A Preview of the AIR Earthquake Models for Southeast Asia

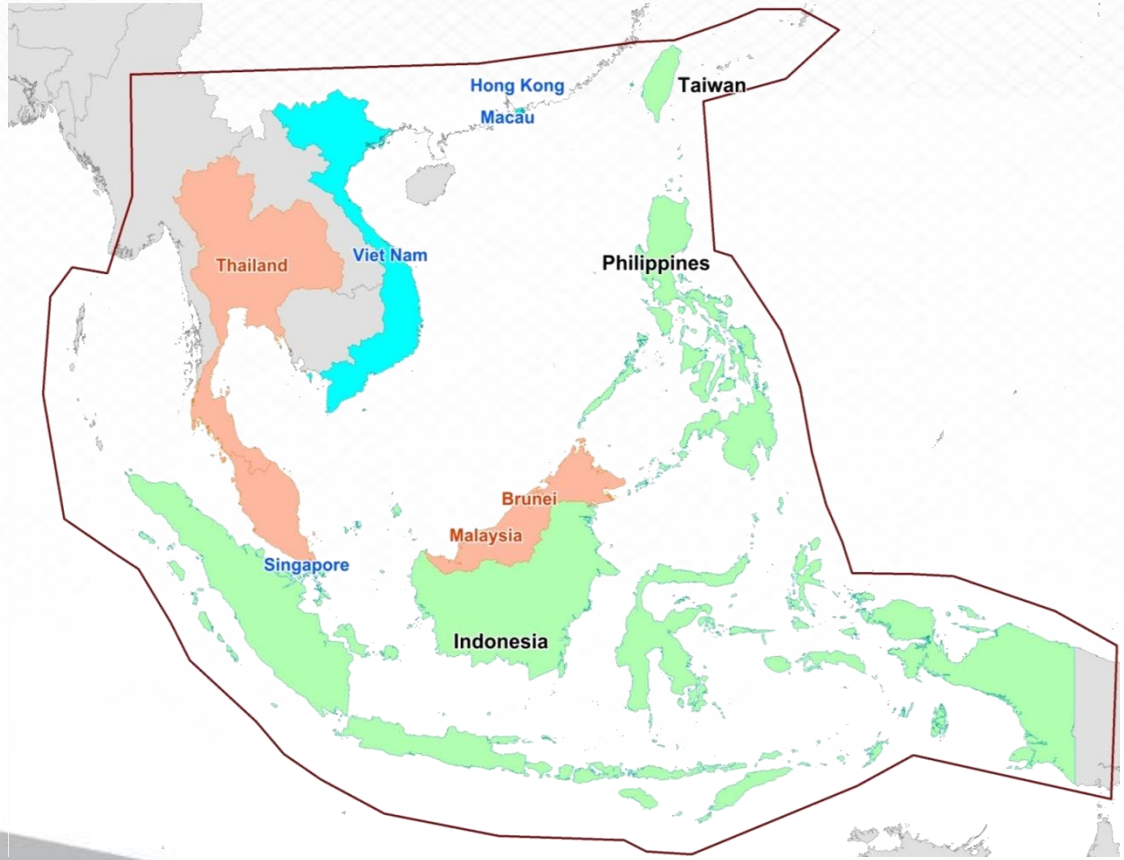
Apoorv Dabral, Ph.D., Elliot Klein, Ph.D., Mesut Turel, Ph.D.

AIR WORLDWIDE®

Some of the Major Earthquakes Affecting Southeast Asia

- 1999 Chi-Chi Earthquake
  - Significant losses
  - Best recorded data
- 2004 Banda Aceh
  - Tsunami
  - Multiple countries affected
- 2013 Bohol Earthquake
  - Recent earthquake
  - Impacted population center

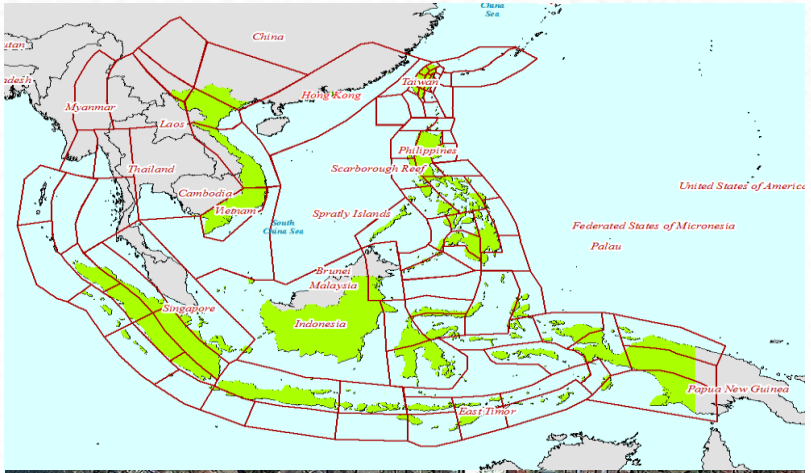
In 2016, the AIR Earthquake Models for Southeast Asia Are Being Updated and Expanded



- **Updated Countries**
  - **Taiwan**
  - **Philippines**
  - **Indonesia**
- **Added territories**
  - **Hong Kong**
  - **Macau**
  - **Vietnam**
  - **Singapore**
  - **Thailand**
  - **Brunei**
  - **Malaysia**

The Southeast Asia Earthquake Models Will Include Significant Hazard Updates

- Additional seismicity data
- New regional hazard and seismic zonation studies
- Vast amount of new GPS data and a new global strain-rate model
- New GMPEs
- High-resolution soil maps and other regional site characteristics
- Explicit liquefaction modelling
- Tsunami modelling for Indonesia, the Philippines, and Taiwan



Shoreline of Banda Aceh, Indonesia, shortly after the 2004 Indian Ocean tsunami

The Updated Earthquake Models for Southeast Asia Provide the Capability to Assess a Wide Variety of Risk Types

- Conventional buildings, contents, and business interruption
- Infrastructure
- Marine cargo and hull
- Large industrial facilities
- CAR / EAR
- General auto
- 2-wheeled vehicles
- Warehouses

Upcoming AIR Events Will Feature More Comprehensive Model Details

envision '16

Philadelphia
6–8 April

ASIA SEMINAR SERIES 2016

June and August

- Singapore – 16 June
- Philippines – 21 June
- Indonesia – 23 June
- Vietnam – 28 June
- Beijing – 30 August
- Taiwan – 1 September

Agenda

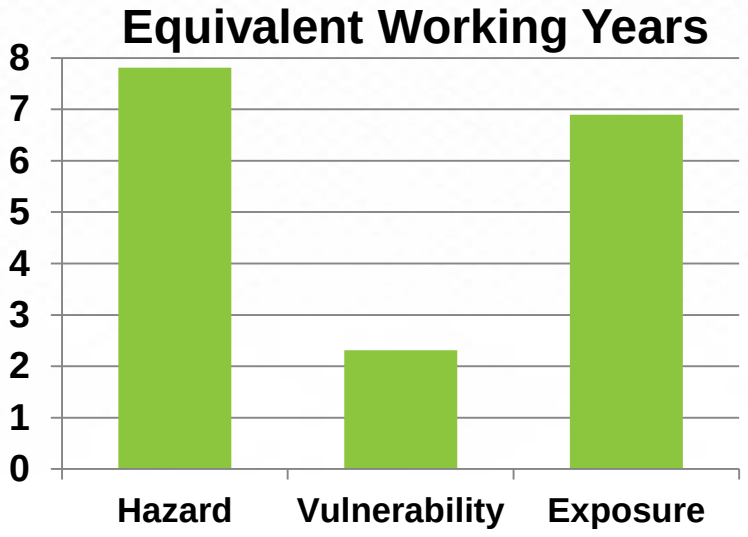
- New hazard modelling: data and methods
- New vulnerability modelling: data and methods
- Model validation: component-level and loss estimation

34 research staff

22 PhD holders

17 equivalent working years

10 modelled territories

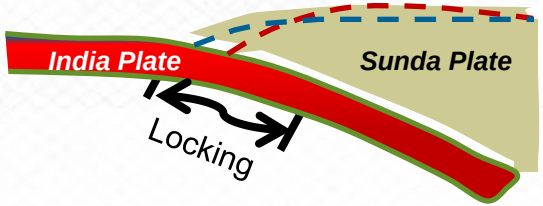


Hazard Module Updates

AIR

Elliot Klein, Ph.D.

Southeast Asia Is One of the Most Seismically Active Regions of the World



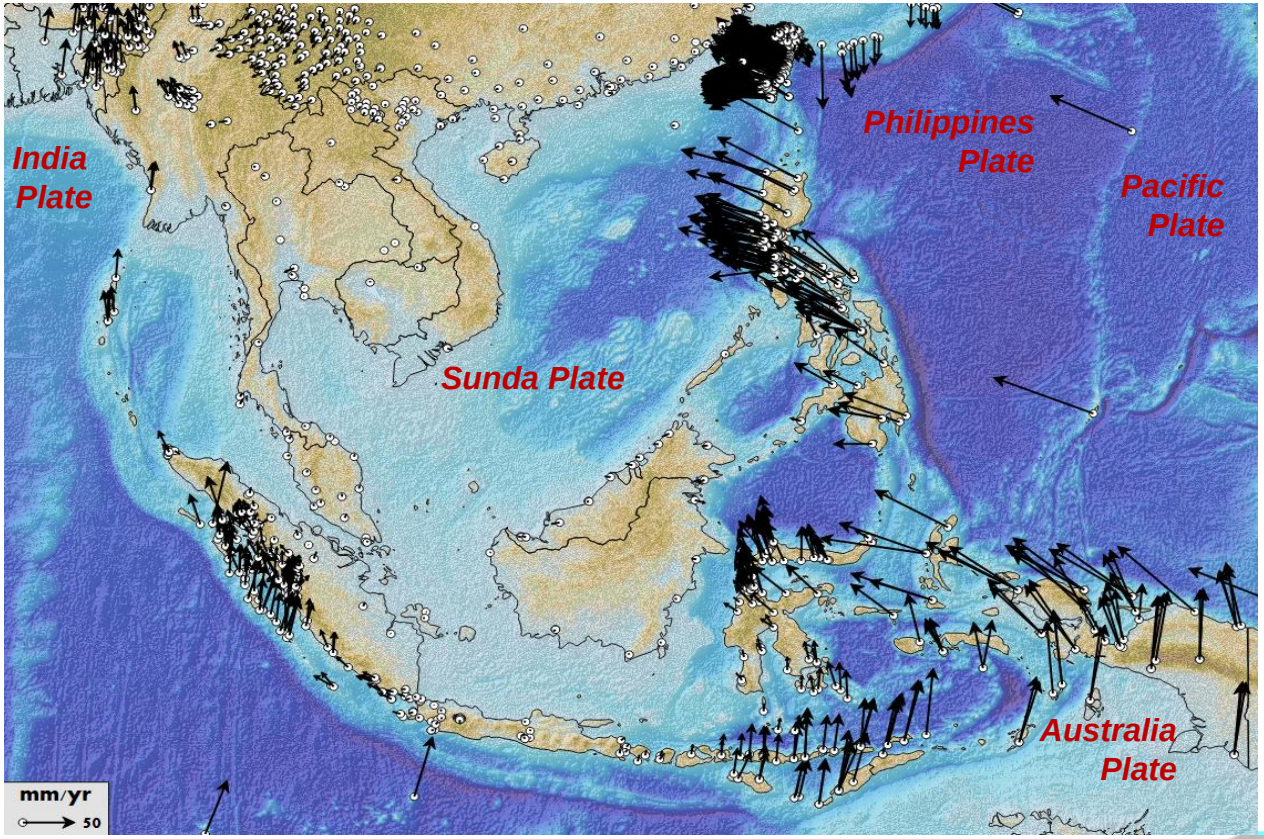
Sumatra-Andaman "Boxing Day" Earthquake

2004 M9.3 Earthquake

Length: 1,350 km

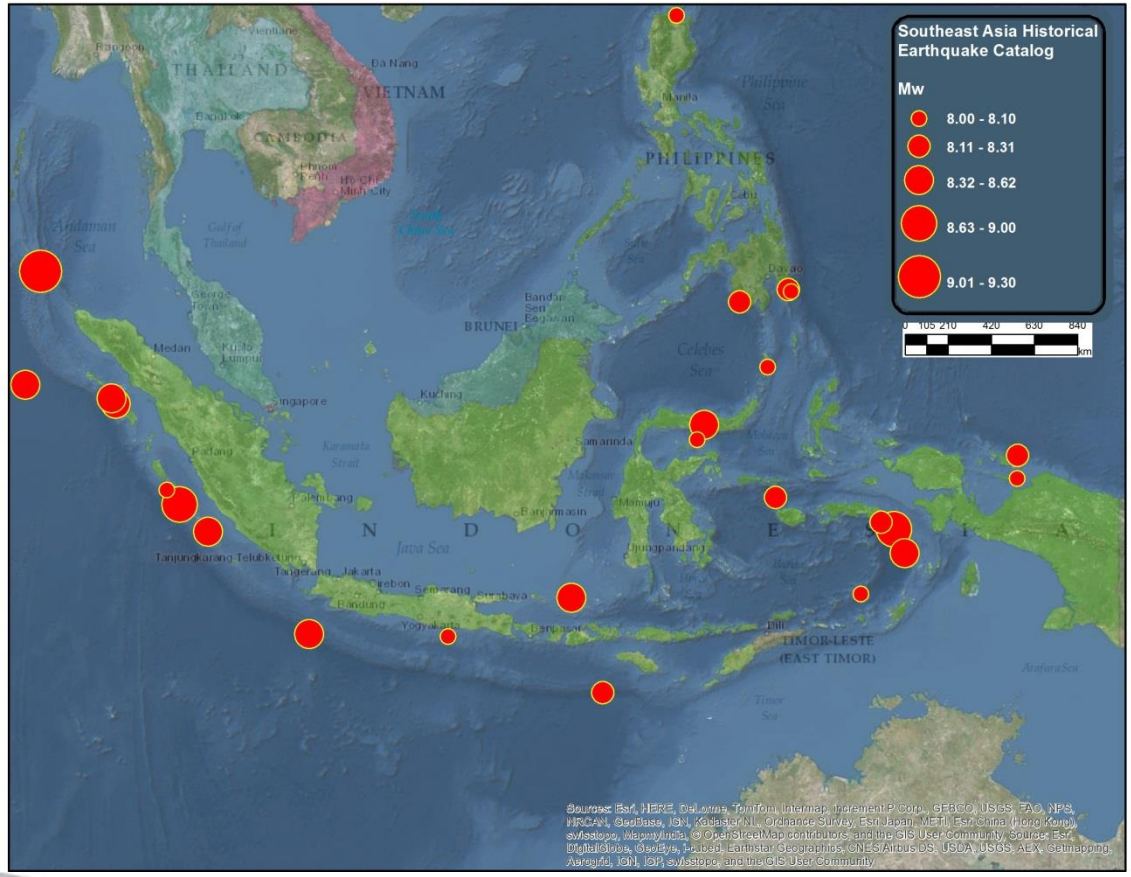
Width: 160 – 200 km

Average Displacement: ~ 12.8 m



The Model Incorporates Data from Subduction Zones…

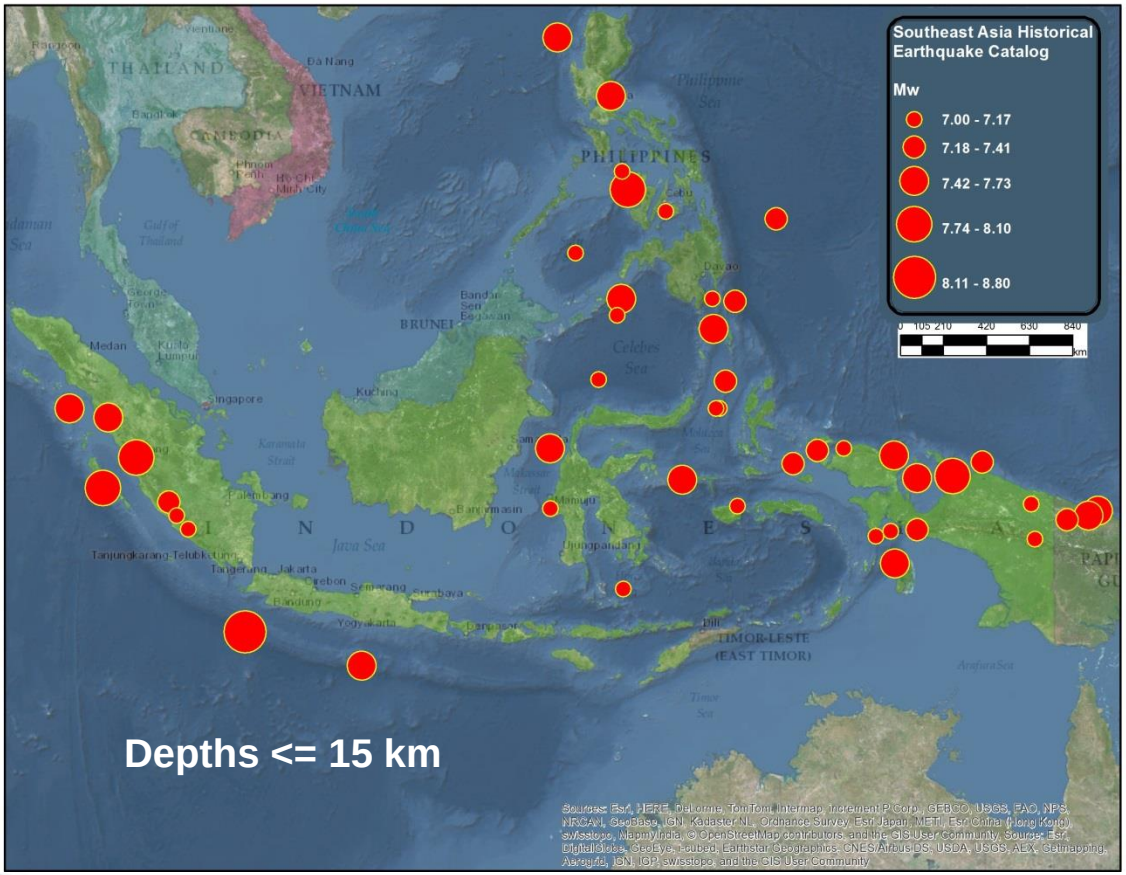
- **Philippines**
- **Indonesia**



Great Earthquakes

…As well as Data from Shallow Earthquakes

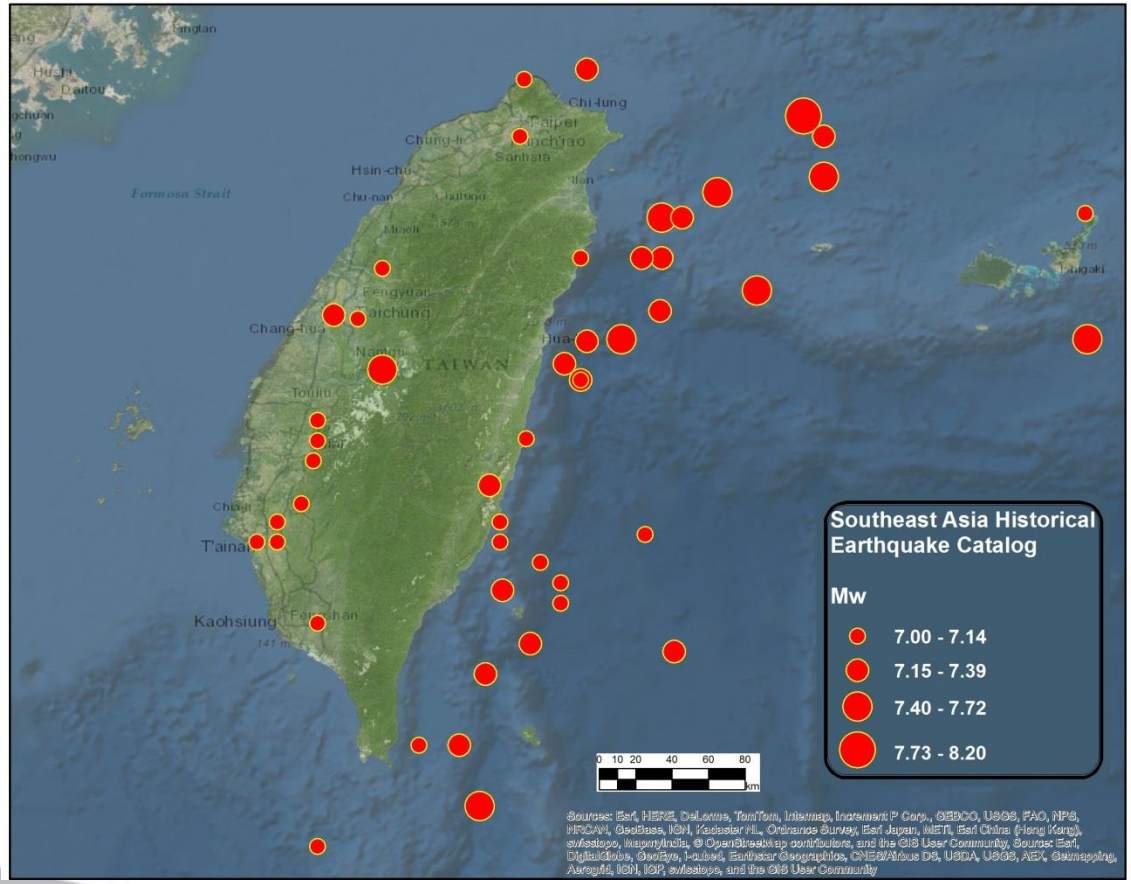
- **Philippines**
- **Indonesia**



Historical Earthquakes

The Model Incorporates Historical Data from Taiwan…

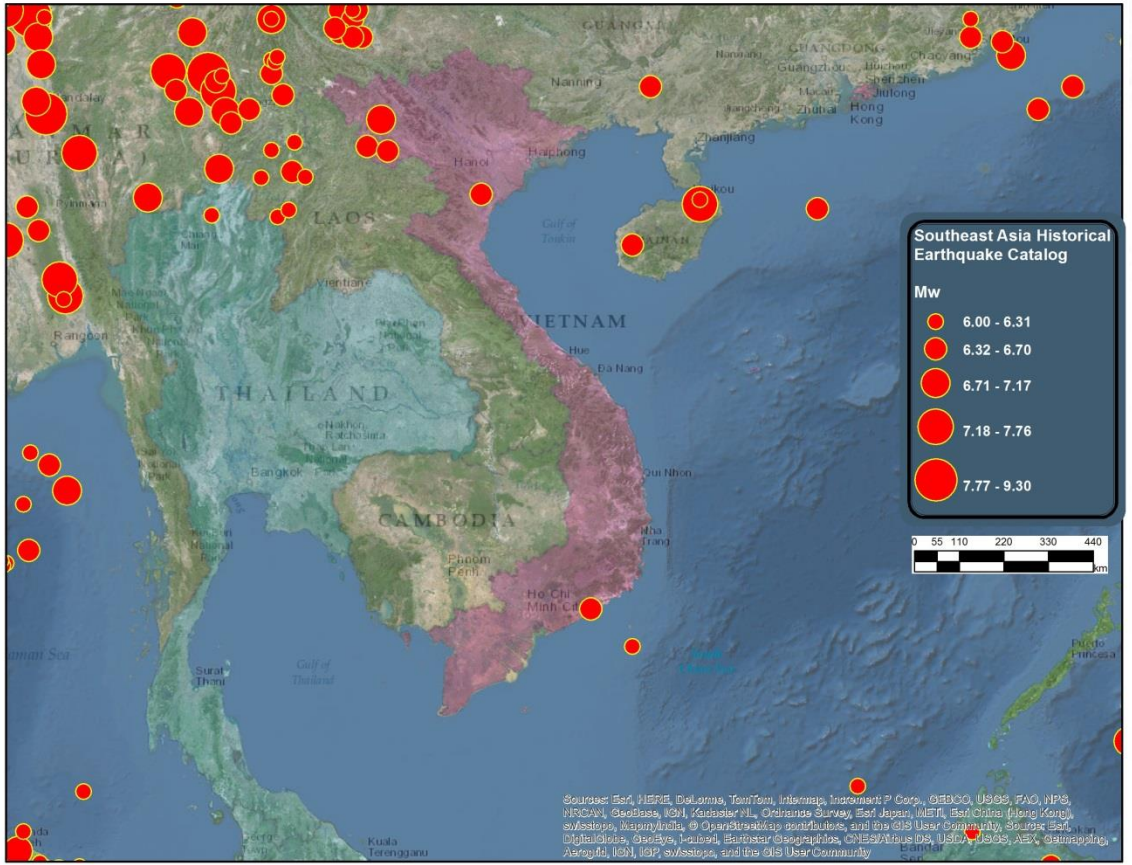
- **Taiwan**



Historical Earthquakes

…As well as Thailand and Vietnam…

- **Thailand**
- **Vietnam**



Historical Earthquakes

2014

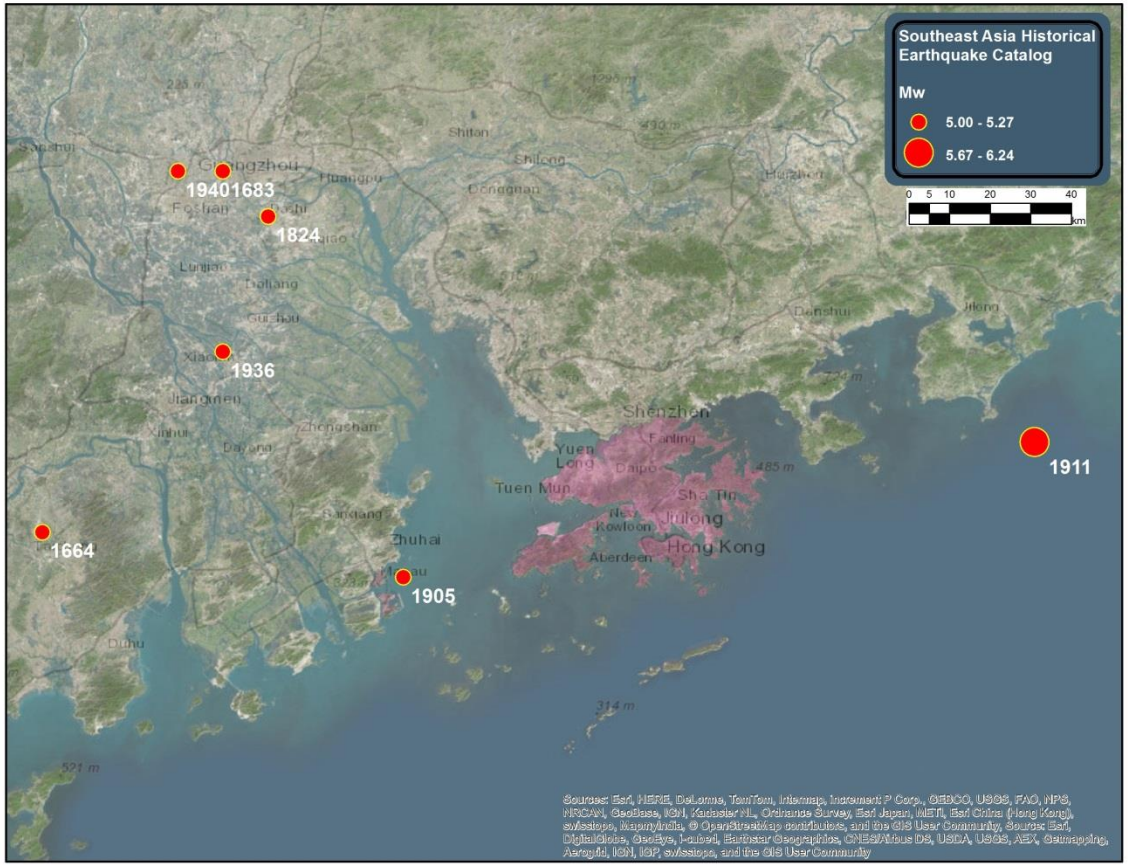
Mae Lao, M6, Thailand

1983

Tuan Giao, M6.8, Vietnam

…And Hong Kong and Macau…

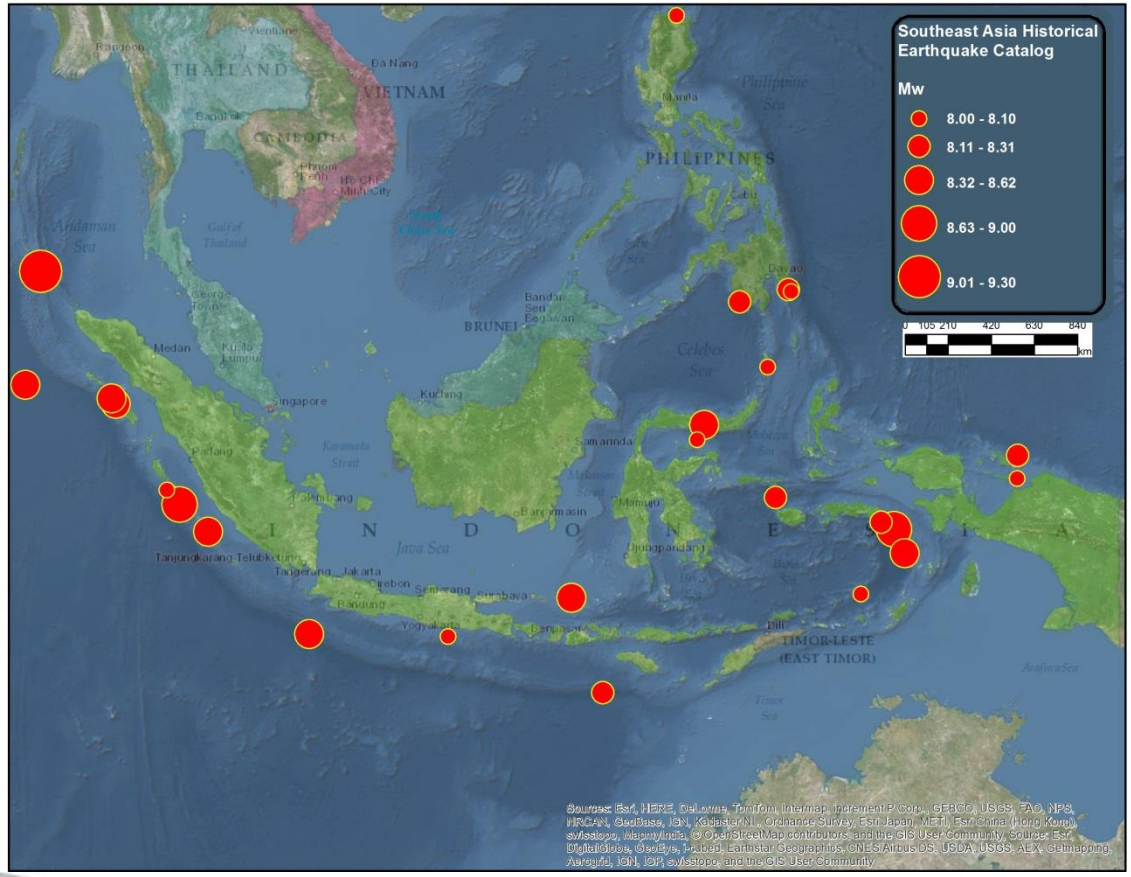
- **Hong Kong**
- **Macau**



Historical Earthquakes

Singapore and Malaysia Have No Record of Large Earthquake Occurrences …

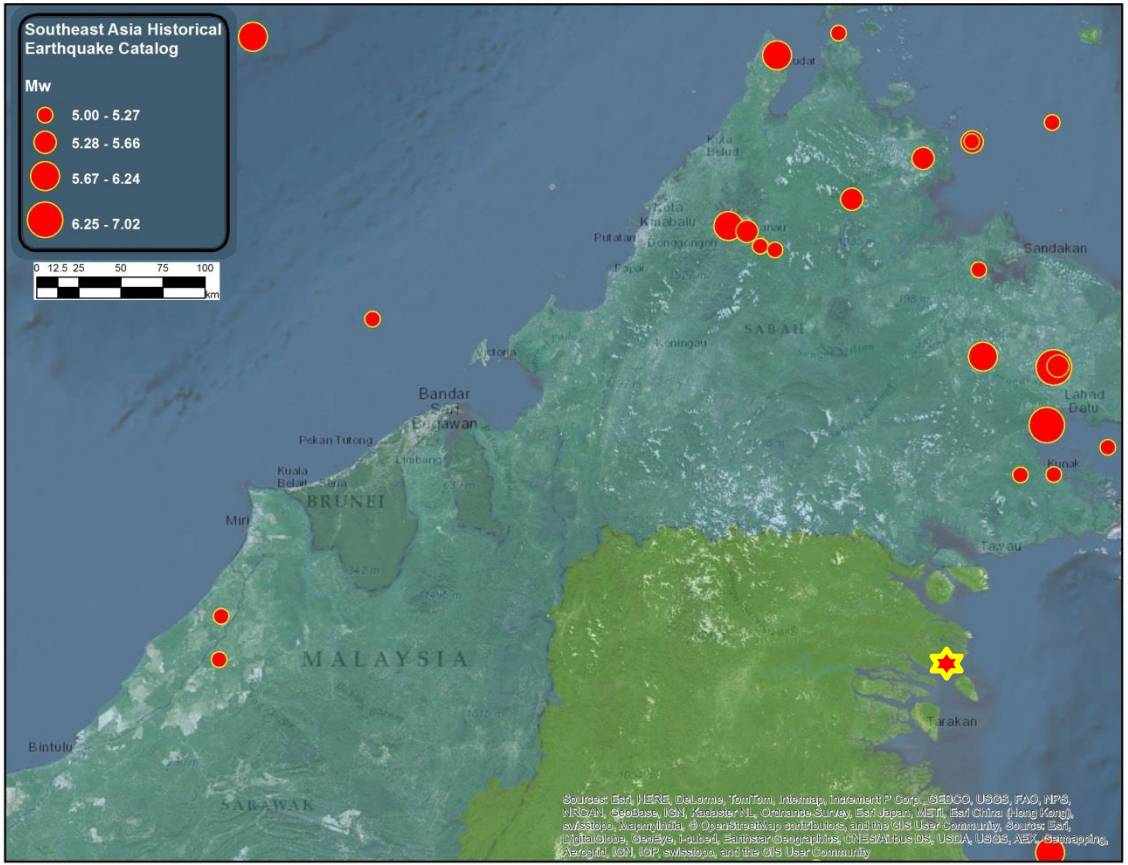
- **Singapore**
- **Malaysia**



Great Earthquakes

Brunei Has Not Experienced Any Strong Earthquakes

- **Brunei**



Historic Earthquakes

6.1 M 12/20/2015

North Kalimantan

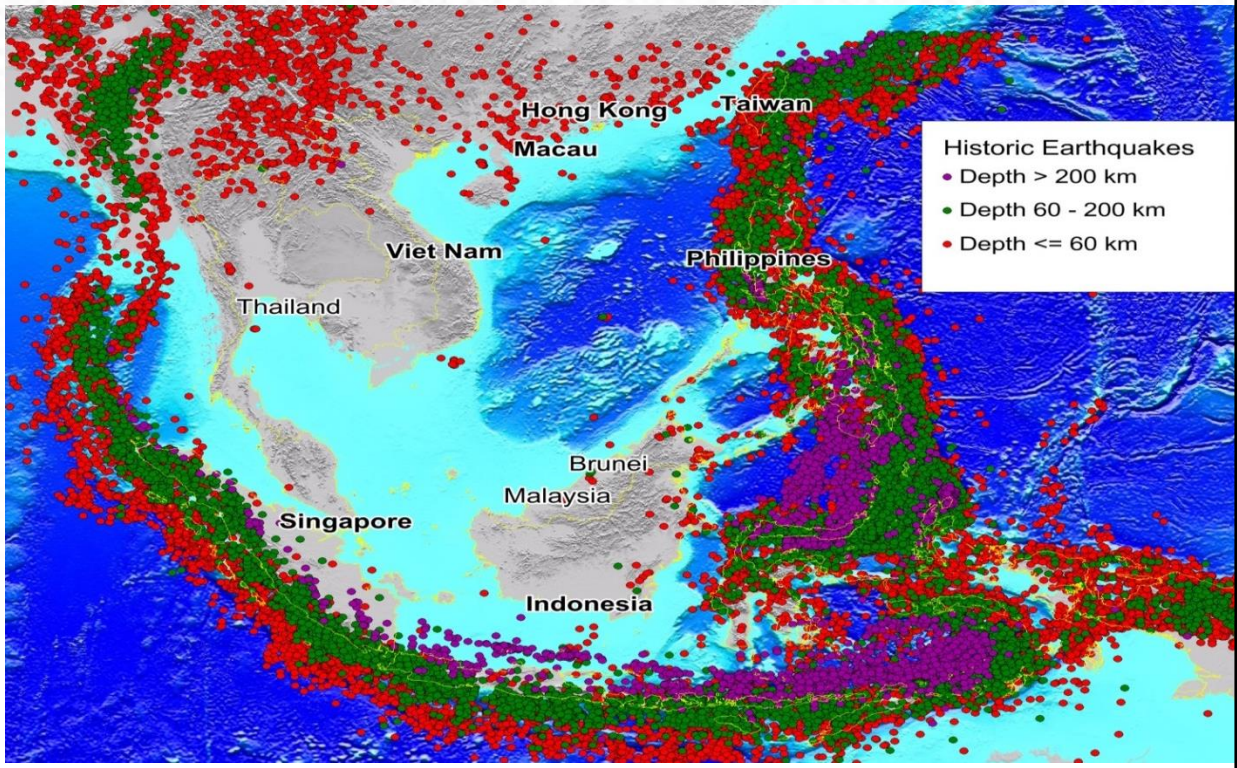
Key Catalogue Seismicity Improvements

		Model Update	Existing Model
Modelled Territories		10	3
Historic Catalogue	Duration	684 to 2014	1800 - 2002, mainly 1900-2002
	Source	All major global and local catalogue sources	GSHAP and PDE
	Magnitude	Developed new regression equations	Relied on original sources
Active Faults		150 +	32
GPS Data		2,000 +	420
Modelling Procedure	Deep seismicity	Source zone based Benioff Zone contouring	Not source zone based No Benioff Zone contouring
	Time dependent	Y	N
	Peer Review	Y	N

The History of Past Events Is Critical to Characterizing Seismic Hazard

Catalogue Sources

- Global Earthquake Model (GEM) Historic and Instrumental
- International Seismological Centre (ISC) bulletin
- Global CMT
- USGS Centennial
- ANSS
- Central Weather Bureau of Taiwan
- Taiwan BATS
- Vietnam local catalog
- Chinese Historic catalog from IG, CEA
- Bautista and Oike (2000) – Philippines historic
- Ng et al. (2008) Taiwan historic

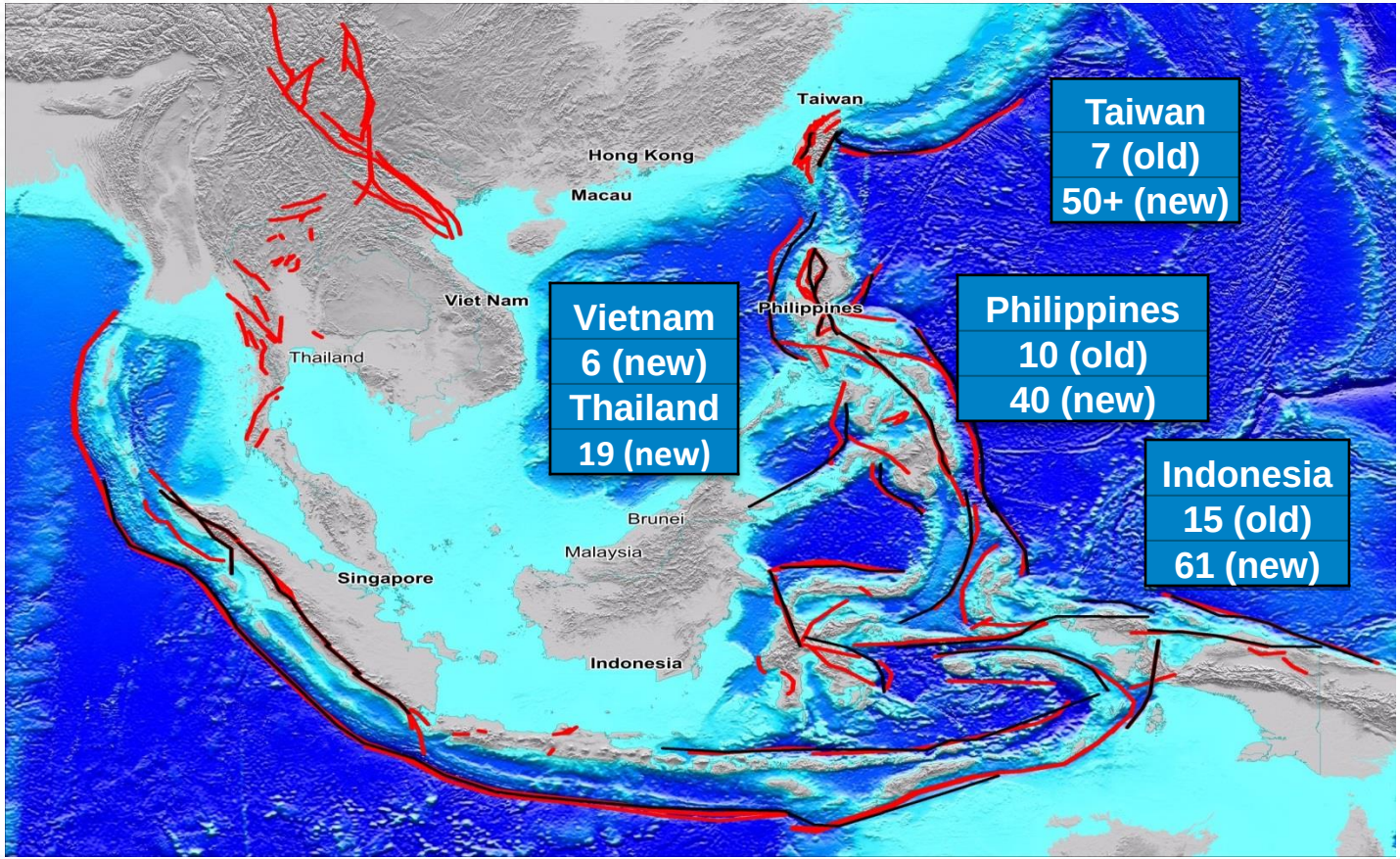


Comprehensive unified catalogue: 120,000+ events with homogenized moment magnitude, Mw ≥4.5

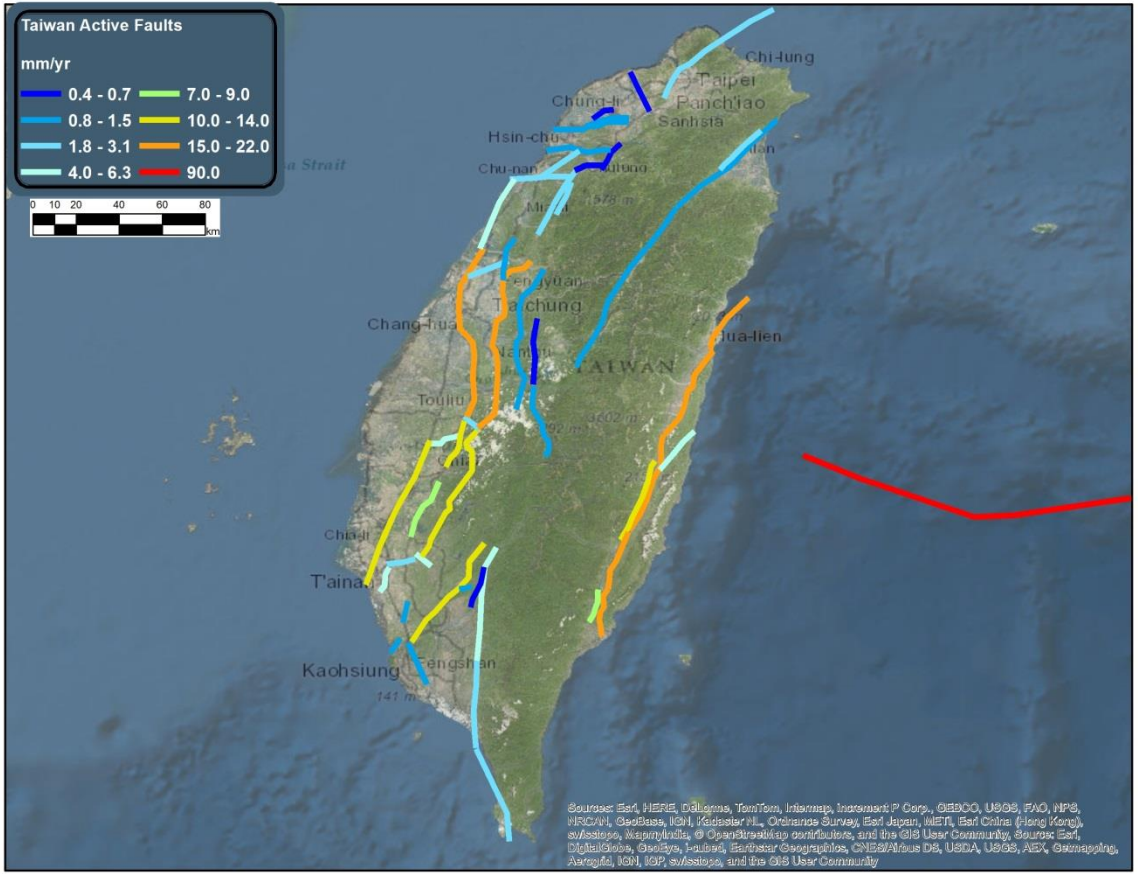
The Number of Modelled Active Faults Increased Significantly

Faults in Existing Model

Faults in Model Update



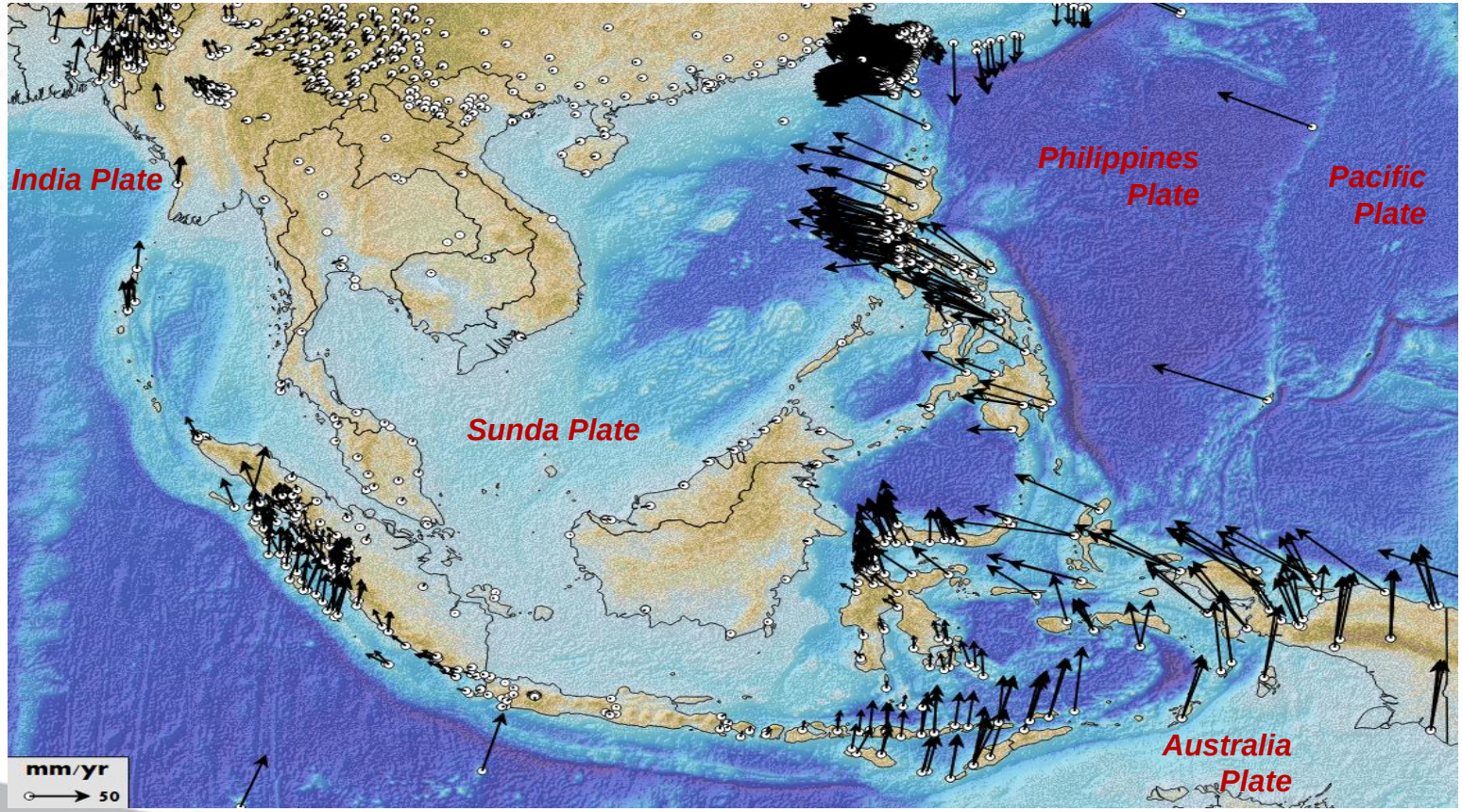
The Number of Modeled Active Faults Increased Significantly



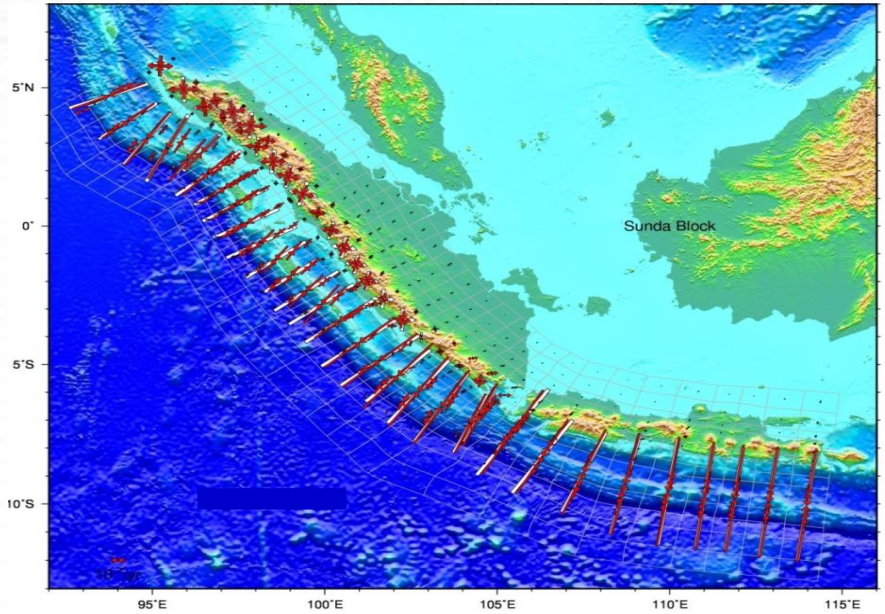
References:

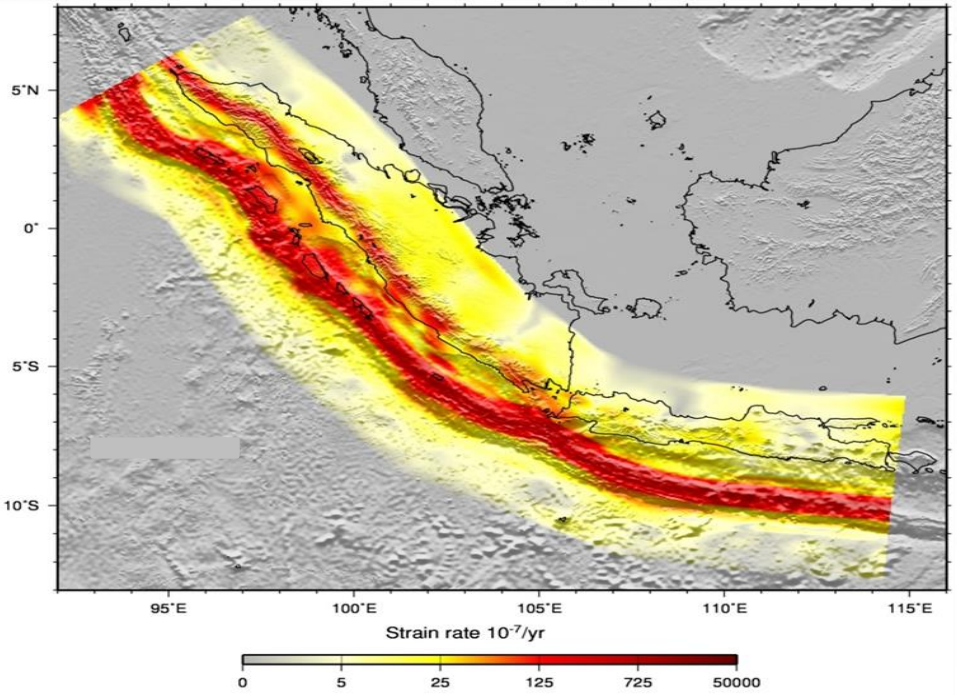
- *Central Geological Survey, 2015*
- *Cheng, 2002*
- *Cheng et al., 2007*
- *Cheng et al., 2010*
- *Lee ,1999*
- *Rau et al., 2008*
- *Shyu ,1999*
- *Simoes et al., 2007*
- *Simoes et al., 2008*
- *Yen et al., 2008*
- *USGS Slab 1.0*

The Number of GPS Observations Has More than Tripled, Providing Better Constraints on Long-Term Moment Rates



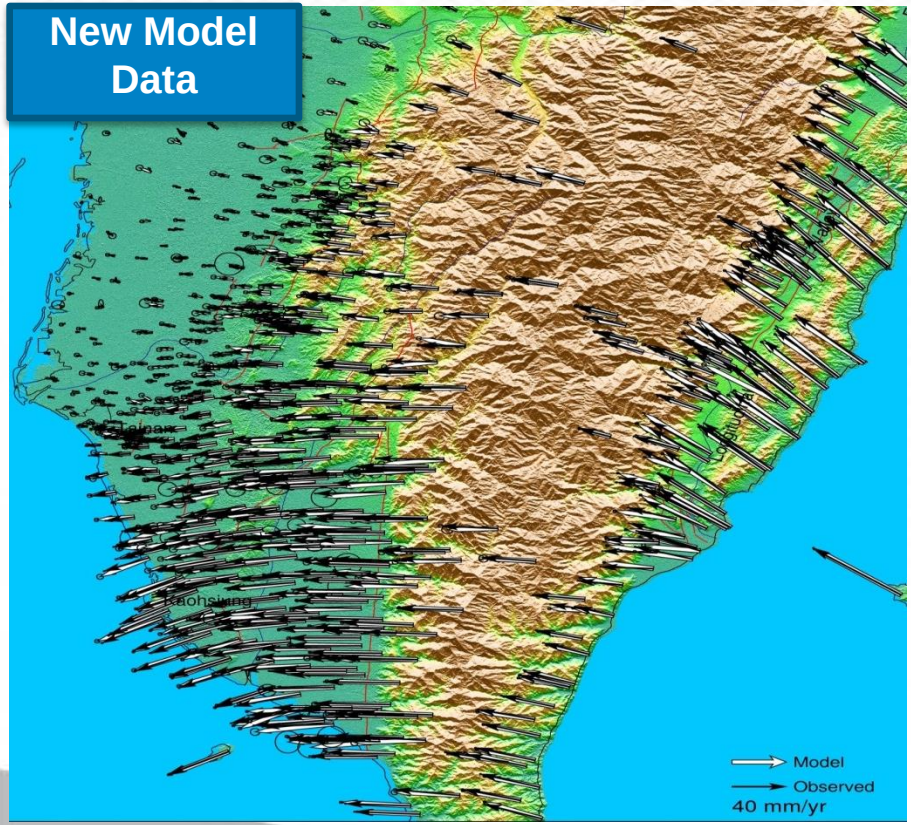
Kinematic Models Constrain Seismic Moment Rates



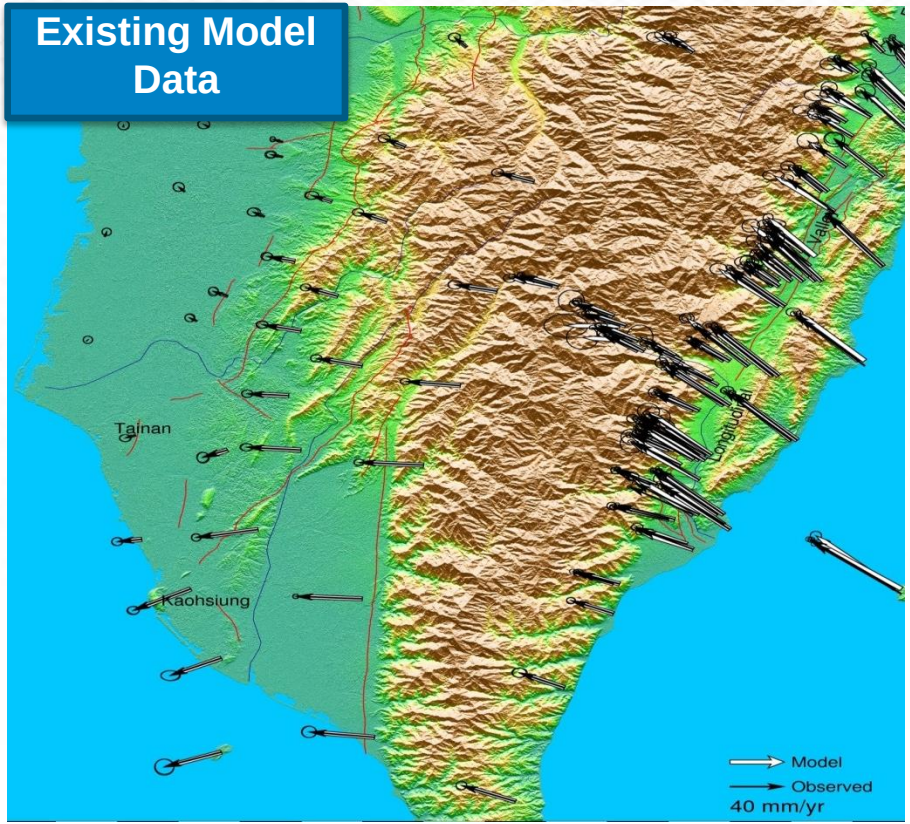


Significantly More GPS Data Was Available for Southern Taiwan

New Model Data



Existing Model Data



Stochastic Event Generation Is Based on the Latest Data Sources and Knowledge

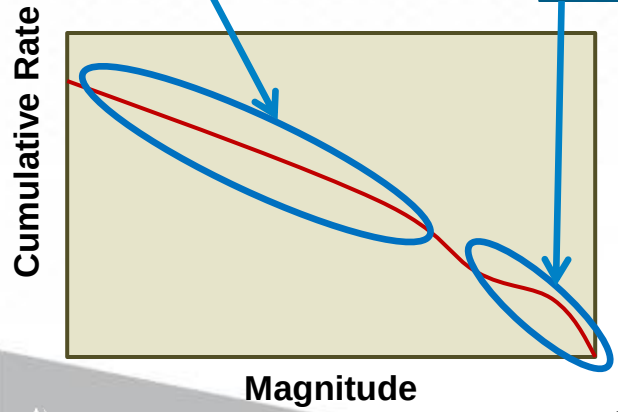
- We integrate historical earthquakes, fault parameters, and GPS data to constrain the magnitude-rate in a seismic source zone.

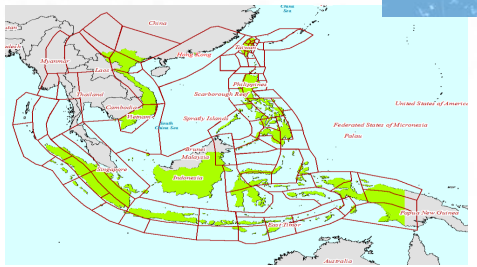
- **Historical earthquake catalog data**
- **Fault slip rates**
- **GPS strain rates**

Seismic moment rate (Seismic budget)

- **Historical earthquake catalog**

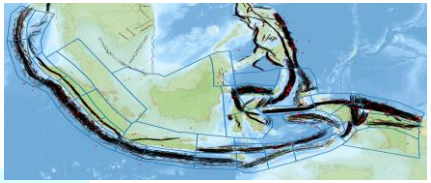
- **Fault slip rates**
- **GPS data**





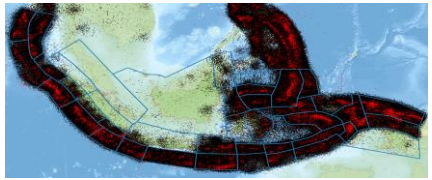
Seismic Source Zone Model

Characteristic earthquakes on known faults

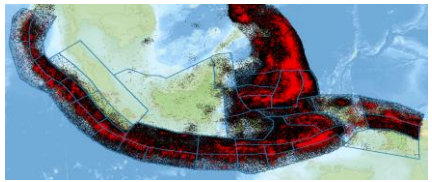


Characteristic Events

Background seismicity on unknown faults and major fault systems

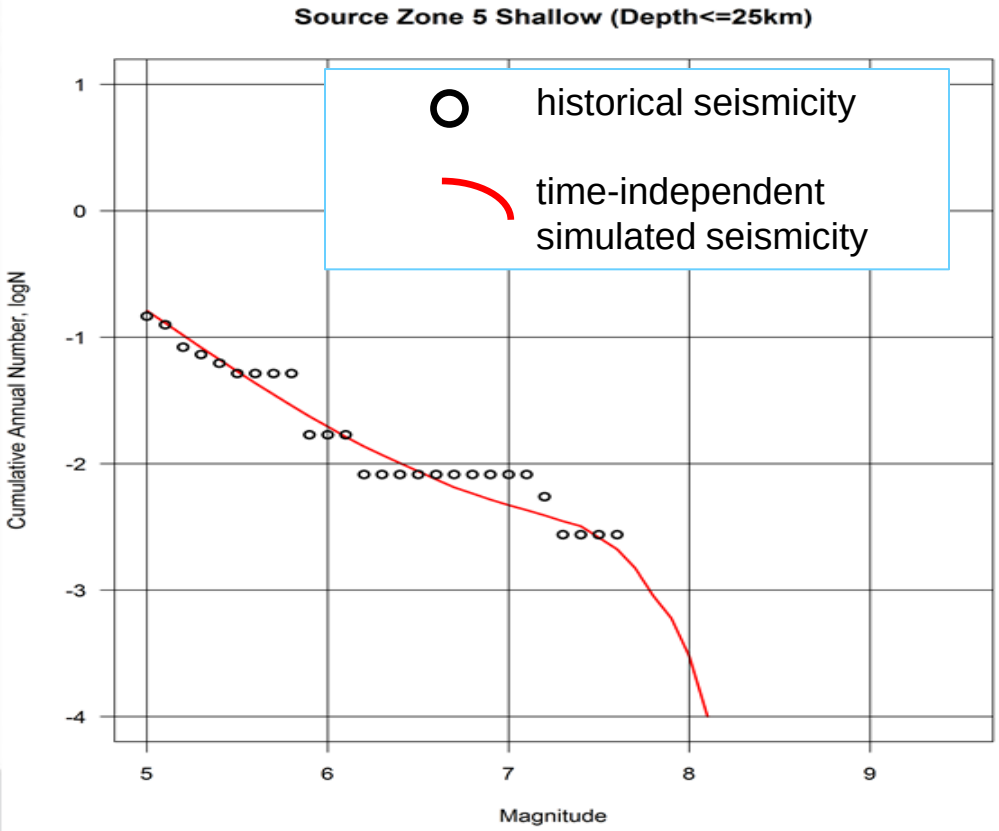


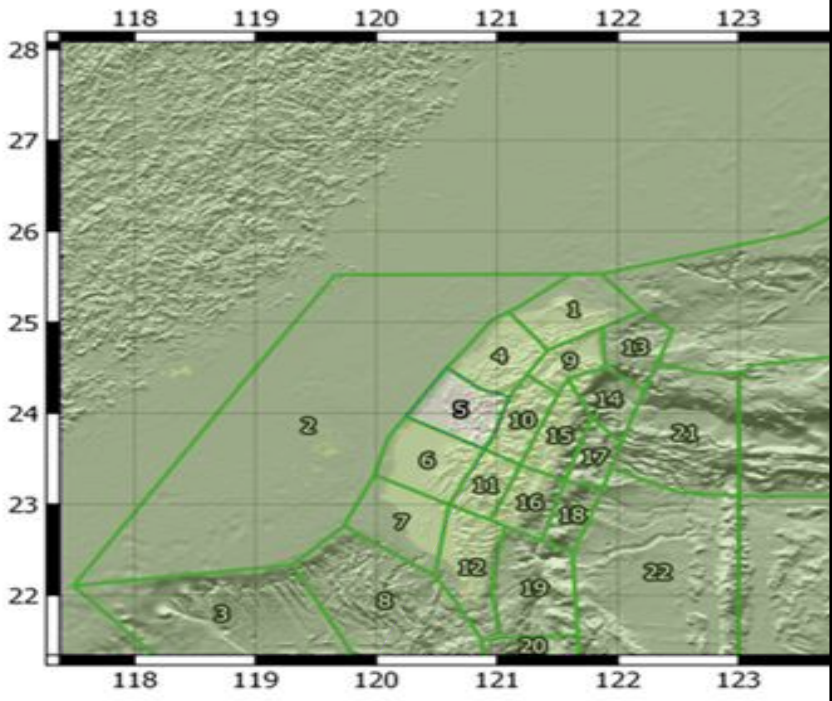
Shallow Events



Deep Events

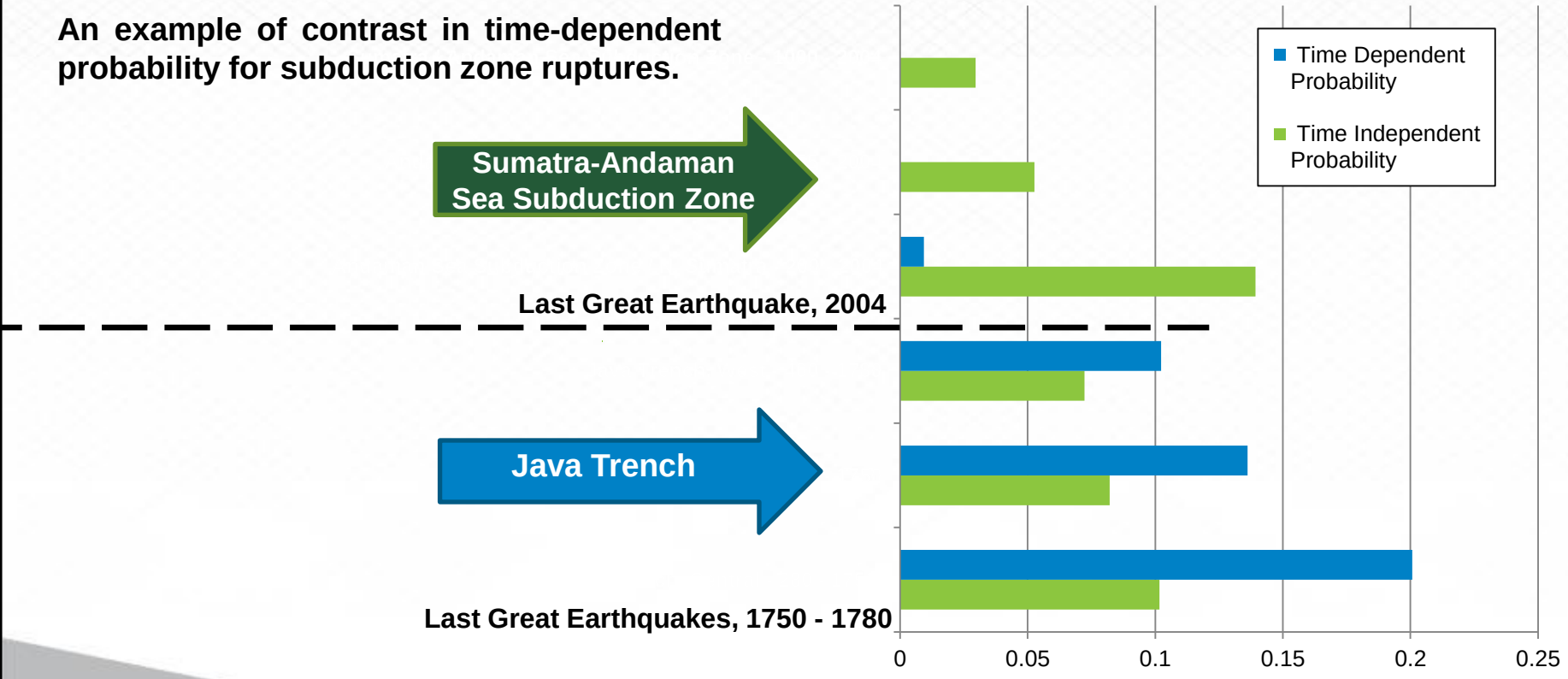
Magnitude-Rate Distributions Have Been Validated





Time-Dependency Was Applied to Some Major Subduction Zone and Crustal Faults

An example of contrast in time-dependent probability for subduction zone ruptures.



Key Intensity Modelling Improvements

		Updated Model	Existing Model
GMPE	Crustal	NGA-west2, Taiwan local	1997 GMPE series
	Subduction zone	GMPE developed after 2000	GMPE developed before 2002
	Amplification	NGA1 and NGA2	NEHRP
Soil Data		New large-scale Geological maps, Detailed microzonation studies for major cities (Jakarta, Manila, and Taipei), V_s 30 map	Far less V_s 30 map for validation No geotechnical data for validation, base map at 3 km

Latest Ground Motion Prediction Equations (GMPE) Are Being Used

Active Shallow Crustal Earthquakes (NGA-West2 GMPEs)

- Abrahamson et al., 2014 (0.22)
- Boore et al., 2014 (0.22)
- Campbell and Bozorgnia 2014 (0.22)
- Chiou and Youngs 2014 (0.22)
- Idriss 2014 (0.12)

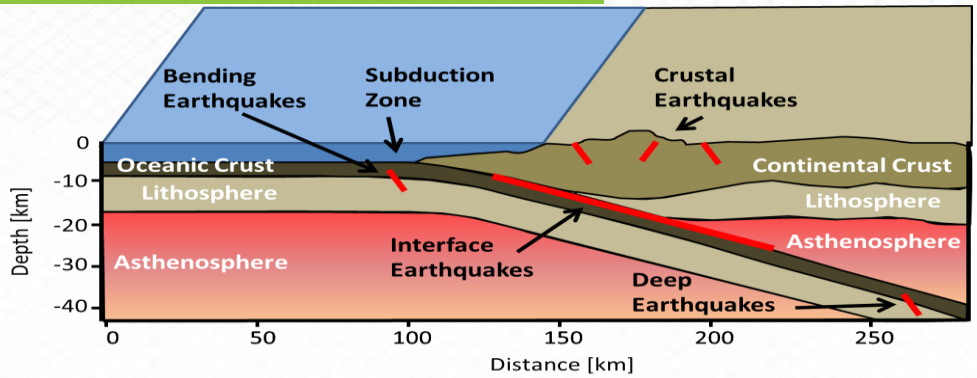
Interface Subduction Zone

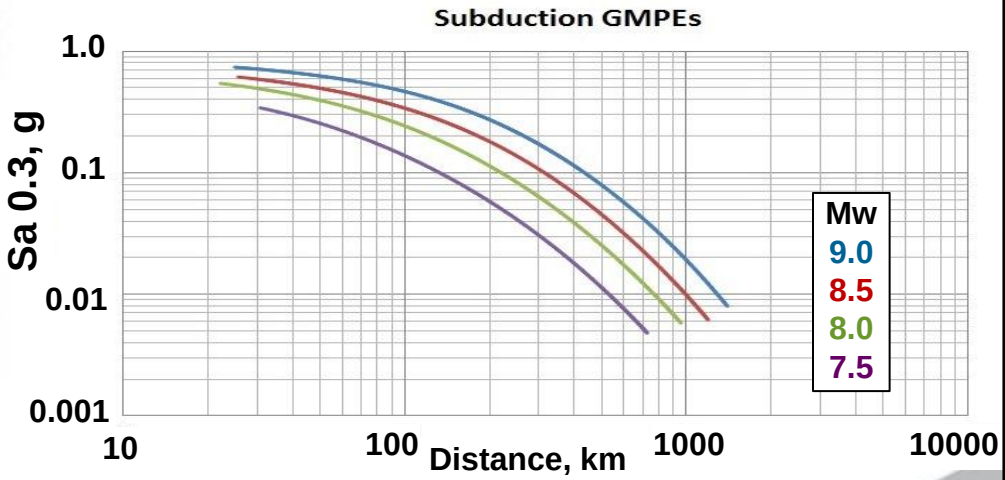
- Addo et al., 2012 (0.3)
- Atkinson and Boore, 2003 (0.1)
- Zhao et al., 2006 (0.3)
- Atkinson and Macias, 2009 (0.3)

Inslab Subduction Earthquakes

- Addo et al., 2012 (1/3)
- Zhao et al., 2006 (1/3)
- Atkinson and Boore, 2003 (Global and Cascadia) (1/3)

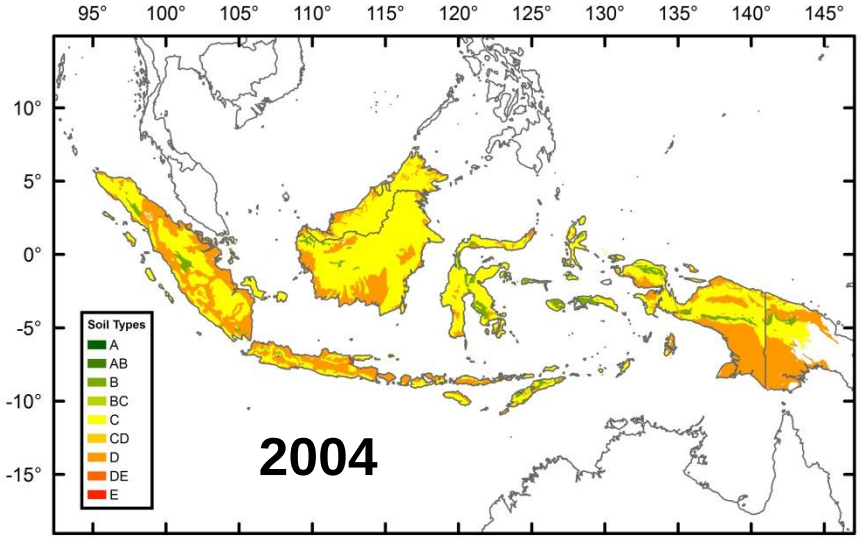
For Taiwan: Local GMPEs of *Lin et al.*, 2008 (subduction), and *Lin et al.*, 2011 (crustal) GMPEs (0.2)

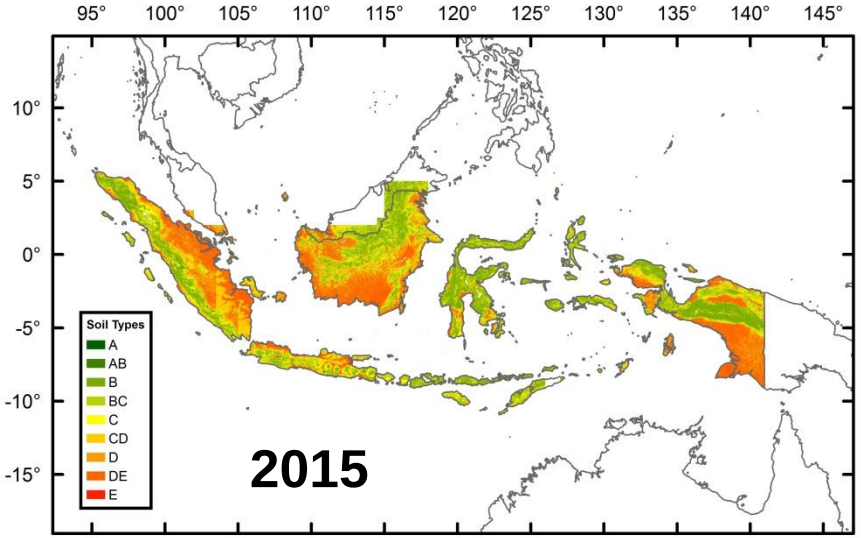




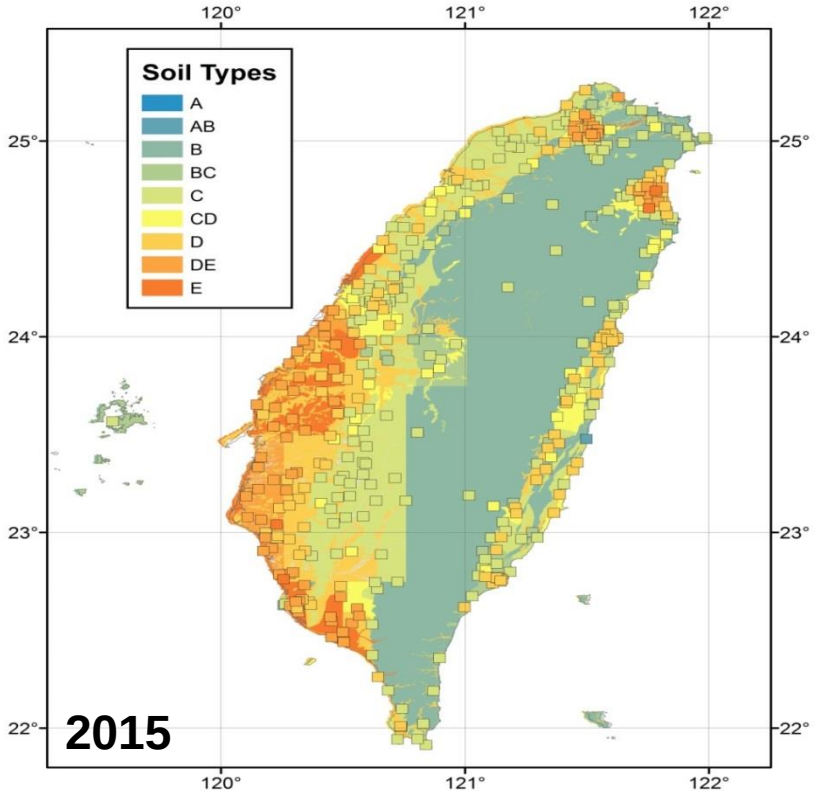
Soil Maps Have Received a Comprehensive Update…

- ***Regional geological maps with higher resolution***
- ***New soil maps developed for Hong Kong, Macau, Malaysia, Singapore, Thailand, and Vietnam***
- ***Detailed microzonation studies for major cities (Jakarta, Manila, and Taipei)***
- ***Topographic-slope maps as a proxy soil maps for Indonesia, Philippines, part of Malaysia, and Brunei***

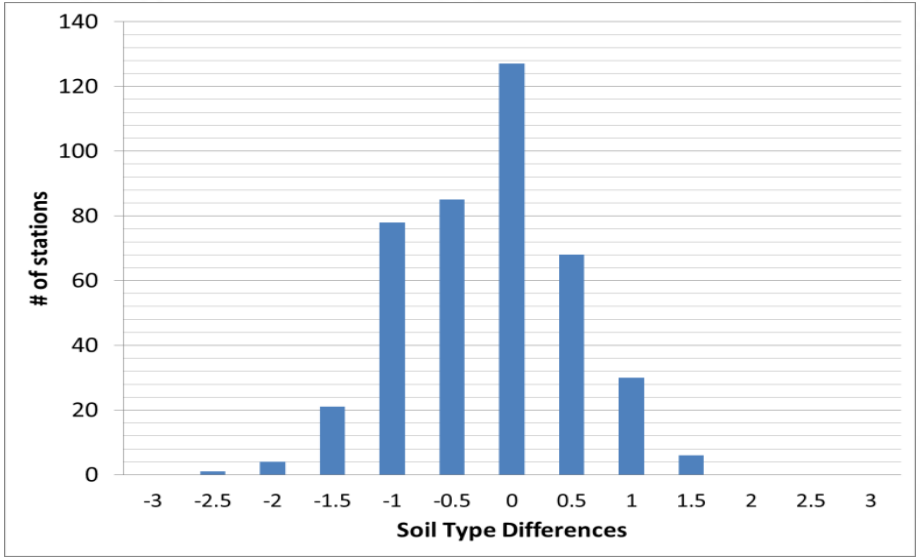




…And Have Been Validated Using NGA-2 Data

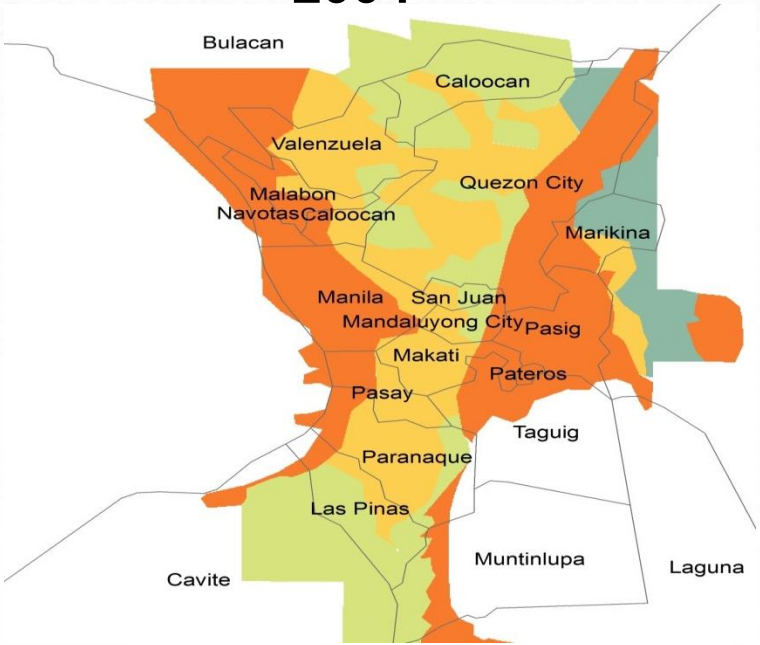


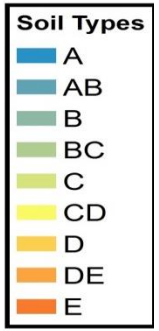
Comparison between soil classification of AIR model and soil types estimated from preferred V_s30 listed in NGA-2 database



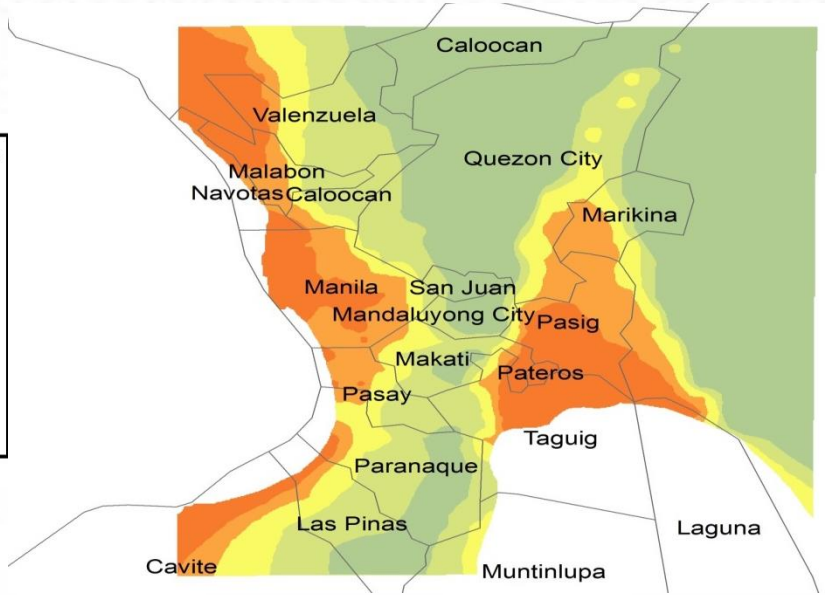
Soil Maps Have Been Updated for Major Metropolitan Areas (e.g., Manila)

2004



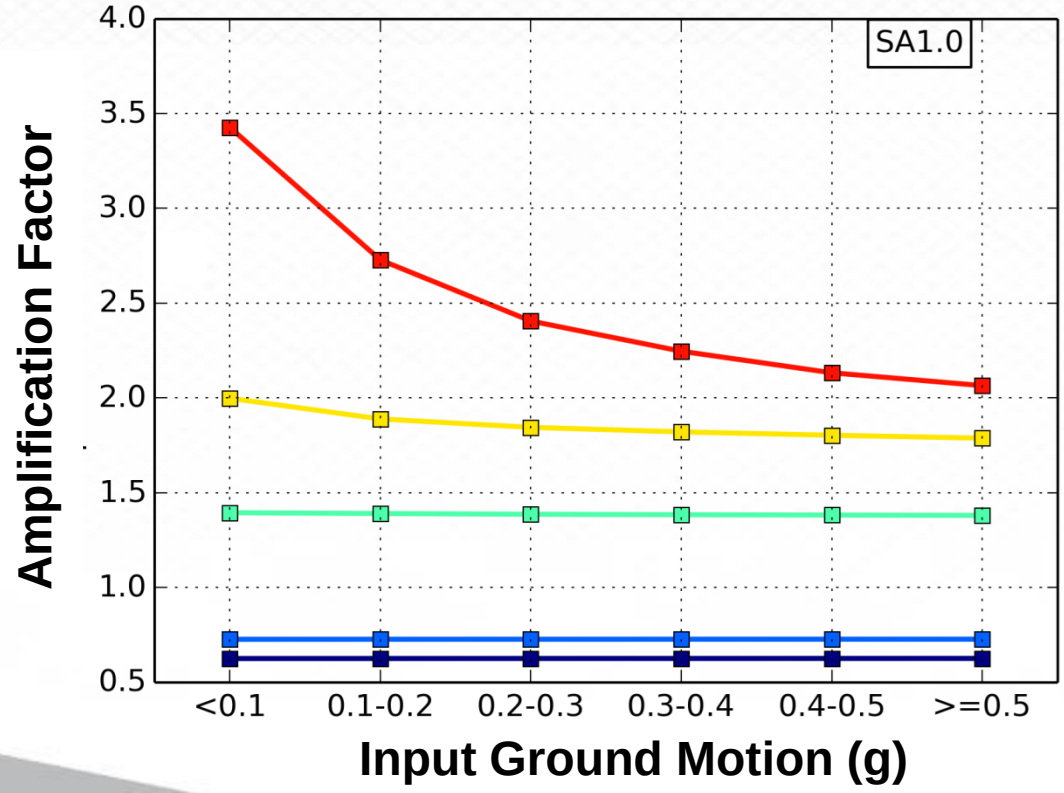


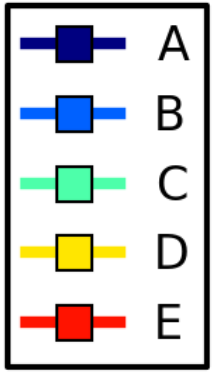
2015



Utilizing the microzonation studies of *Grutas* (2012) and the Metropolitan Manila Earthquake Impact Reduction Study (2003)

Amplification Is Significant in Soft Soils for Long Period Waves





Long Period Waves (SA 1.0)

Peer Reviewers' Comments on the Hazard Model Are Very Positive

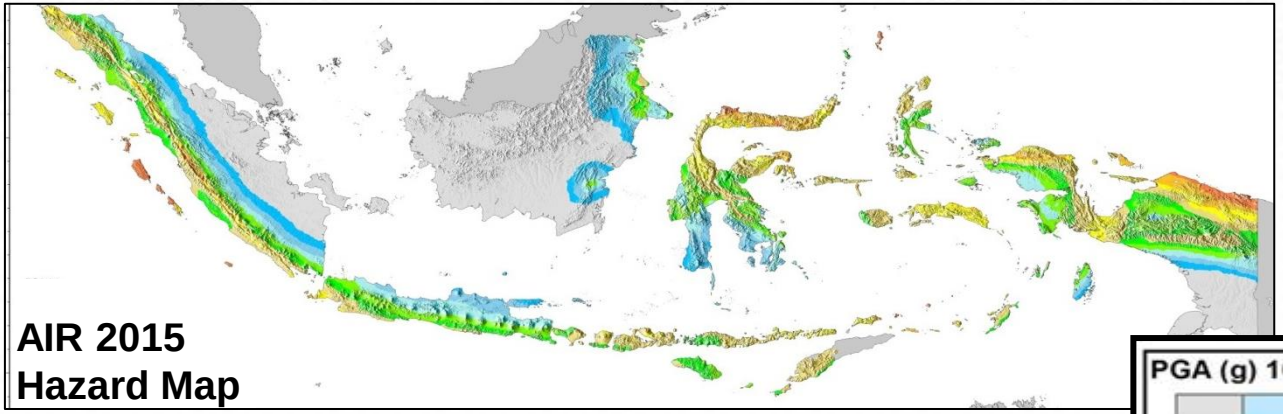
Professor Masyhur Irsyam,
Chairman, National Team for Revision of Seismic Hazard Maps of Indonesia:

> We have previously reviewed seismic hazard studies for Indonesia region that were conducted by other well-known international consultants, and we consider that AIR's study is the most impressive one. We would like to congratulate AIR Worldwide for this excellent work.

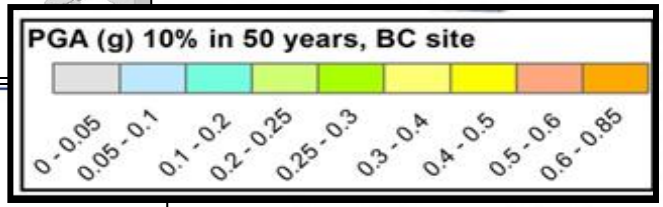
Professor Kuo-Fong Ma,
National Central University, Director of Taiwan Earthquake Research Center:

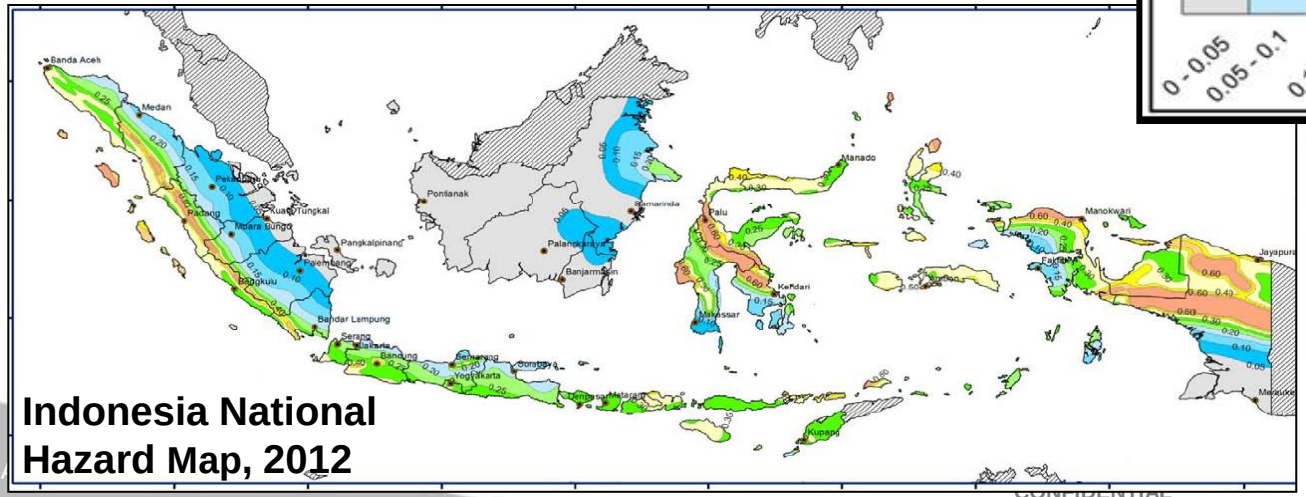
> The 2016 AIR Taiwan earthquake model gives good compilation of up to date literature research related to Taiwan Earthquake Model and gives comprehensive studies of the literature to present the seismic hazard model of Taiwan. The use of data is accurate in good completeness. The analysis is robust under reasonable assumptions. It is quite impressive that this seismic hazard model as based mainly from kinematic modeling of GPS data of the 25 seismic source zones could give good estimation on the long-term slip rate individually compared to available geological data. This is a new technique built into seismic hazard model analysis. The further application of the slip rate model to the stochastic synthesis catalog provides important constraints in maximum earthquake magnitude determinations for time-dependent analysis. The Figures and

PGA Hazard Maps Compare Well with Those Produced by Indonesia at the 475-Year Return Period…



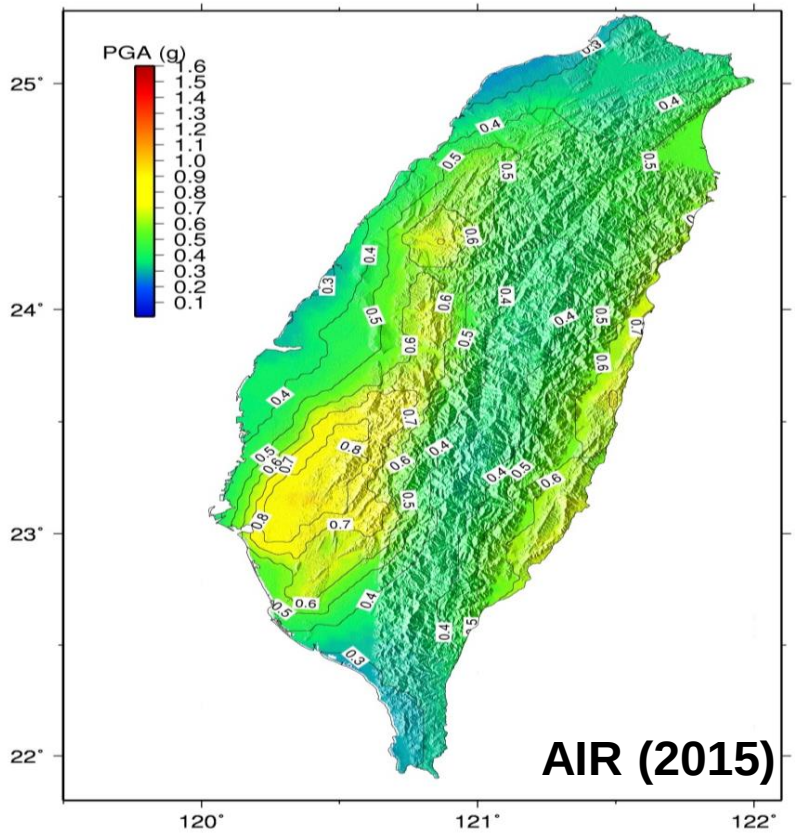
AIR 2015 Hazard Map

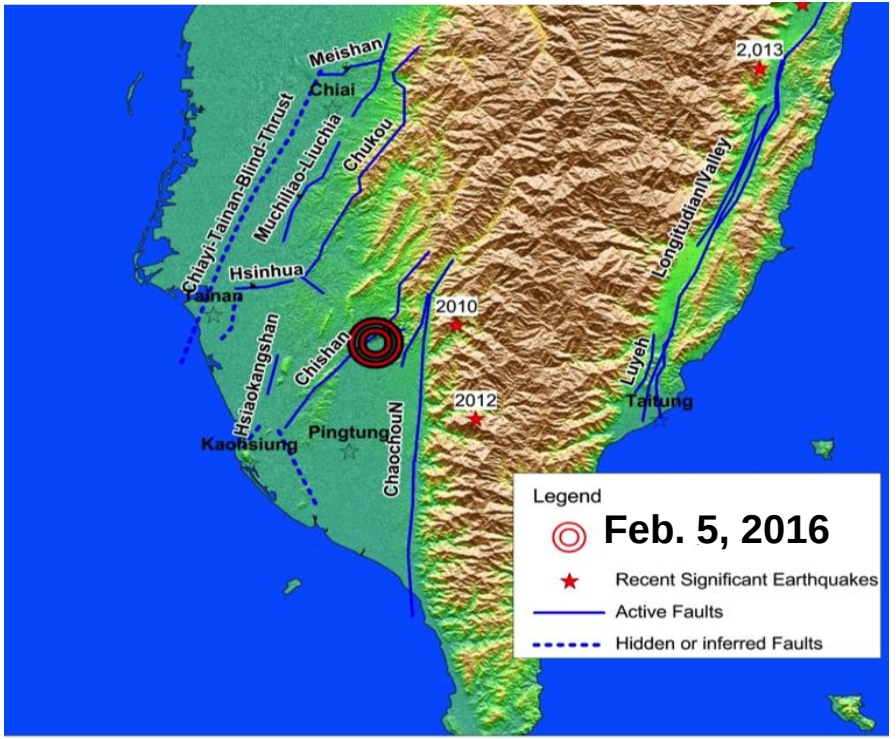




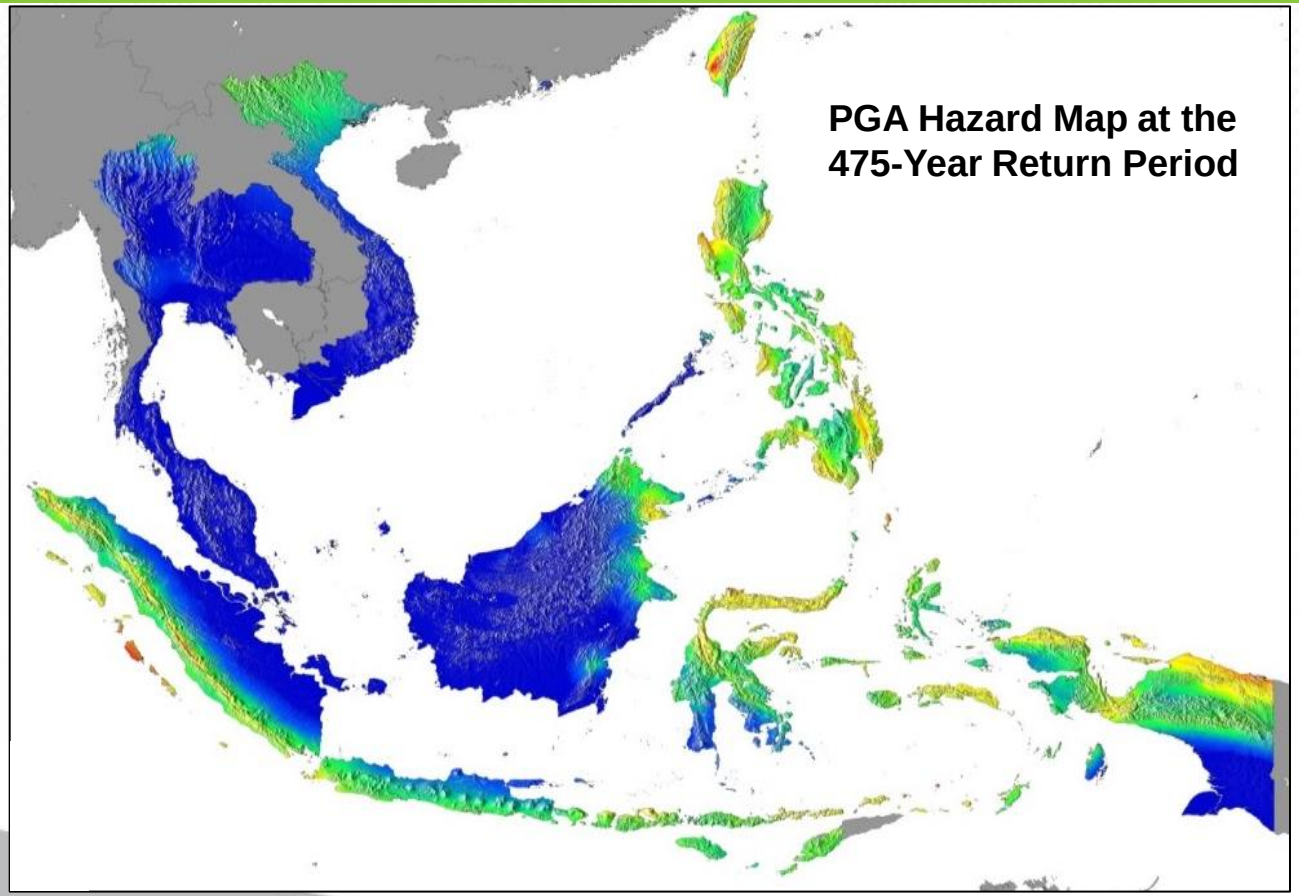
Indonesia National Hazard Map, 2012

…As Well as Those Produced for Taiwan





AIR's Comprehensive Hazard Model Has Been Peer Reviewed



Vulnerability Module Updates

Mesut Turel, Ph.D.

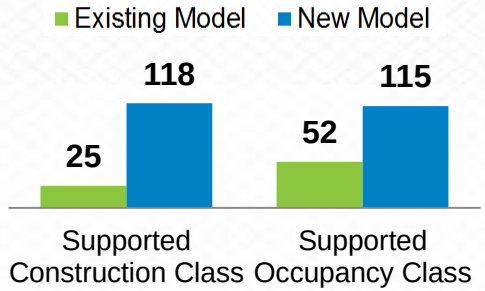
Vulnerability Update Uses State-of-the-Art Engineering and Data for Damage Estimation

Modelled Risks	Shake	Liquefaction	Tsunami
Regular Building/Content/BI	Existing	New	New
Infrastructure	New	New	New
Cargo, Hull, Warehouse	New	New	New
Large Industrial Facilities	New	-	New
Builder's Risk	Existing	New	New
Auto (4-wheeler)	Existing	New	New
2-wheeler vehicle	New	New	New

Large Industrial Facilities

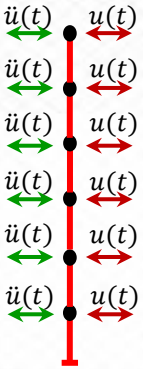
Infrastructure

Tall buildings



Height Band	Existing	New
Low rise	1 – 3	1 – 3
Mid rise	4 – 7	4 – 7
High rise	8 and above	8 – 20
Tall	Not available	21 and above

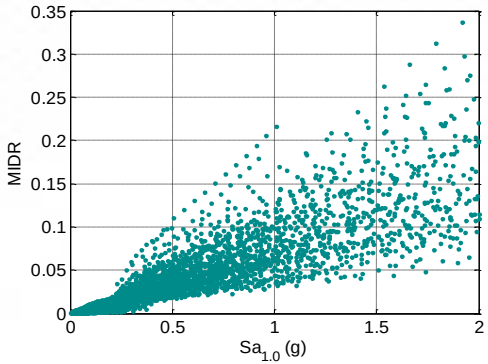
The Updated Damage Functions Are Generated Through Extensive Engineering Analyses



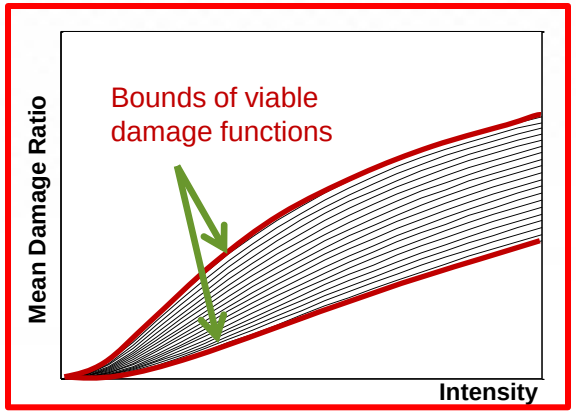
Numerical Models

Subjected to **6,900** Ground Motion Records from Earthquakes **Worldwide**

Nonlinear Dynamic Analysis

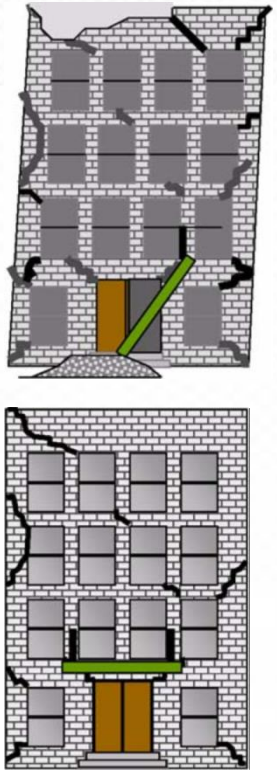


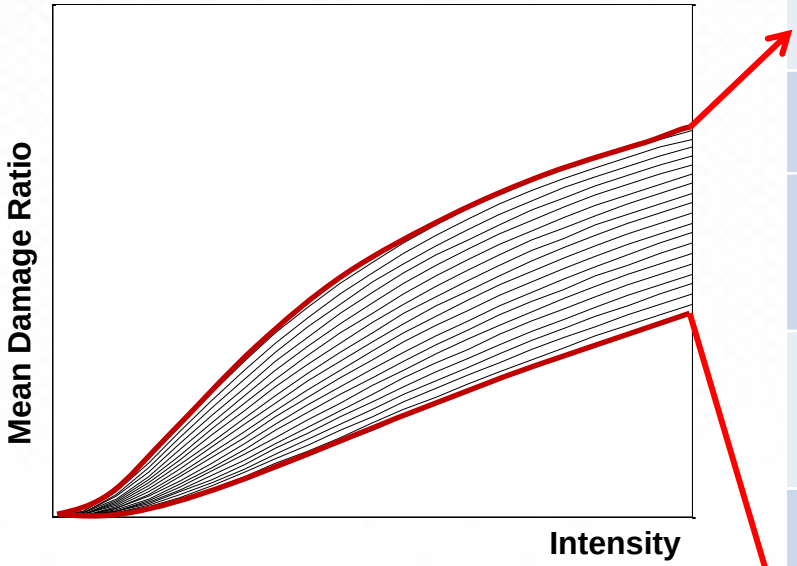
Building Response vs. Ground Motion



Damage Ratio vs. Ground Motion

Not All Buildings Are Created Equal





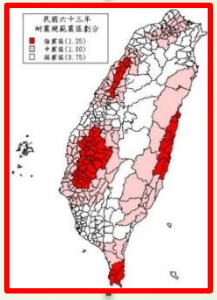
Seismic Code Levels to Classify Vulnerability in AIR Model

Code Level		Description
Pre		Without seismic consideration
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	
	III	
	IV	

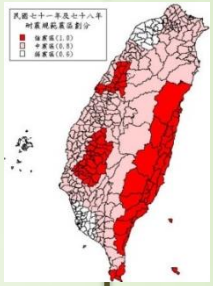
Seismic Design Codes in Taiwan Evolve Over Time, Based on the Understanding of Seismicity and Engineering Design

1970 1980 1990 2000 2010

1974 Code
民國63



1982 Code
民國71



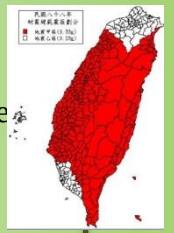
1986
M6.8
Hua Lien
Earthquake

1989 Code
Revision to Taipei basin
民國78

1997 Code
民國86

1999
M7.6
Chi-Chi
Earthquake

1999 Code
Emergency revision
民國88

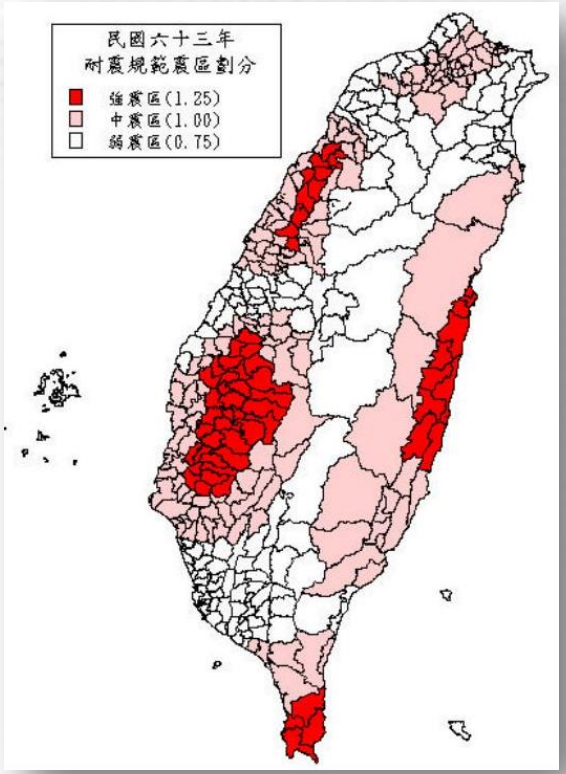


2005 Code
民國94

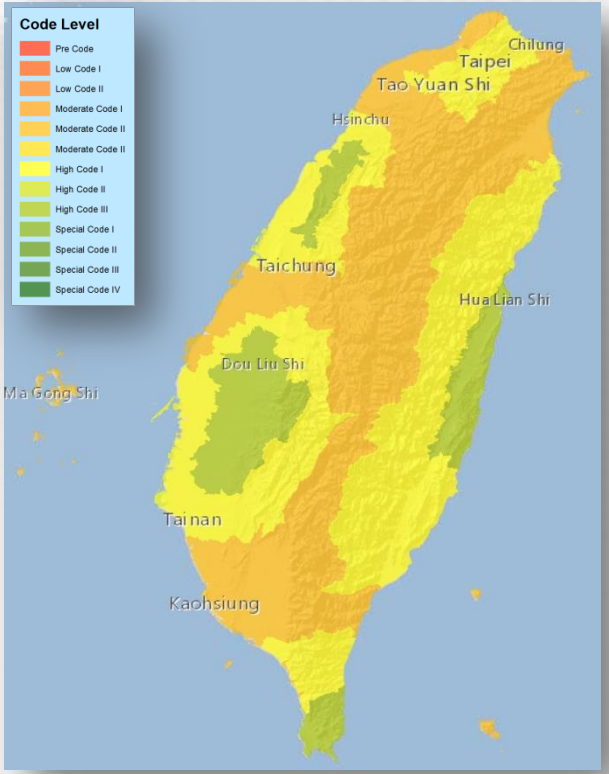
2011 Code
民國100

Pre 1975 | **1975 - 1982** | **1983 - 1989** | **1990 - 1999** | **2000 - 2005** | **2006 - 2011** | **Post 2011**

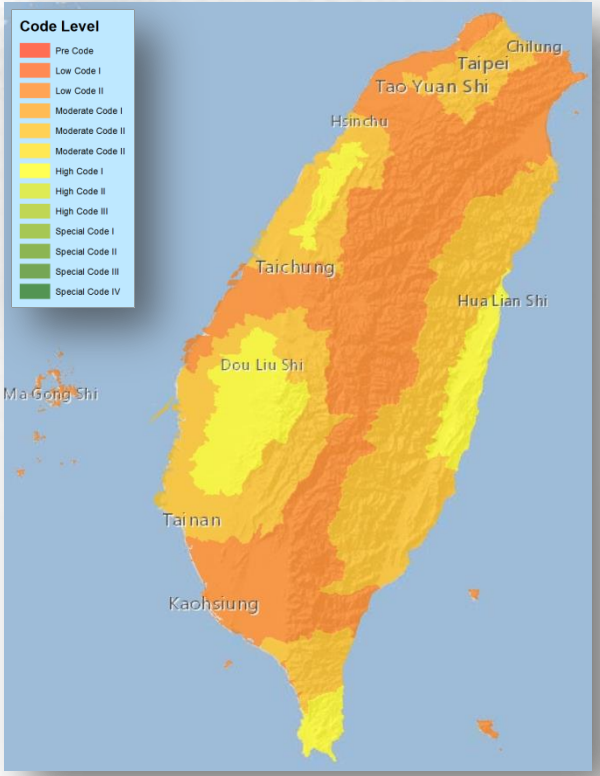
AIR Assigns Vulnerability Classes to Seismic Zones After Detailed Study of the Building Code and Local Expert Feedback



1974 Taiwan Seismic Design Zones



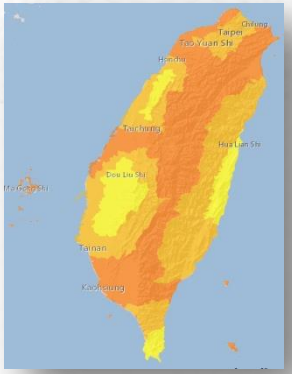
AIR Theoretical Code Levels



AIR Final Code Levels Considering Code Compliance

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

Pre 1975



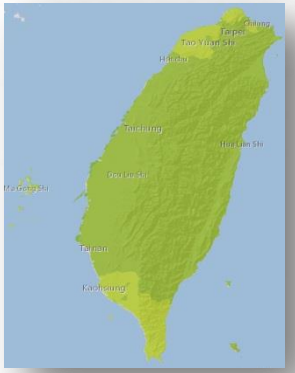
1975 - 1982

1983 - 1989

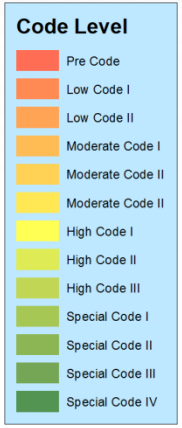
1990 - 1999

2000 - 2005

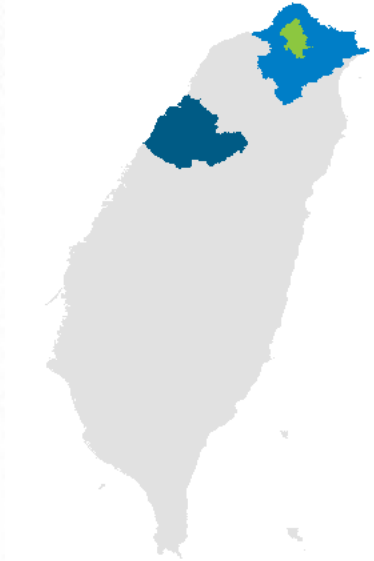
2006 - 2011



Post 2011



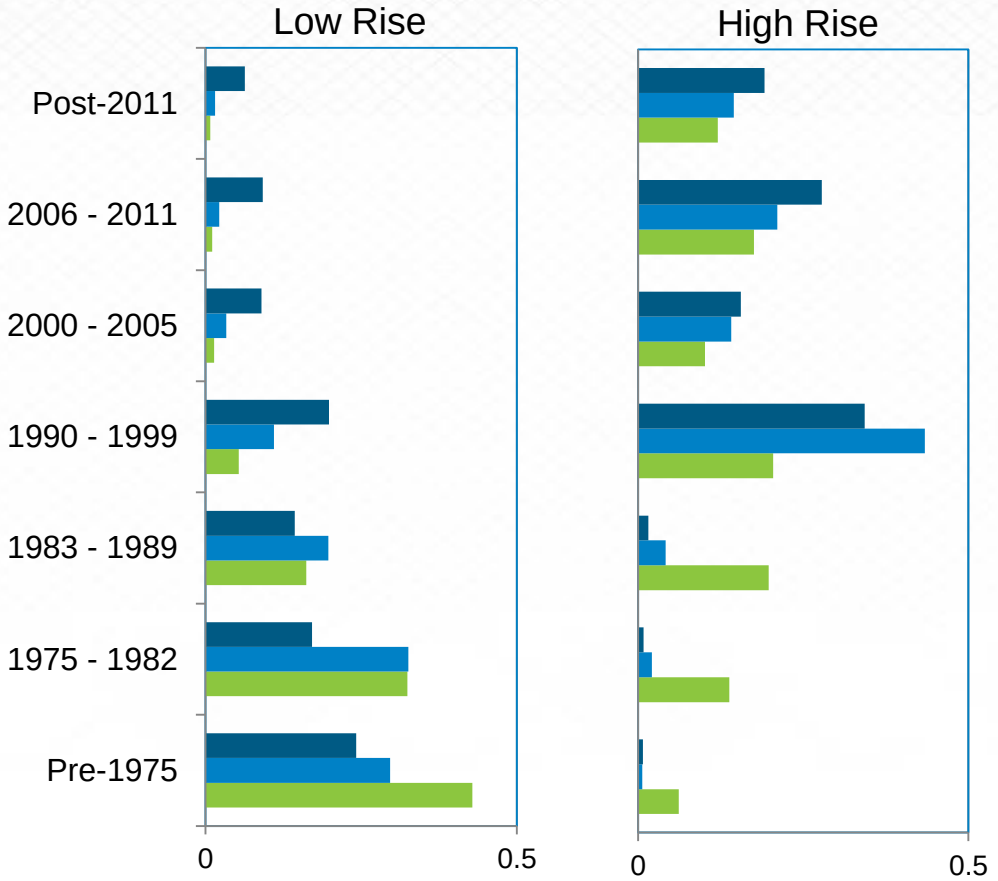
Unknown Year-Built Vulnerabilities Are Calculated Through a Weighted Average of Known Age Bands



Hsinchu

Greater Taipei and Keelung

City of Taipei



One Valuable Component of AIR Models Is the Industry Exposure Database (IED)

Exposure Data Collection

Risk Counts

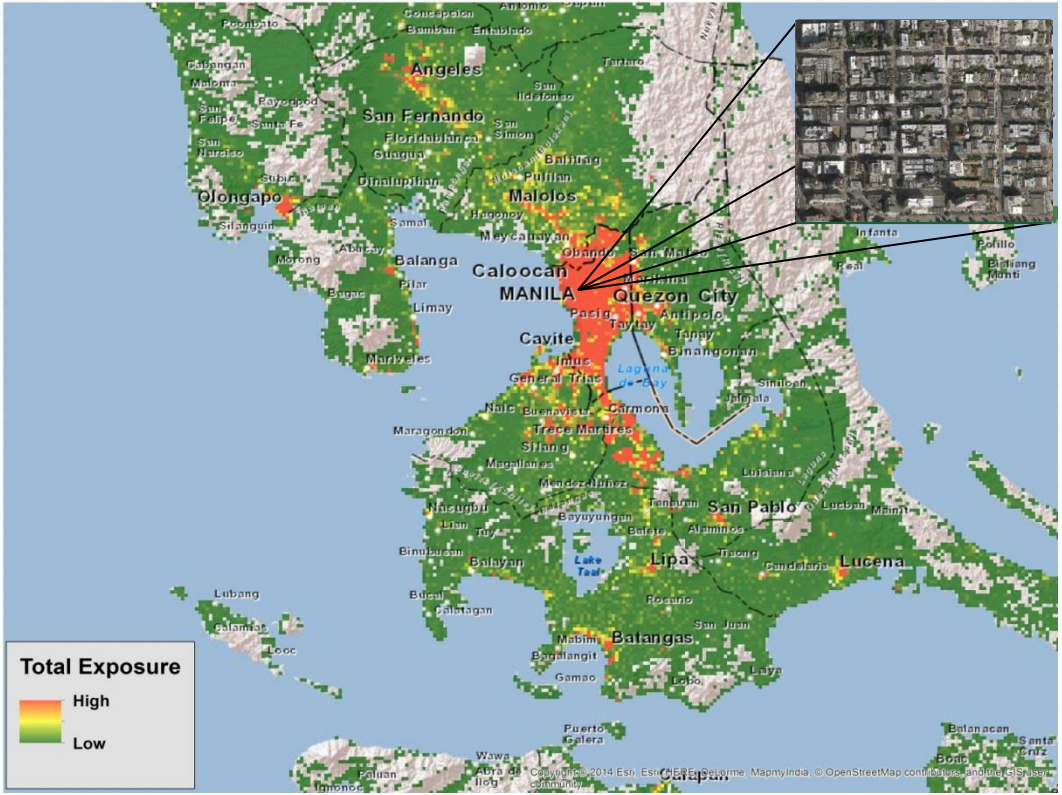
- Population & Economic Censuses
- Housing Surveys

Risk Attributes

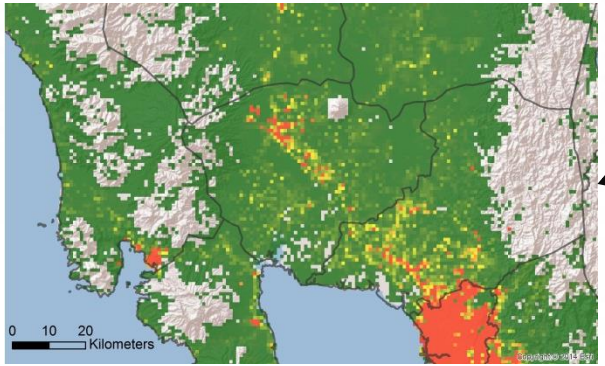
- Occupancy
- Construction & Height
- Floor Area

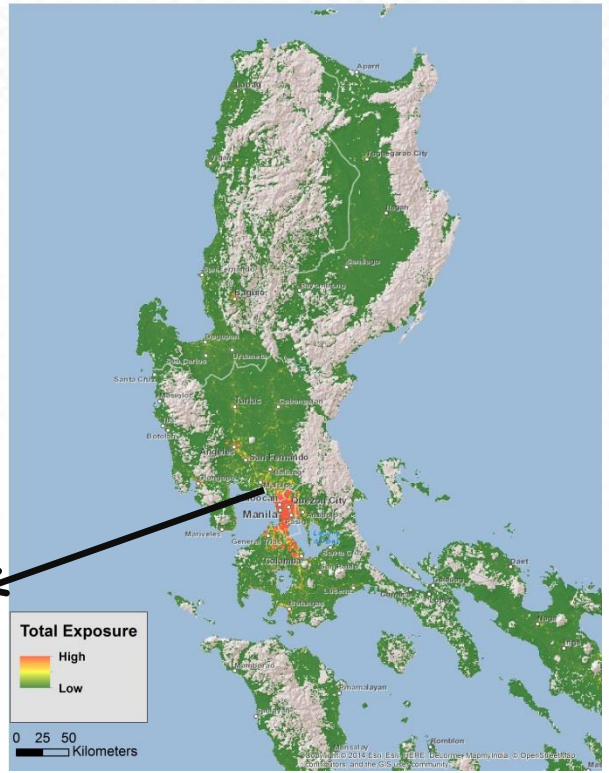
Construction Costs

- Costing Manuals
- Construction Indexes



Higher-Resolution Industry Exposure Database Allows for More Accurate Disaggregation and Results

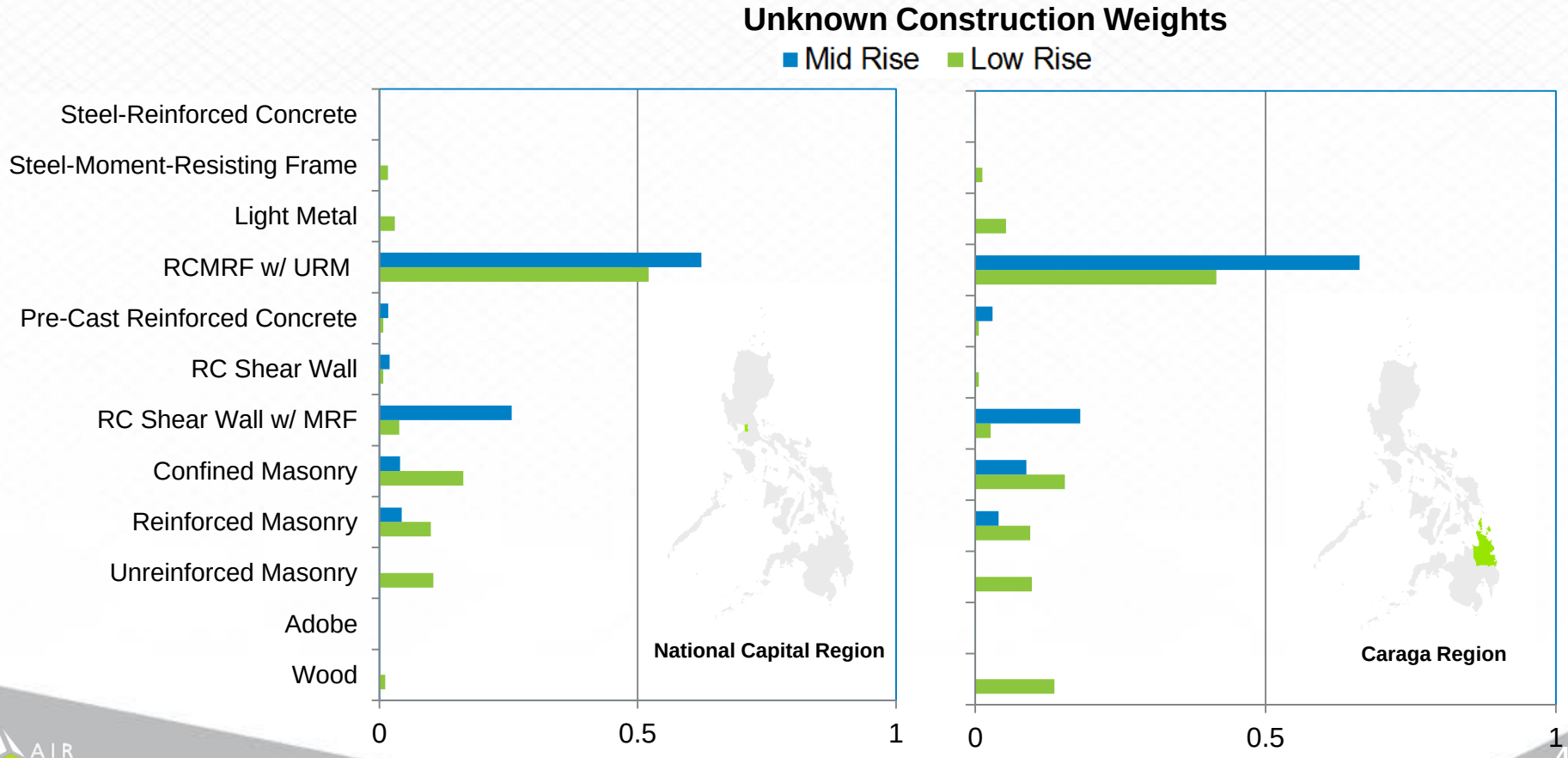




Old Model Uses Province Resolution

New Model Uses 1-Kilometer Resolution

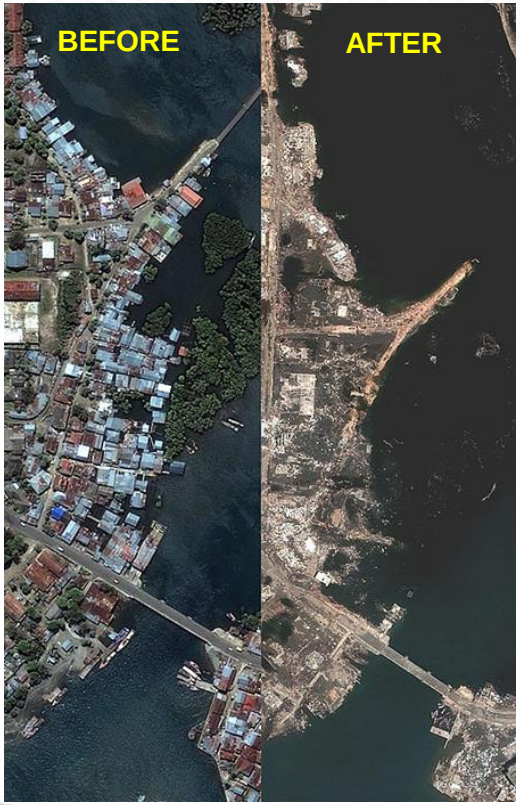
Vulnerabilities of Unknown Characteristics Are Estimated Using Weights Calculated From AIR's Industry Exposure Database

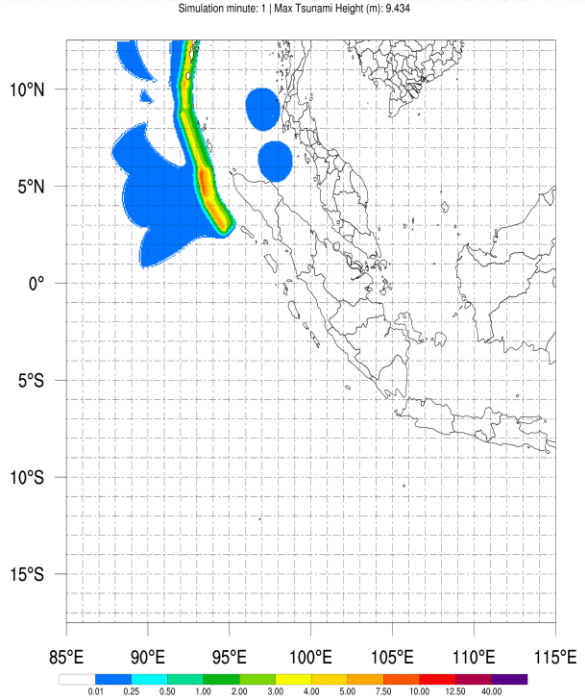


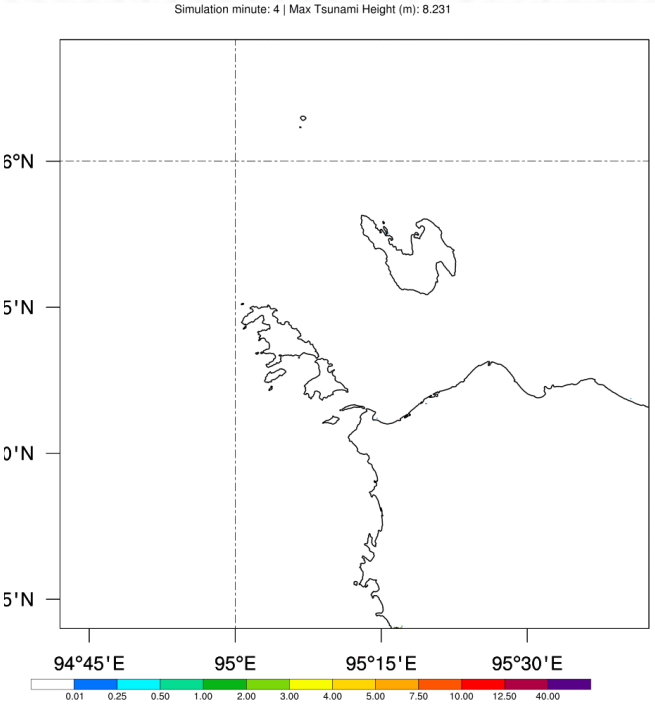
Modelled Sub-Perils

AIR

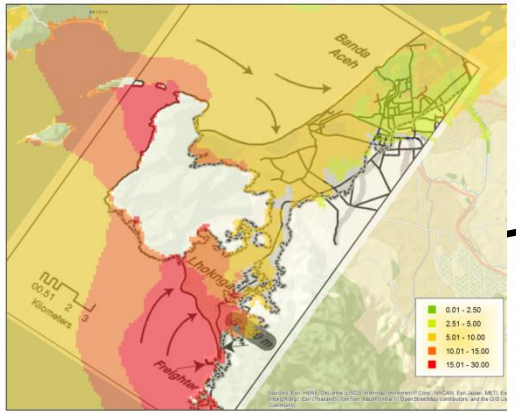
Updated Model Includes a Probabilistic Tsunami Module

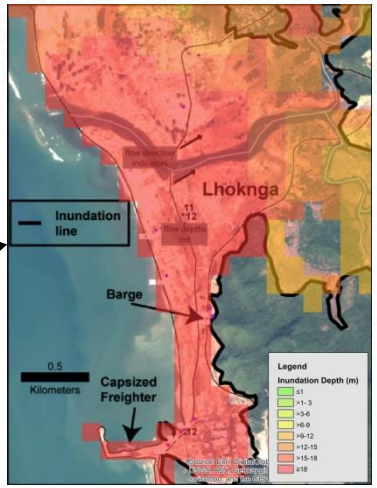




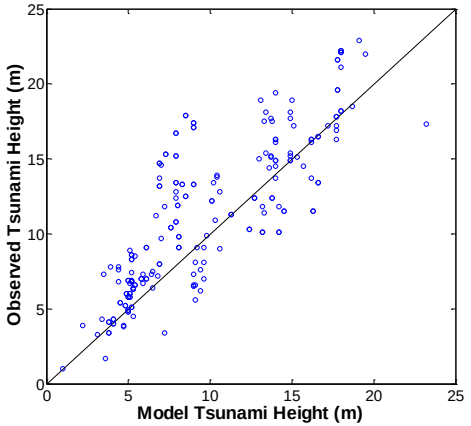


AIR Carefully Validated Tsunami Extents and Maximum Heights Against Historic Event Data

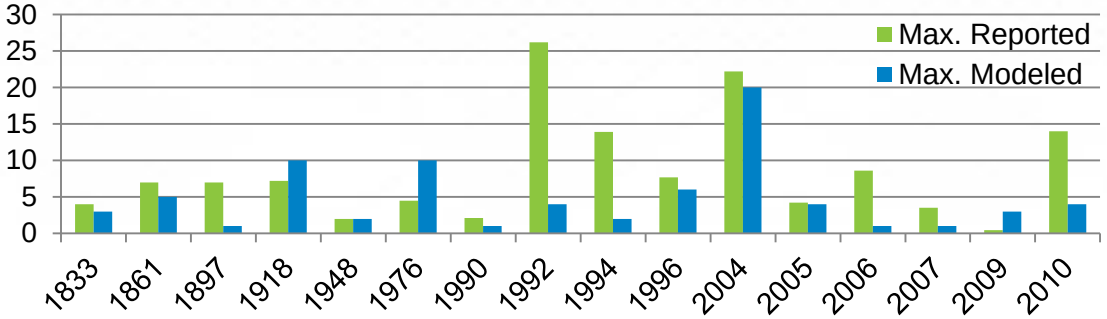




2004 Sumatra-Andaman "Boxing Day" Tsunami
Banda Aceh Observed-Modelled Inundation

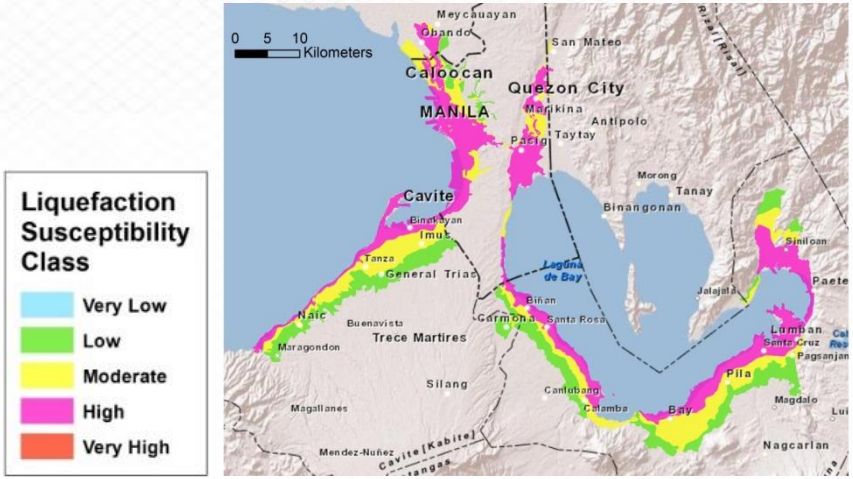


2004 Sumatra-Andaman "Boxing Day" Tsunami
Observed-Modelled Tsunami Height

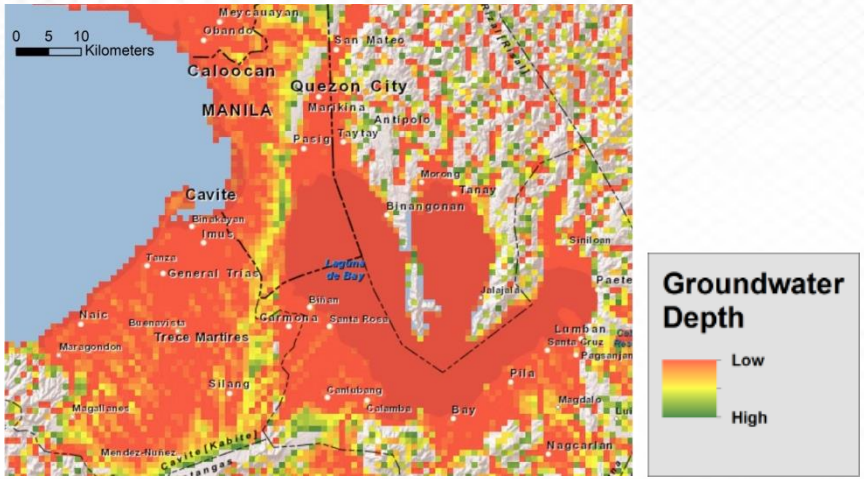


Max. Inundation Validation for Tsunami Historical Events

Earthquake Models for Southeast Asia Now Explicitly Account for Losses from Liquefaction



Liquefaction Susceptibility Maps (The READY Project)

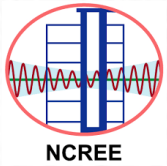


Groundwater Depth Maps

Region	Coverage
Hong Kong, Macau, Singapore, Taiwan	Whole Region
Philippines	Antique, Aurora, Benguet, Bohol, Cagayan, Catanduanes, Cavite, Cebu, Davao, Dinagat, Eastern Samar, Ilocos, Iloilo, Isabela, Laguna, Leyte, Manila, Northern Samar, Pampanga, Quirino, Southern Leyte, Suriago del Norte, Suriago del Sur, Zambalaes
Indonesia	Bali, Bandung, Central Java, Jakarta, Lombok, Malang, North Sumatra, Padang, South Sumatra, Surabaya, West Sumatra
Vietnam	Hanoi

Validation

The Vulnerability Components Have Been Peer Reviewed by Local Experts



National Center for Earthquake Engineering
TAIWAN

"AIR engineers conducted a comprehensive study of Taiwan seismic building codes, and their vulnerability assessment reasonably approximates requirement and evolution of seismic design codes and their performance in Taiwan."

Prof. Fernando J. Germar
University of the Philippines - Diliman

"… a rational way of assessing vulnerabilities of any particular building class … Both strength and ductility are accounted ... local construction practices and degree of code enforcement are also solicited in order to capture both global and local perspectives in the structure's vulnerability assessment…"

Prof. Ir. Iswandi Imran
Institut Teknologi Bandung (ITB) INDONESIA

"…AIR's framework is basically simple, practical and flexible for adjustments. Therefore, it is suitable to be used in the development of large scale, regional seismic risk of large archipelago country such as Indonesia…"

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

NARLabs 國家實驗研究院
國家地震工程研究中心
National Center for Research on Earthquake Engineering

Kementerian PPN/ Bappenas

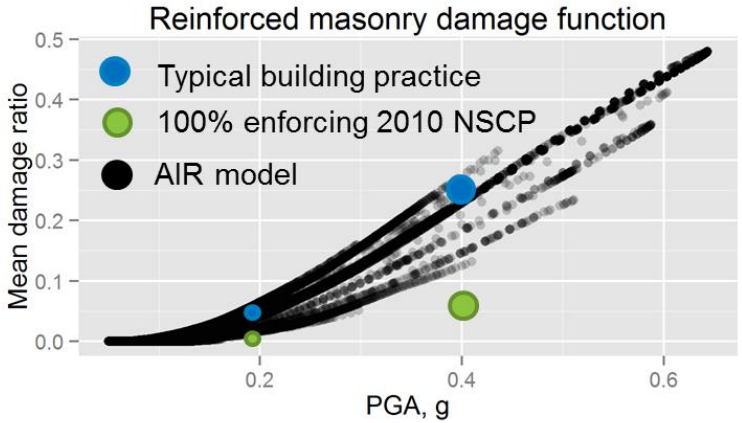
PHIVOLCS
Philippine Institute of Volcanology and Seismology

GEM

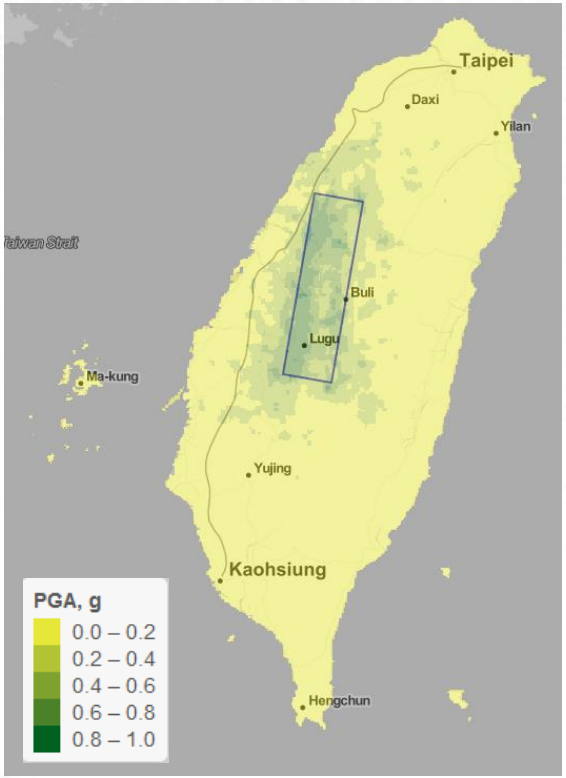
SYNER-G

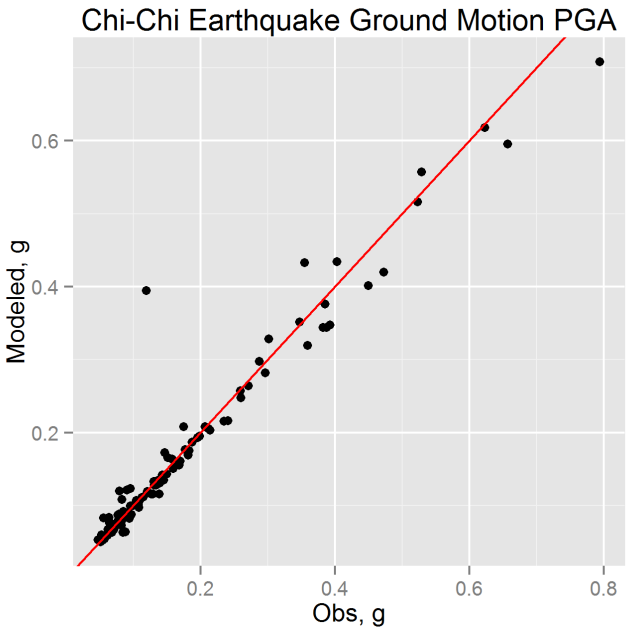
HAZUS MH
EARTHQUAKE • WIND • FLOOD

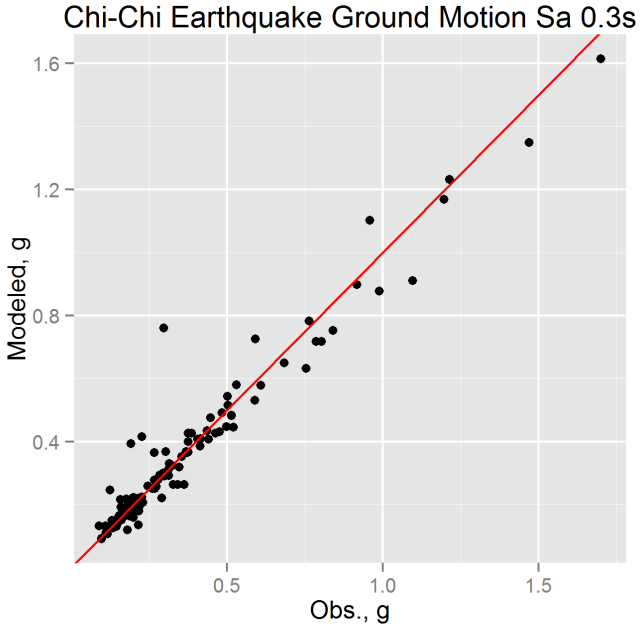
Two full-scale RM (CHB) buildings tested by Imai et al. (2015)



Model Correctly Reproduces the 1999 Chi-Chi Earthquake Observed Ground Motions



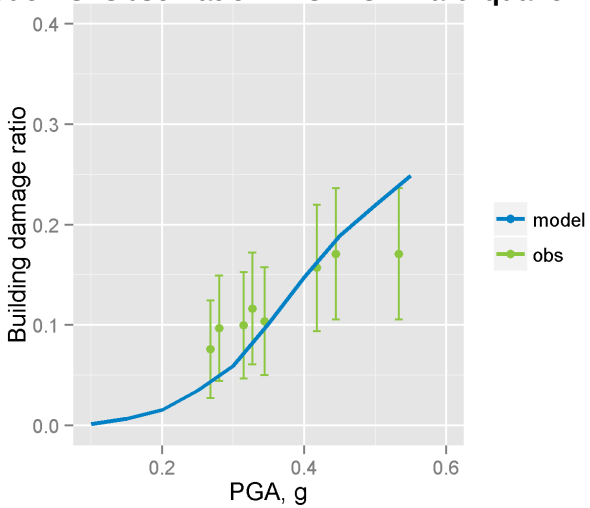




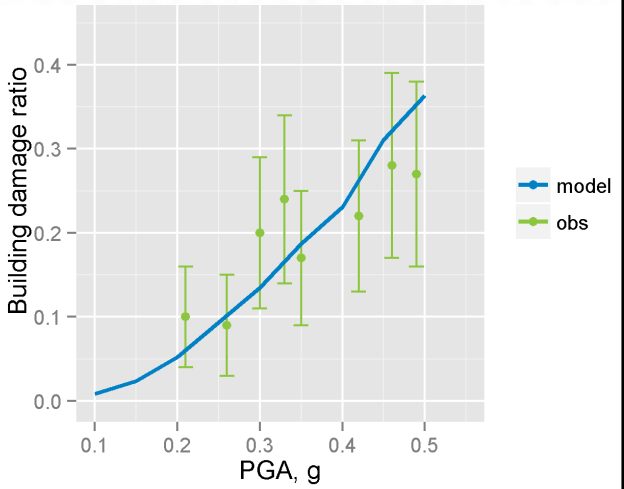
Model's Damage Curves by Construction Type Compare Well with the Observations from Reports – 1999 Chi-Chi

Photos: NCREE

Reinforced Concrete Building Damage: Model vs. Observation in Chi-Chi Earthquake

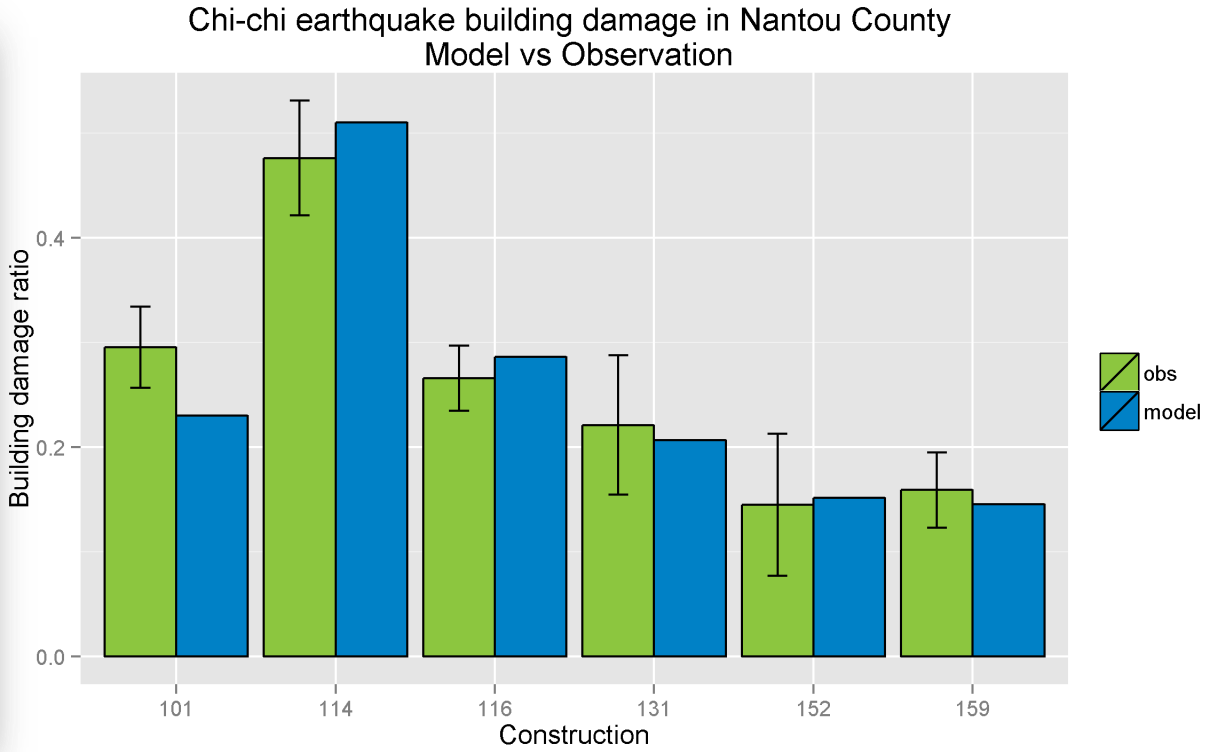


Masonry Building Damage: Model vs. Observation in Chi-Chi Earthquake

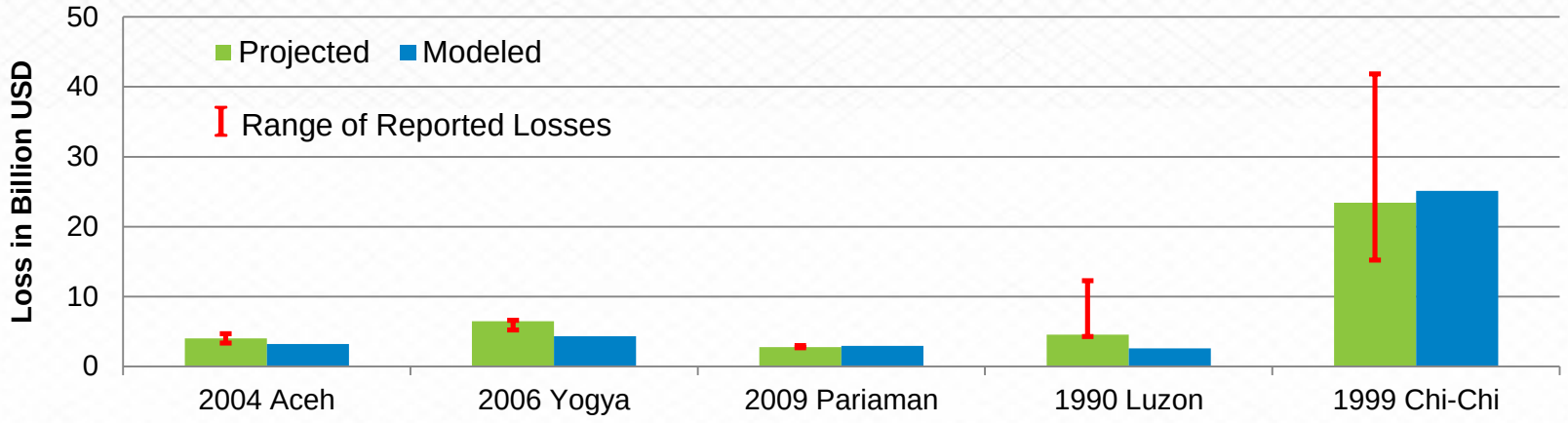


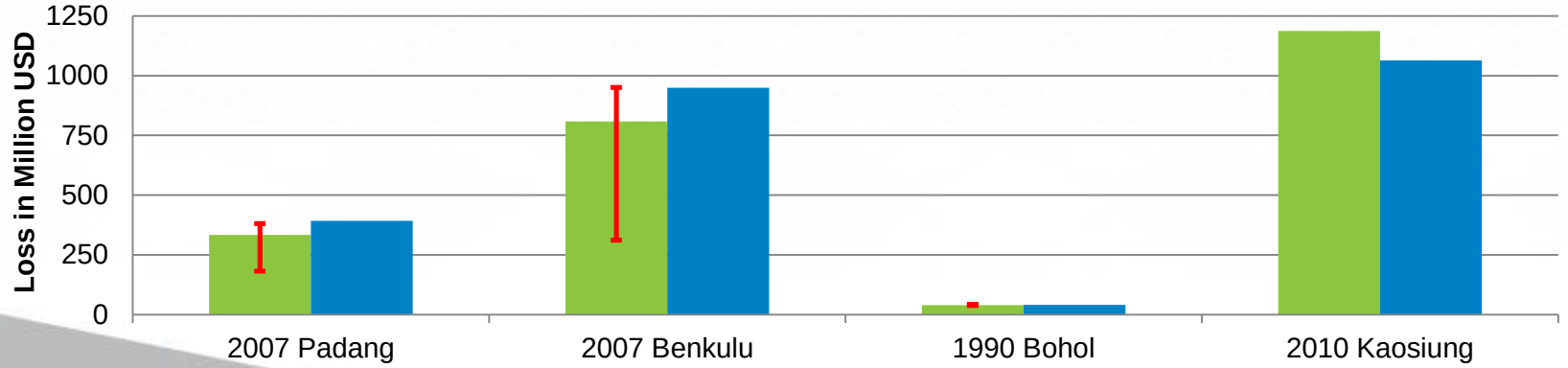
Obs. source: Lee et al. (2002). Development of Hazard Damaged Buildings Model by Chi-Chi earthquake Data

Model's Calculated Damage Ratios by Construction Type by Region Match the Regional Observations from Reports – 1999 Chi-Chi



More Than 50 Historical Events Were Used for Validation of Southeast Asia Earthquake Models





AIR's New Earthquake Models for Southeast Asia Raise the Bar in Terms of Scope, Innovation, and Quality

- Innovations in hazard modelling: AIR has applied new approaches to kinematic modelling, time-dependency, ground motion prediction, and the development of the new sub-perils, tsunami and liquefaction
- Considerable expansions of the scope of the model: AIR has added new risk types, including industrial facilities, public infrastructure
- Extensive component-level validation: AIR used observational data and with inputs from local engineers and geo-scientists in the modelled countries

Upcoming AIR Events Will Feature More Comprehensive Model Details

envision '16

Philadelphia

6–8 April

June and August

- Singapore – 16 June
- Philippines – 21 June
- Indonesia – 23 June
- Vietnam – 28 June
- Beijing – 30 August
- Taiwan – 1 September