Latest Advances in Modelling Tsunami Risk Worldwide and in Israel

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Agenda

- Motivation for tsunami modelling
- AIR’s real-time modelling of tsunami events
  - Tohoku, Japan. 2011
- AIR’s probabilistic tsunami models
  - Japan, Canada, South America, South East Asia, US (summer 2017)
- Validating probabilistic tsunami models
- Modelling tsunami risk in Israel and the Mediterranean

Motivation for Tsunami Modelling

Events From the Past Decade Illustrate the Potential Economic Loss and Social Impact of Tsunamis

Tohoku Event	• 11/03/2011 • Japan and Pacific rim
Economic Loss (EQ & Tsunami)	• USD 210 Billion
Loss of Life	• 19,846

Maule Event	• 27/2/2010 • Chile and South America
Economic Loss (EQ & Tsunami)	• USD 30 Billion
Loss of Life	• 562

Boxing Day Sumatra Event	• 26/12/2004 • South East Asia
Economic Loss (EQ & Tsunami)	• USD 4.45 Billion
Loss of Life	• 165,708

* Loss statistics from EMDAT database

Existing Coastal Tsunami Defences in Japan Did Not Withstand the Force of the Tohoku Tsunami

- The 2004 Indonesian Boxing Day Tsunami served as a warning to the potential coastal risk from tsunami.
- Prior to Tohoku, existing Japanese Coastal Defence Systems were thought to provide sufficient protection

Figure 1. **Rikuzen-takata City before and after the disaster***

* Reproduced with permissions from the Iwate Prefectural Government

Real-Time Modelling of Tsunami Events

AIR Estimated Losses for Tohoku in Real Time

MAIN SHOCK – M9.0 Tohoku Region (Mar. 11, 2011)

USD 20 Billion to 30 Billion in Insured Loss

Probabilistic Tsunami Modelling

Tsunamis Can Form When the Earth's Crust Deforms Under Stress

- When strong earthquakes occur offshore, water above the deformed area is displaced and can create a tsunami

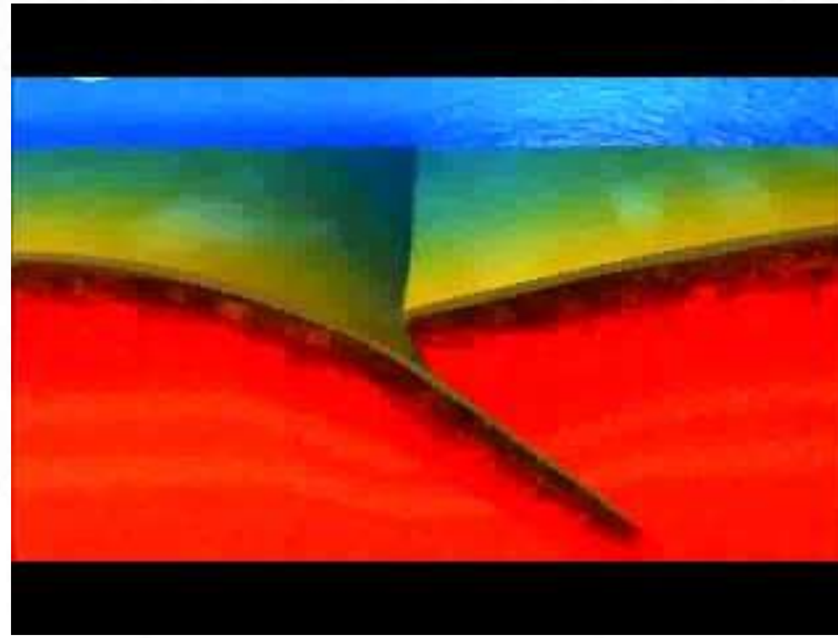
- Tsunamis move very quickly in the open ocean, but with long wavelengths and small amplitudes they are scarcely detectable

- At an ocean depth of 4 km, the tsunami wave speed is roughly 800 km/h!

- As a tsunami nears shore, the wave slows, the height increases, and the wavelength decreases

- As the tsunami comes onshore, friction and terrain height determine how far inland the water penetrates

- Damage is caused by hydrostatic pressure, buoyancy (uplift), and the hydrodynamic force of the moving water



Courtesy of The History Channel – How The Earth Was Made - Tsunami

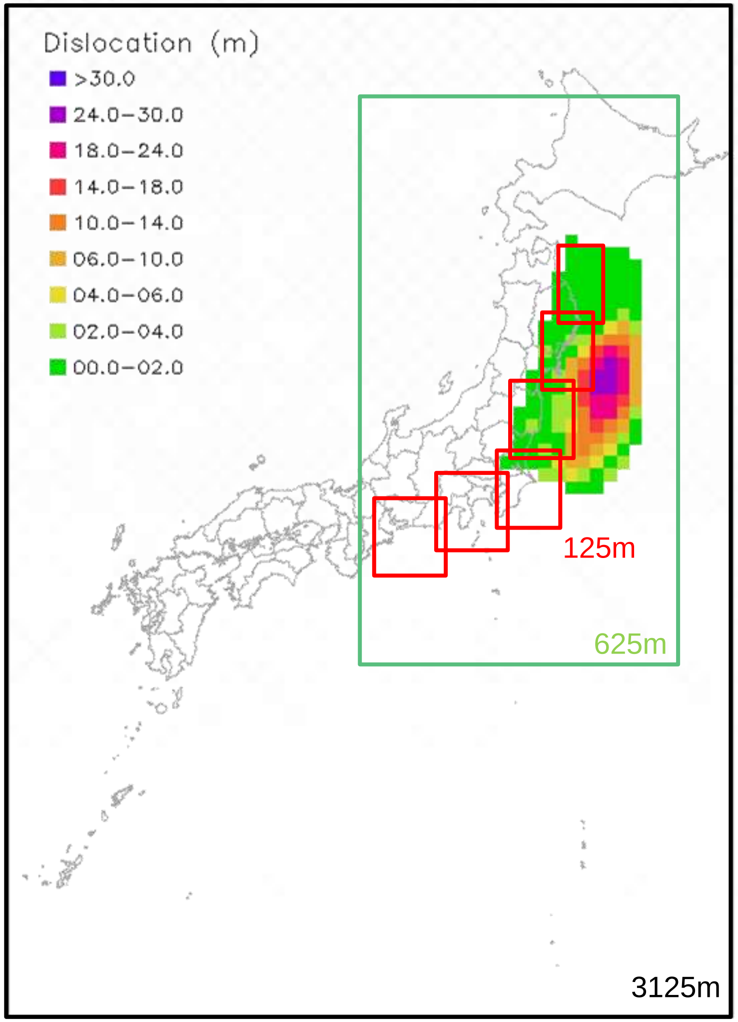
AIR Tsunami Models Are a Modified Version of TUNAMI

Tohoku **U**niversity's **N**umerical **A**nalysis **M**odel for **I**nvestigation of Near-field Tsunamis

- Developed by Dr. Fumihiko Imamura
- 2-D shallow water equations of motion (mass, momentum)
- Non-linear/linear

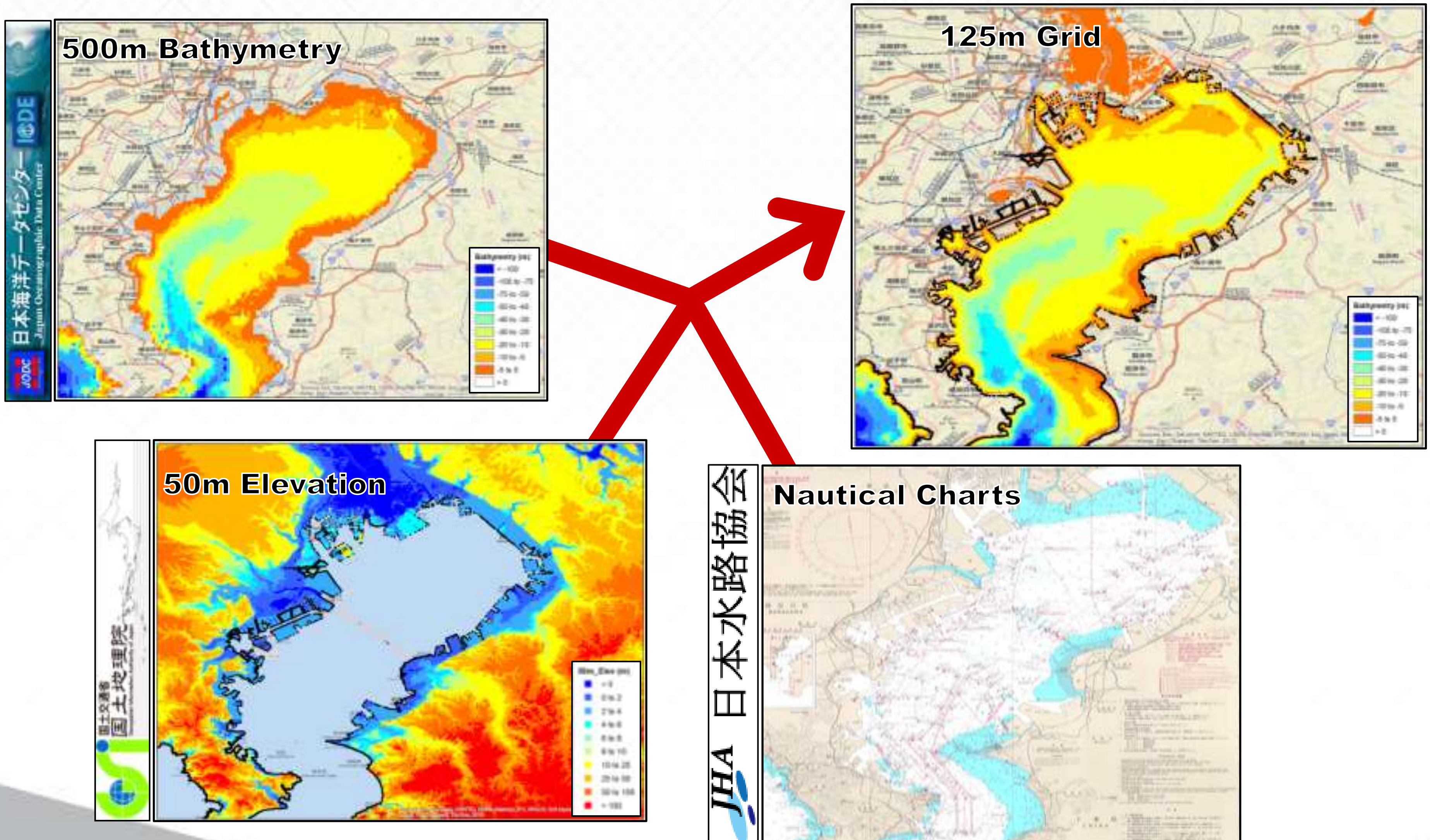
AIR enhancements

- *Subsidence*
- *Multiple sub-faults*
- *Multiple nested domains*
- *Dynamic time step*
- *Hi-resolution Terrain/Bathymetry*
- *Enhanced harbors, channels, etc.*
- *Friction (Manning Coefficients)*
- *Astronomical Tides*
- *Levees & Failure*
- *Outputs of water height, velocity, and wet-time to an intensity file*



Ozawa slip distribution for Tohoku 2011 Event

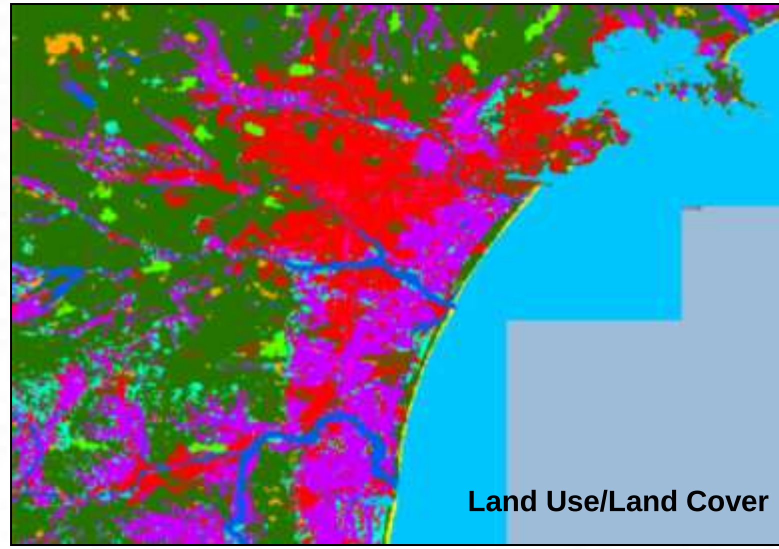
Resolving Coastal Geographic Details Is Crucial



Friction Is Important for Determining Inland Extent and Velocity

- Model we received had a constant Manning coefficient value = 0.025 everywhere
- LULC data from Japan MLIT at 100 meter resolution used to identify different land types in high resolution domains
- Land use types converted to Manning Coefficients using available tables
- Northern Sendai Bay characterized by high variability within first few kilometers
- Sensitivity tests showed significant impact between constant Manning and grid-specific values

国土交通省



Category	*Manning*	*Category*	*Manning*
Paddy	0.050		
Farm	0.050	River and Lake	0.025
Forest	0.200	Seashore	0.020
Waste Land	0.050	Sea	0.025
Building	0.050	Golf Course	0.050
Traffic	0.020	Other Open Land	0.025

Levees and Probabilistic Levee Failure Are Included

- 50 meter levee data, high-resolution topographic maps, and 5 meter terrain data are used to identify and define levees

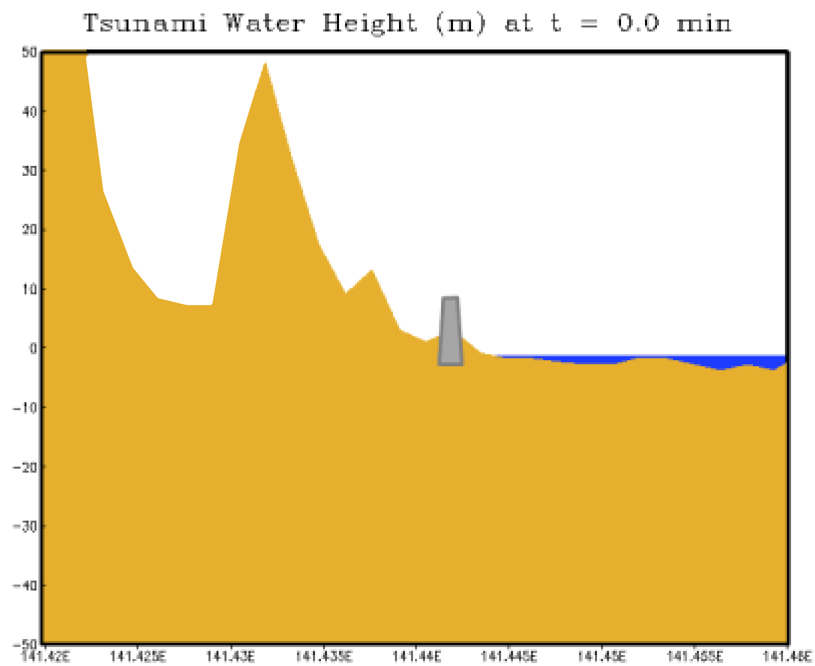
- Levee information incorporated into 125 meter model grids

- Overtopping occurs when tsunami water height exceeds the height of the levee and terrain

- Breaching occurs probabilistically when tsunami energy exceeds threshold

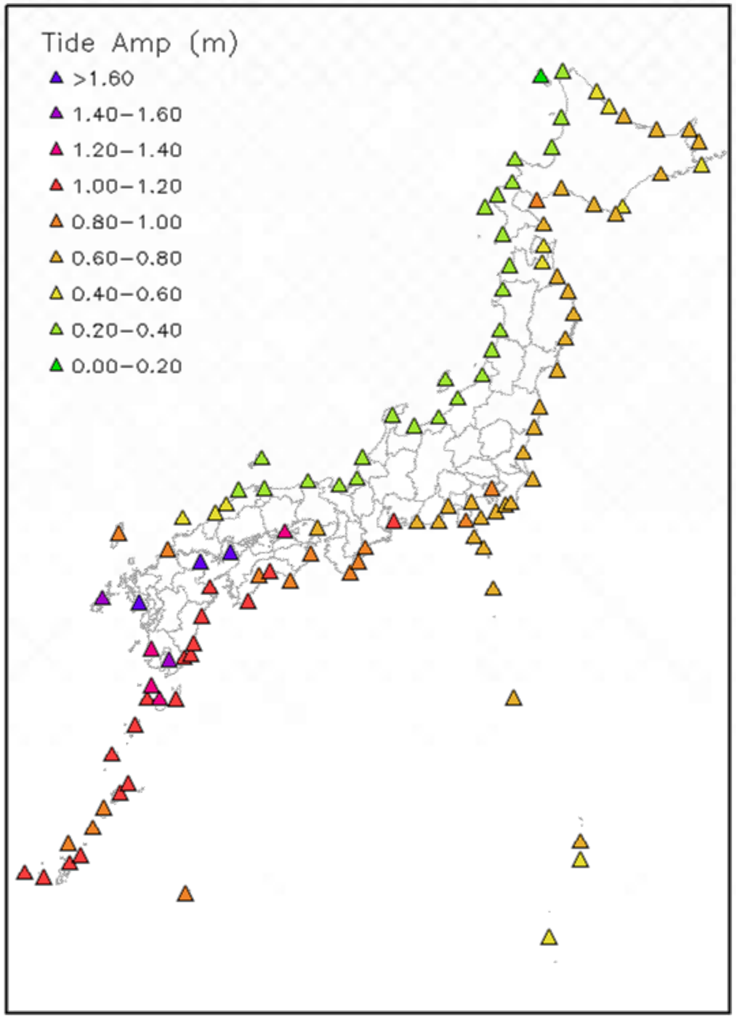
- Fragility curves used to determine probability of breaching. Curves adjusted based on Tohoku 2011 observations that 40-60% of levees were destroyed

- Subsidence and tides influence overtopping, breaching, and inundation



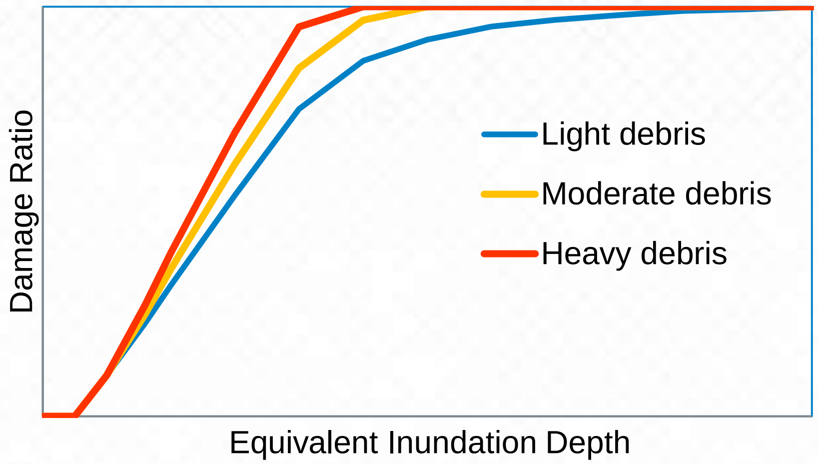
Astronomical Tides Can Make a Difference

- A tsunami at high tide can turn a non-loss causing event into a loss causing one
- Maximum tidal amplitudes vary considerably all along the coast – especially on the eastern side
- For the stochastic catalogue each event is assigned a tide height value for each domain
- Julian day and hour of each event determines which values are chosen

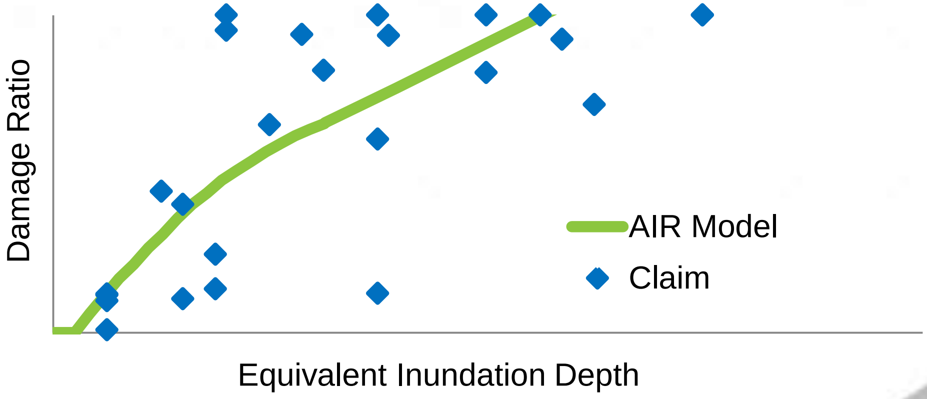


Tide amplitudes at stations used in tsunami model

AIR's Tsunami Damage Functions Account for Debris and Are Validated Based on Claims Data



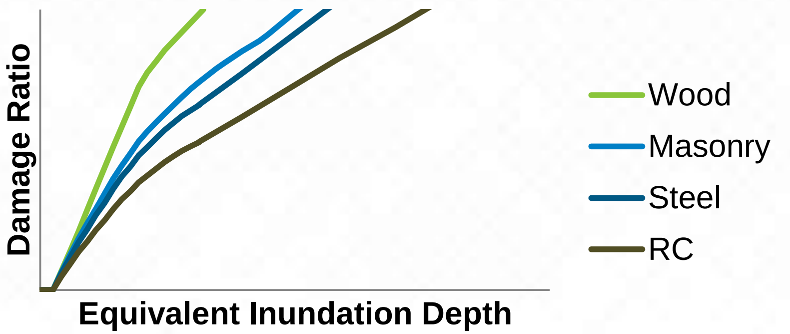
- Claims data from 2011 Tohoku earthquake is used for validation

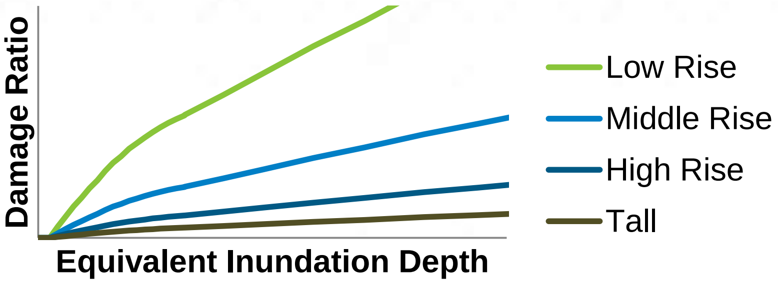


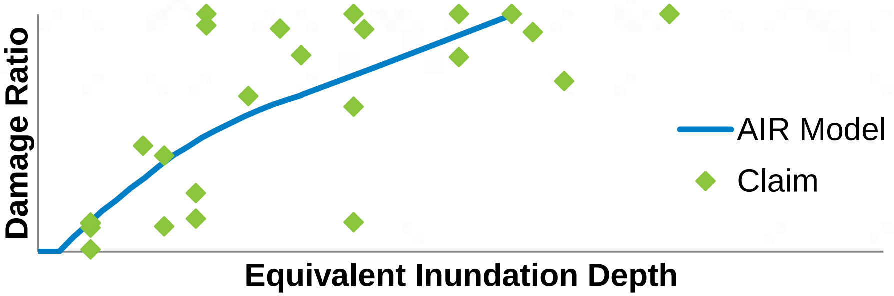
Validating Probabilistic Tsunami Models

Tsunami Vulnerability Functions Fit Well with Claims Across Many Different Types of Buildings

- Based on extensive literature review, mainly Japanese sources
- Claims data used only for validation

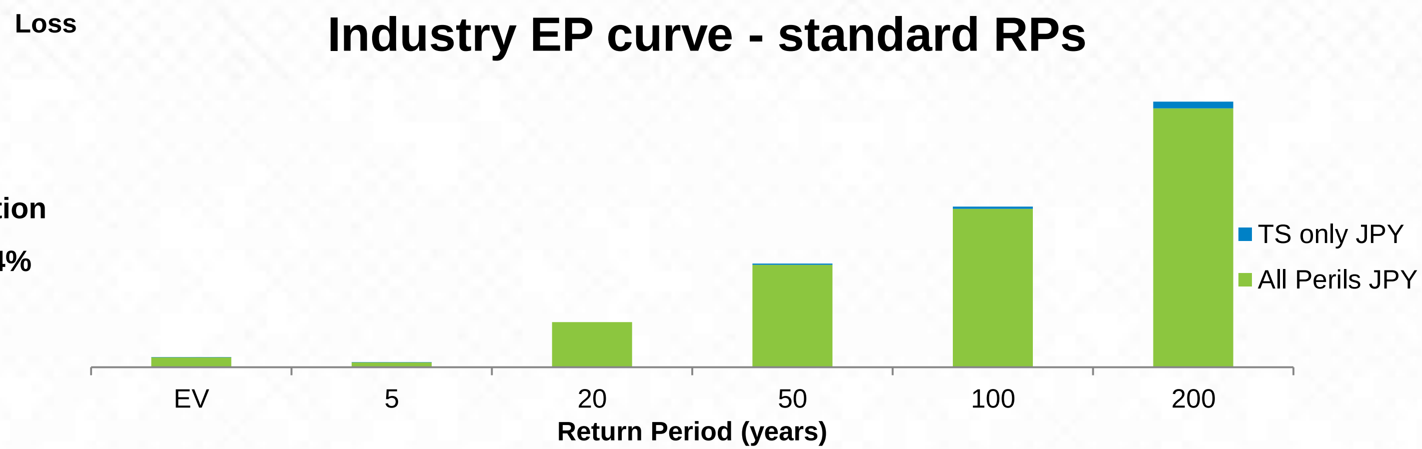




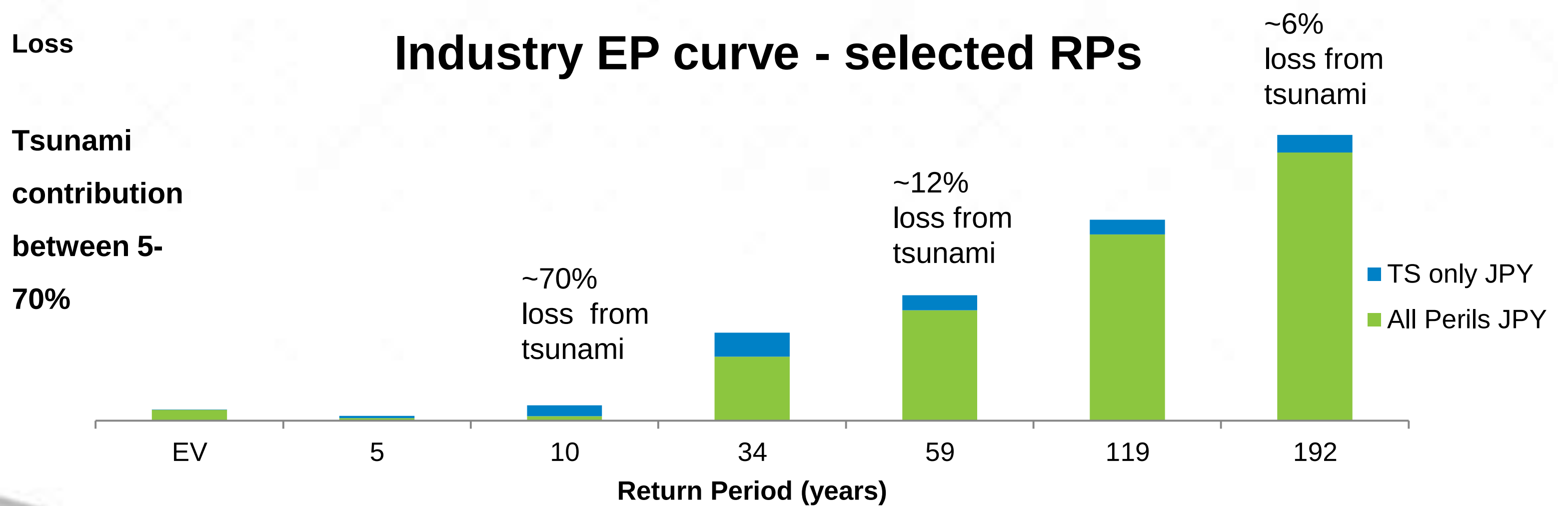


Tsunami Losses Can Have Large Impact at Certain Return Periods (Japan)

Tsunami contribution about 1-4%



Tsunami contribution between 5-70%

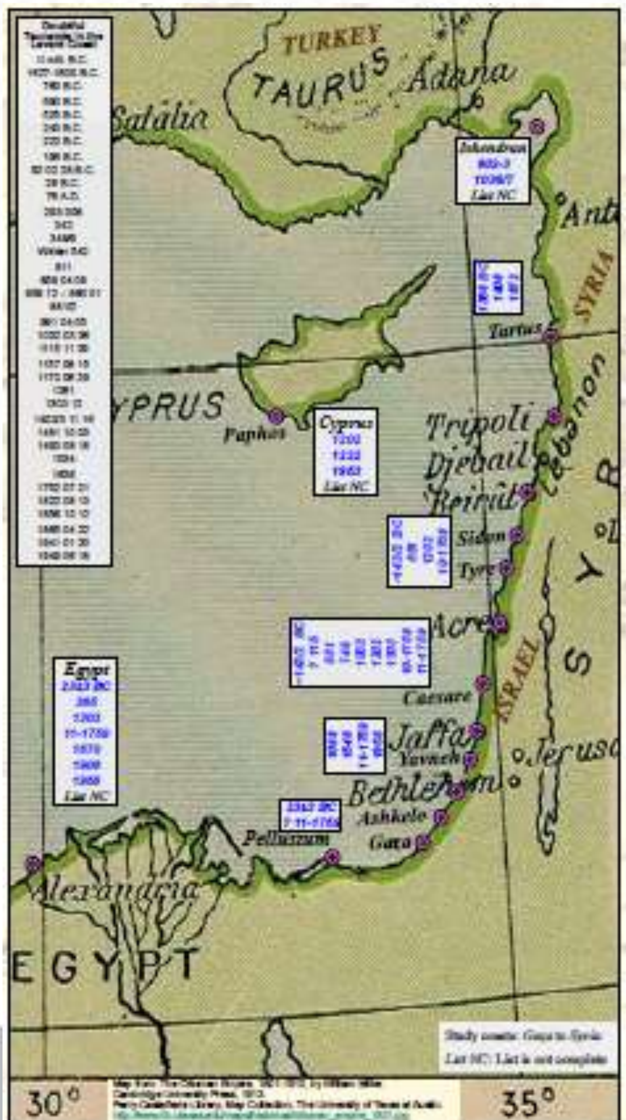


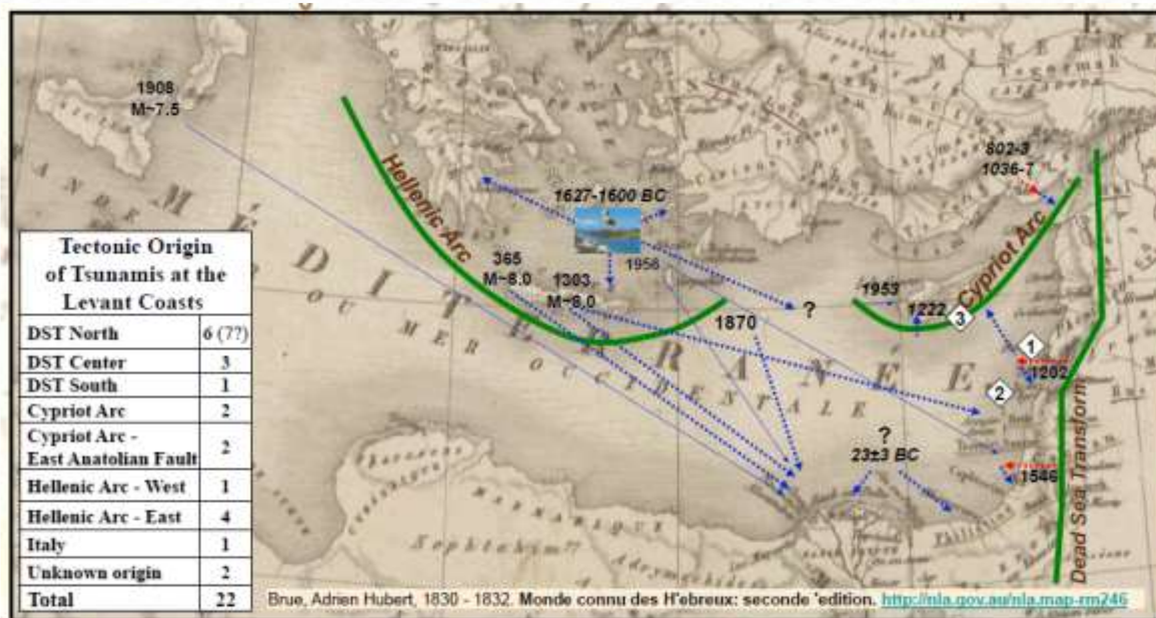
AIR's Tsunami Models Have Worldwide Coverage

* Loss statistics from EMDAT database

Modelling Tsunami Risk in Israel and the Mediterranean – A Simplified Model

Historical Tsunami Events in the Eastern Mediterranean Highlight Different Source Areas and Trigger Mechanisms





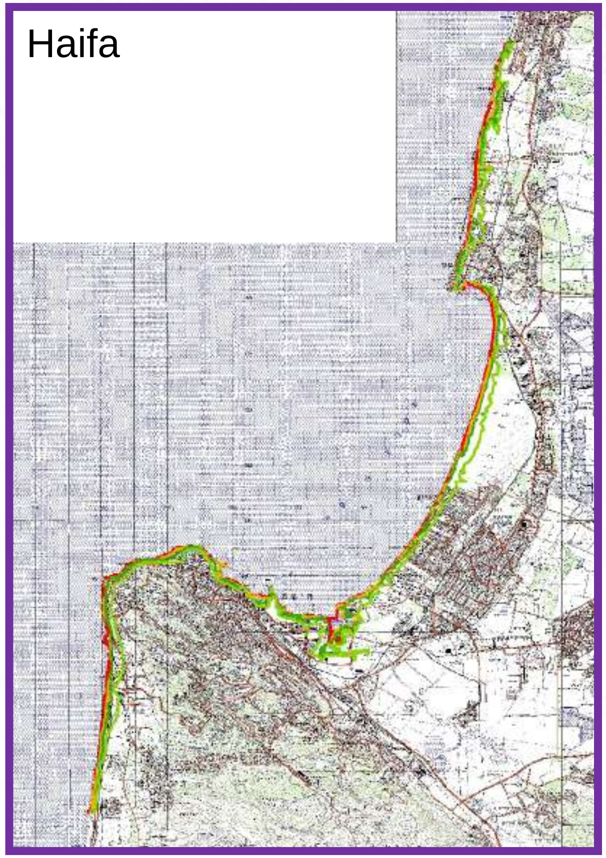
Tectonic Origin of Tsunamis at the Levant Coasts	
DST North	6 (??)
DST Center	3
DST South	1
Cypriot Arc	2
Cypriot Arc - East Anatolian Fault	2
Hellenic Arc - West	1
Hellenic Arc - East	4
Italy	1
Unknown origin	2
Total	22

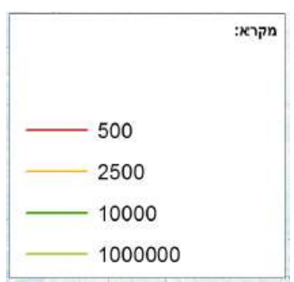
Source: Amos Salamon et al., *Geological Survey of Israel*

- Amos et al., comment that the majority of the historical tsunamis associated with the Dead Sea Transform Zone result from on-land earthquakes that likely triggered offshore submarine landslides

- Tsunamis resulting from offshore earthquakes originate further a field in the Cypriot and Hellenic Arcs

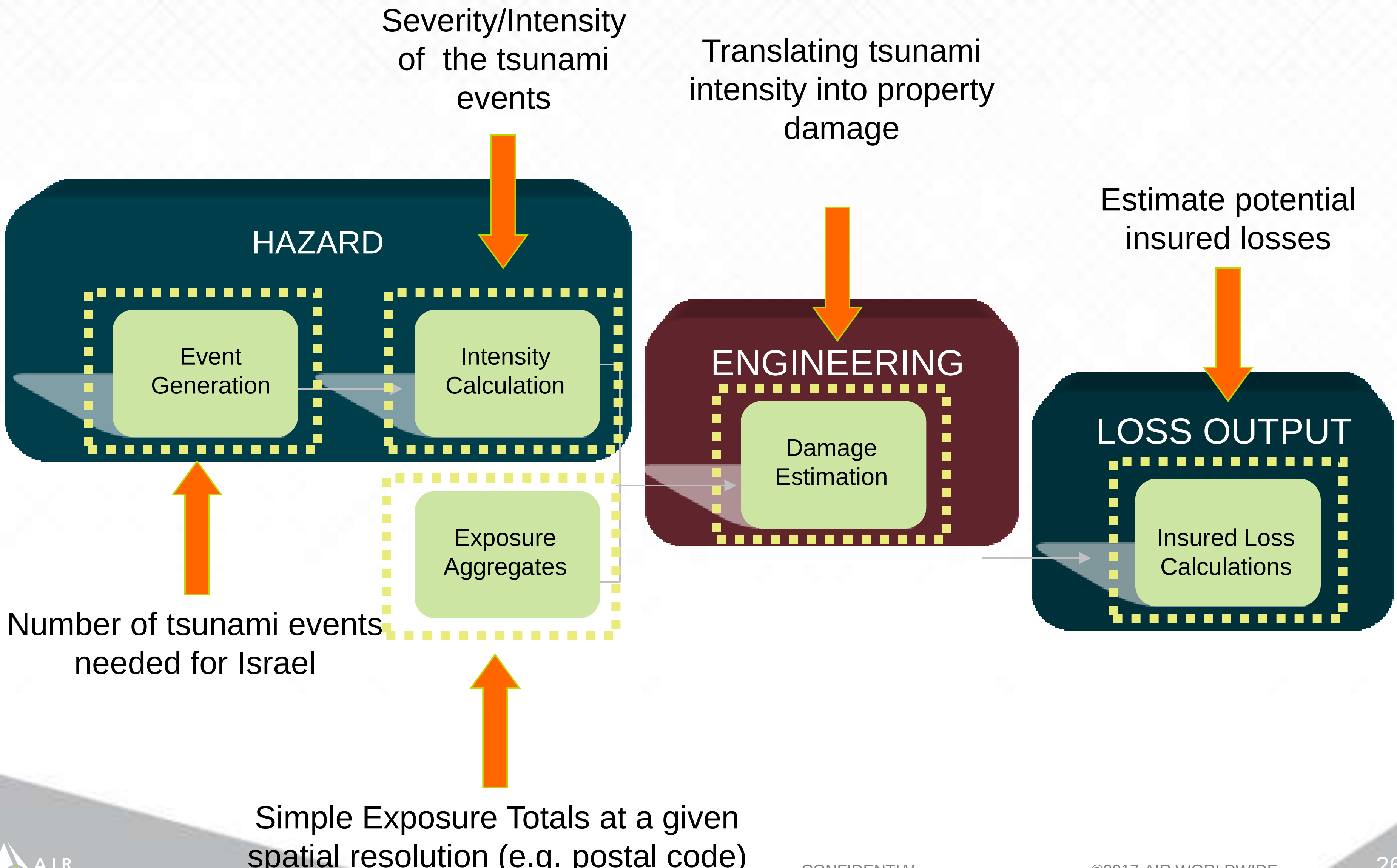
Touchstone Could Provide Estimates of Exposed Limits and a Range of Losses for Probabilistic Tsunami Inundation Maps



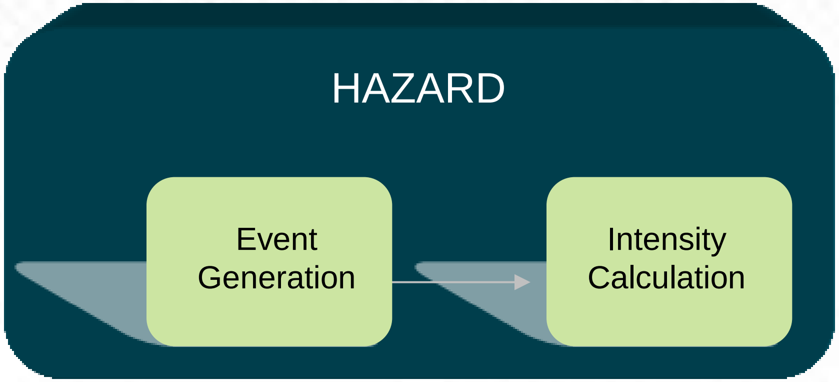


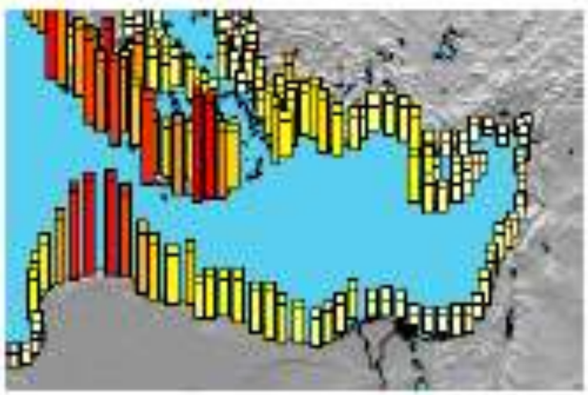
Source: Kie Thio & Salamon, *Geological Survey of Israel*

Generating Tsunami Event Loss Table For Israel Using a Simplified Model of AIR's Probabilistic Components

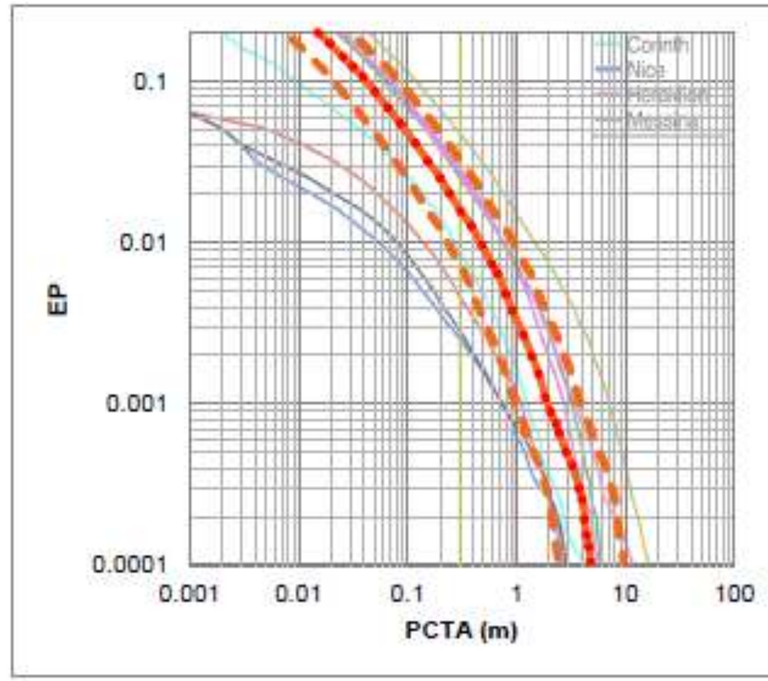


Israel Tsunami Catalogue and Intensity Calculations Informed by Work of Sørensen et al., 2012





Peak Coastal Tsunami Amplitude at 5,000 year return period
Source: Sørensen et al., 2012



Probabilistic tsunami hazard curve and estimated uncertainty bounds
Source: Sørensen et al., 2012

Postal Codes Below an Elevation Threshold Can Be Used to Select Exposure at Risk from Tsunami

Exposure Aggregates

Simple Exposure Totals at a given spatial resolution (e.g. postal code)

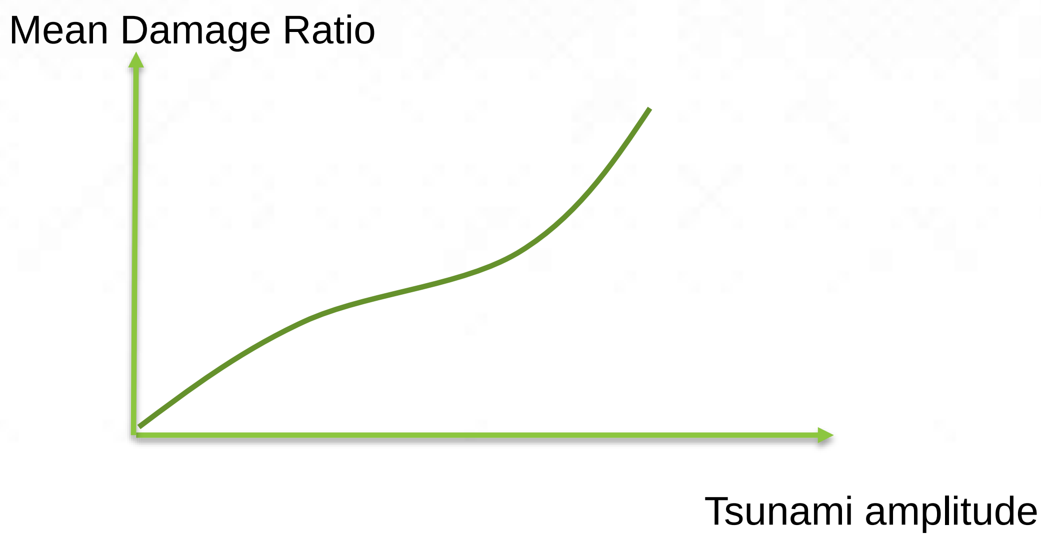
- Coastal exposure is highly concentrated and significant proportion of total industry exposure
- Coastal elevation fairly flat (e.g. Tel Aviv) which increases susceptibility to tsunami inundation

AIR's Industry Exposure Database

Postal codes potentially at risk from tsunami inundation

Simplified Tsunami Damage Function Based on Water Depth Only

- For each simulated event, a function relating tsunami amplitude and damage can be used to estimate losses
- This can be done for each affected postal code of that event and summed to give the total loss for that tsunami



Summary

- AIR has probabilistic tsunami models in Japan, U.S., Canada, South America and Southeast Asia
- Tsunami risk for a given event can be significant and should not be ignored
- Typically, the impact on Average Annual Loss basis is a few percent of shake loss
- Tsunami impact to Israel is rare, but historical occurrences have been recorded
- AIR's initial investigation into the magnitude of tsunami loss in Israel shows impacts not dissimilar to those in other regions worldwide