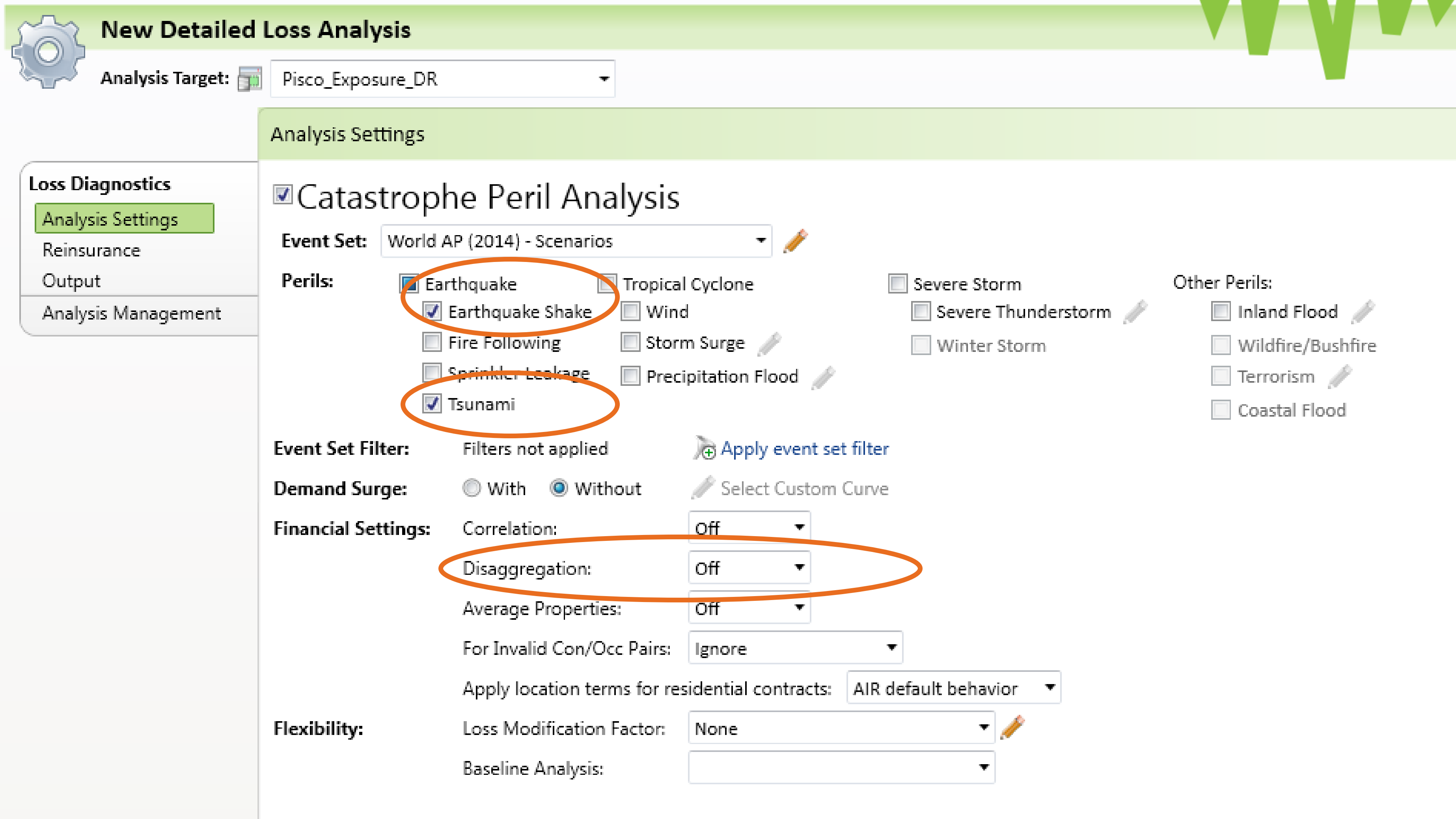
Modeled vs. Observed Loss Ratios Chincha Province

District	Observed Damage Lower Bound	Observed Damage Upper Bound	AIR Modeled Damage
ALTO LARAN	18%	35%	35%
CHINCHA ALTA	25%	43%	35%
CHINCHA BAJA	27%	46%	30%
EL CARMEN	20%	39%	33%
GROCIO PRADO	28%	48%	41%
PUEBLO NUEVO	29%	48%	40%
SUNAMPE	30%	50%	38%
TAMBO DE MORA	26%	45%	32%

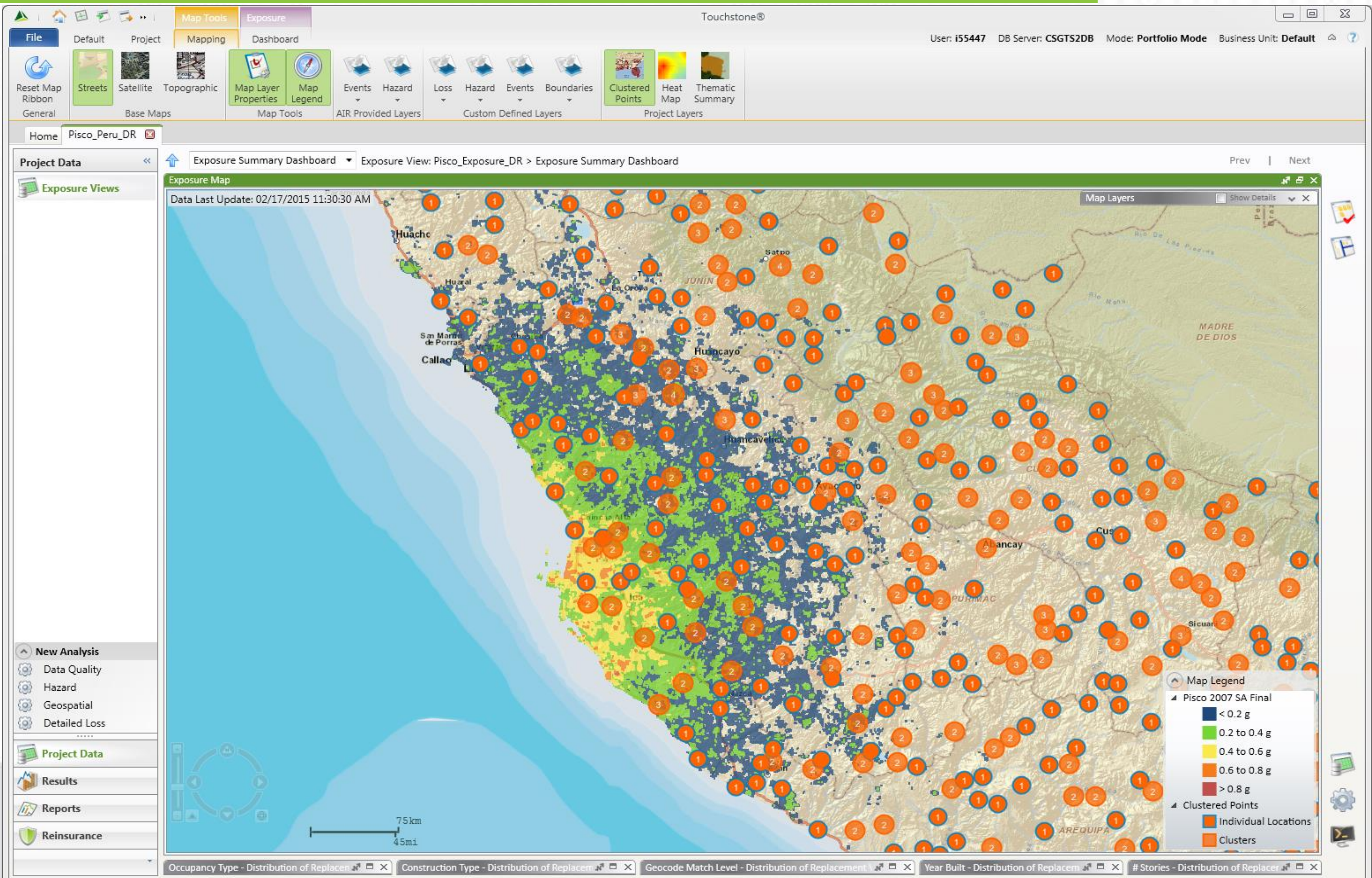
2010 M8.8 Event in Concepción, Chile Provided Good Data Source of Claims Data for Validation



Touchstone's Flexible Options Allow for Separate Evaluation of Tsunami and Shake Losses and Improved Disaggregation

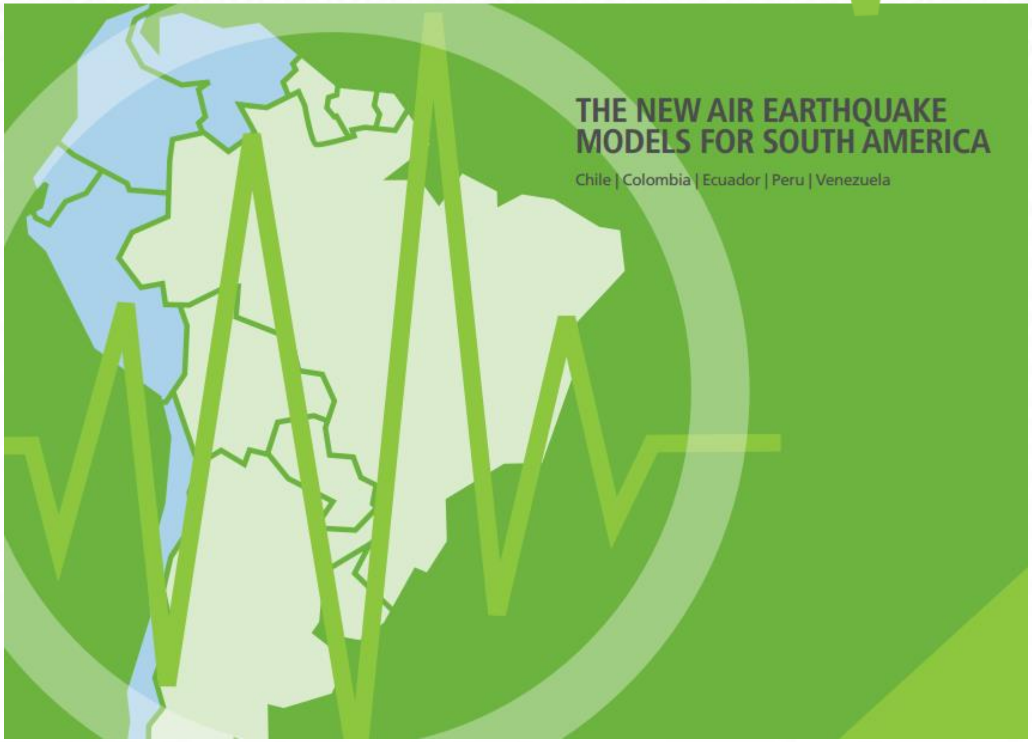


AIR's Touchstone Platform Allows Analysis of Exposure Distribution and Deterministic Studies Relative to Hazard



AIR's New South America Earthquake Models Set the Bar in Terms of Scope, Innovation, and Quality

- Tsunami modeling for the Pacific Coast subduction zone from Chile to Colombia <u>and</u> liquefaction
- New risk types: industrial, public infrastructure, CAR builder's risk
- Extensive validation of components, loss outputs using real loss data and with inputs from local engineers and geo-scientists in each of the modeled countries



Additional Resources on the AIR Website

April 8th – 10th in Boston