# GIS methodologies for local tsunami risk assessment – validation for the 2009 South Pacific tsunami in American Samoa


C. B. Harbitz[1,2]

*Contributions from:*

K. Sverdrup-Thygeson[1,2], G. Kaiser[2,4], R. Swarny[3], L. Gruenburg[3], S. Glimsdal[1,2], F. Løvholt[1,2], B. McAdoo[3], R. Frauenfelder[1,2]

*1 Norwegian Geotechnical Institute, Norway*

*2 International Centre for Geohazards, Norway*

*3 Department of Earth Sciences and Geography, Vassar College, Poughkeepsie, NY*

*4 Previously Christian-Albrechts University of Kiel, Germany*



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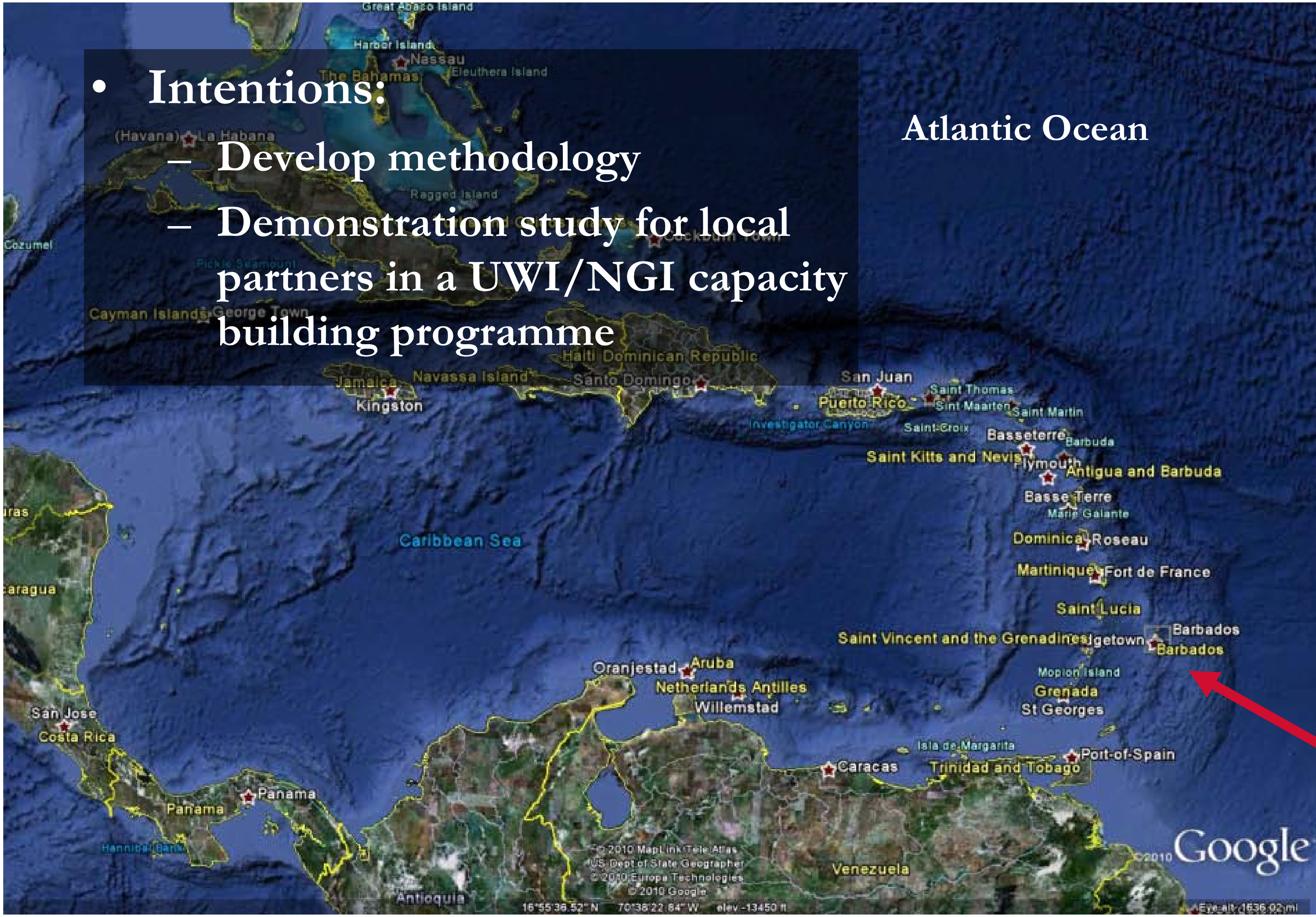
# Background and motivation

- 3 tsunami vulnerability and risk analyses performed
  - GIS model being adapted to the available information
- Bridgetown, Barbados: possible future tsunami scenario, much information available
  - Topography, population from local partners
  - Field survey for building use and vulnerability
- Batangas, The Philippines: possible future scenario, little information available
  - Internet and other sources of information
- American Samoa: hindcast of 2009 South Pacific tsunami for validation of the tsunami vulnerability and risk model
  - Post tsunami field survey data
  - A number of other sources of information

# Methodology Bridgetown, Barbados

- Intentions:
  - Develop methodology
  - Demonstration study for local partners in a UWI/NGI capacity building programme

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# Tsunami risk assessment

- Risk = Hazard * Consequence
  - Hazard = maximum tsunami flow depth related to a certain probability of occurrence
  - Consequence described by exposure and mortality
    - Exposure; density of population
    - Mortality; function of flow depth and building vulnerability
  - 4 factors describing the buildings:
    - Height – material – barrier – use

# Mapping tables with vulnerability scores

| Barrier code | Barrier Vulnerability | Description |
|---|---|---|
| 1 | 4 | No barrier |
| 2 | 3 | Low/narrow earth embankment |
| 3 | 2 | Low concrete wall |
| 4 | 1 | High concrete wall |
| 5 | 2 | Low stone wall |
| 6 | 1 | High stone wall |

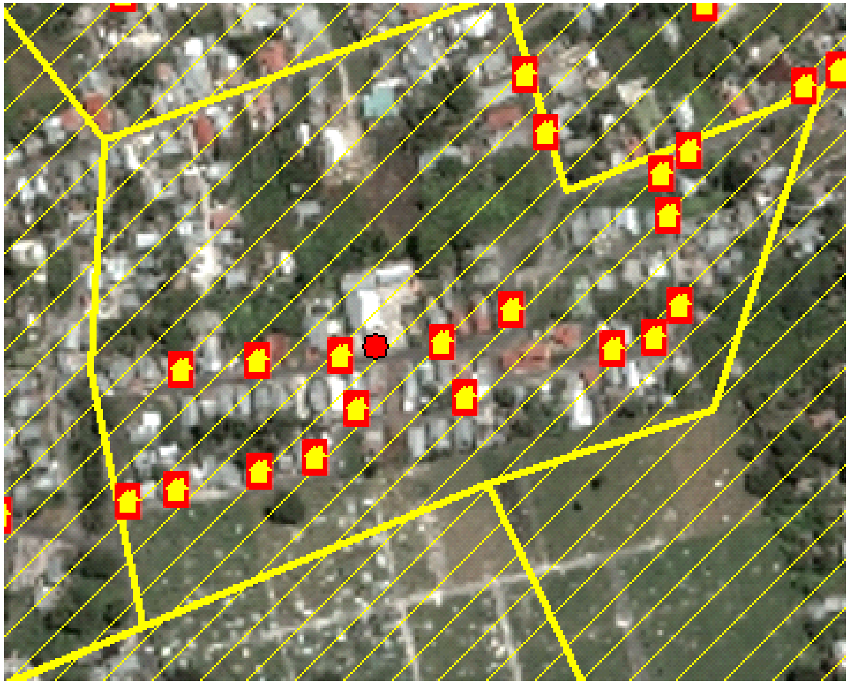
| Height code | Height Vulnerability | Description |
|---|---|---|
| 1 | 4 | Only one floor |
| 2 | 2 | 2 floors |
| 3 | 1 | 3 or more floors |

| Material code | Material Vulnerability | Description |
|---|---|---|
| 1 | 2 | Stone |
| 2 | 4 | Wood or timber |
| 3 | 3 | Wood + concrete |
| 4 | 1 | Concrete |
| 5 | 2 | Metal |
| 6 | 3 | stone and wood |
| 7 | 2 | concrete/metal |
| 8 | 3 | concrete/stone/glass |

| Use code | Use Vulnerability | Description |
|---|---|---|
| 1 | 1 | Residential/community service |
| 2 | 3 | Business/Commercial |
| 3 | 4 | Tourism |
| 4 | 10 | Government Services (Health, Education, Fisheries, transportation etc) |
| 5 | 10 | Emergency Services (Police, Fire, Coast Guard, EMS, medical etc) |
| 6 | 5 | Community facilities (e.g. churches, community centers, recreational areas) |
| 7 | 10 | Utilities (water, electricity, sewage, telecommunications, fuel, gas stations) |
| 8 | 2 | Heritage Sites |
| 9 | 5 | Banking and finance |
| 10 | 0 | Abandoned |

# Extrapolation of vulnerability

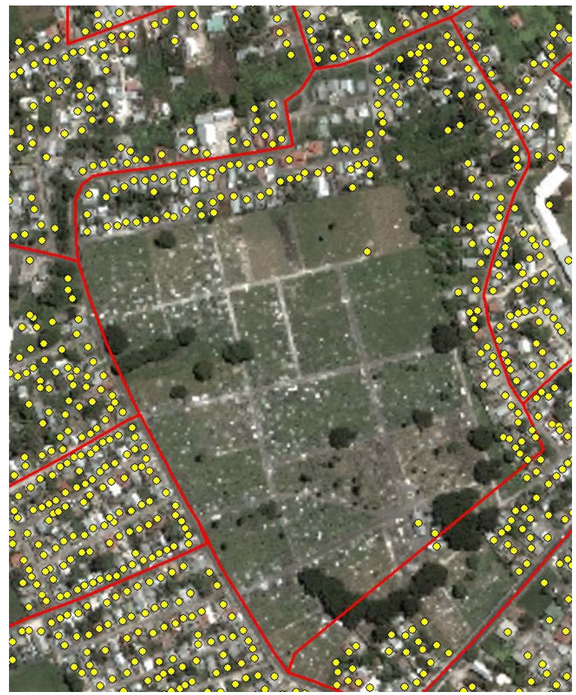
- Field survey covered only 10% of the buildings
- Manual digitalization using satellite image
- ”Homogeneous” regions
- Each region must contain surveyed buildings
- Average residence building vulnerability scores for each 3 factors within each region
- Specific information about each surveyed building is retained



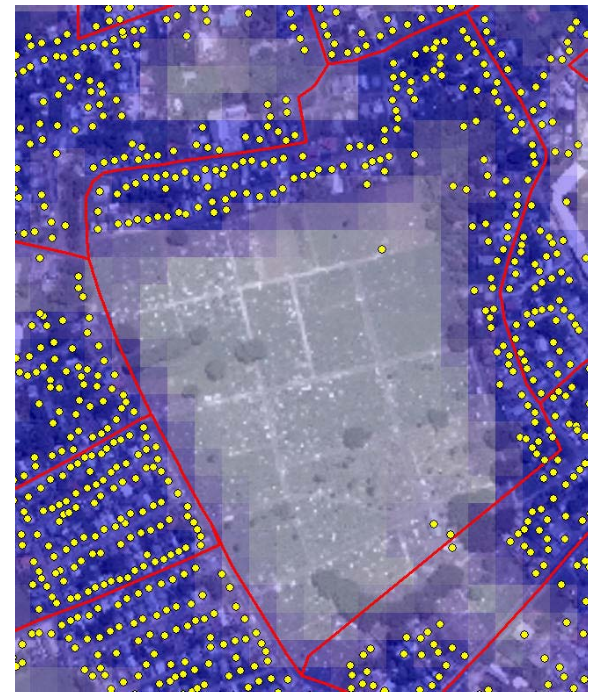
# Creation of POPULATION density raster dataset – avoid making areas with no people into populated zones

Skewed distribution of buildings

Building polygons into points

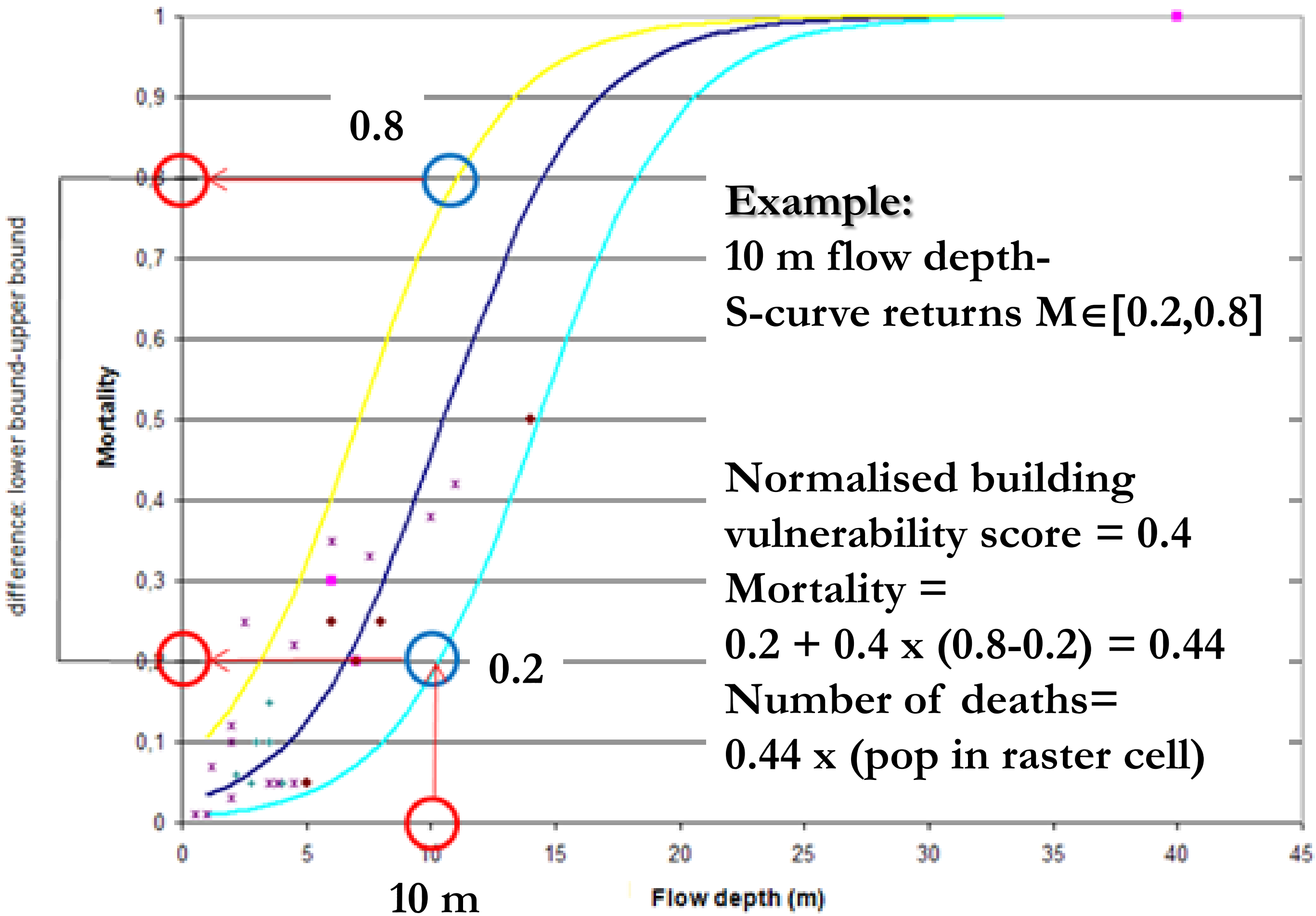


Average population per building ⇒ Population density map



# Total predicted mortality

- Convert all building vulnerability scores to [0,1]
- Use vulnerability score to pick the ”correct S-curve”.

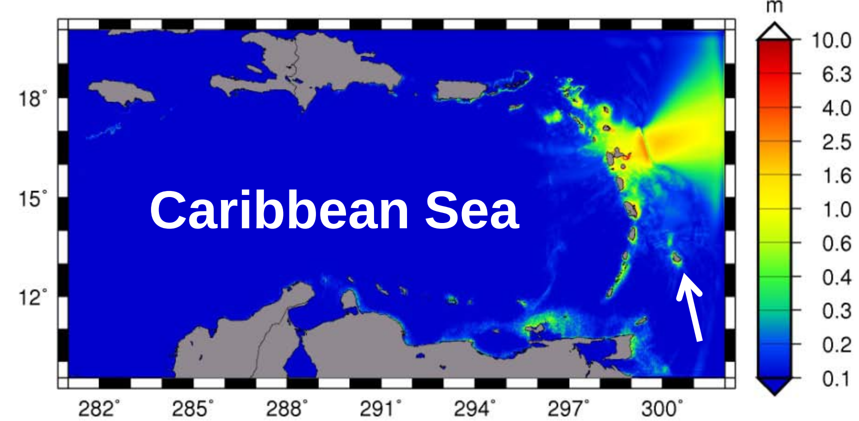


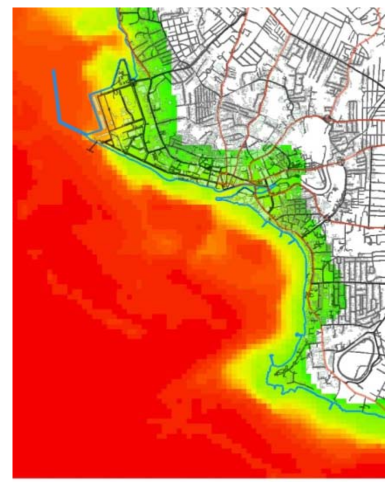

**Example:**
10 m flow depth-
S-curve returns M∈[0.2,0.8]

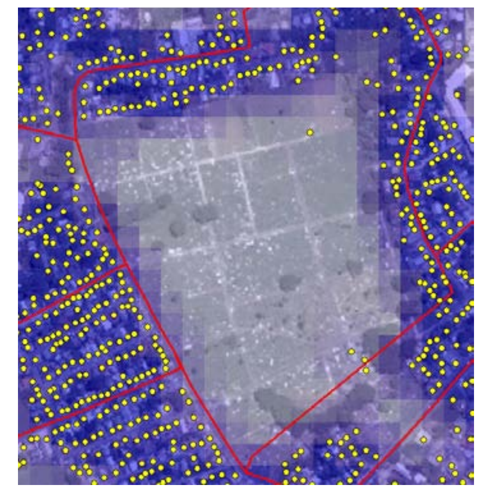
Normalised building vulnerability score = 0.4
Mortality =
0.2 + 0.4 x (0.8-0.2) = 0.44
Number of deaths=
0.44 x (pop in raster cell)

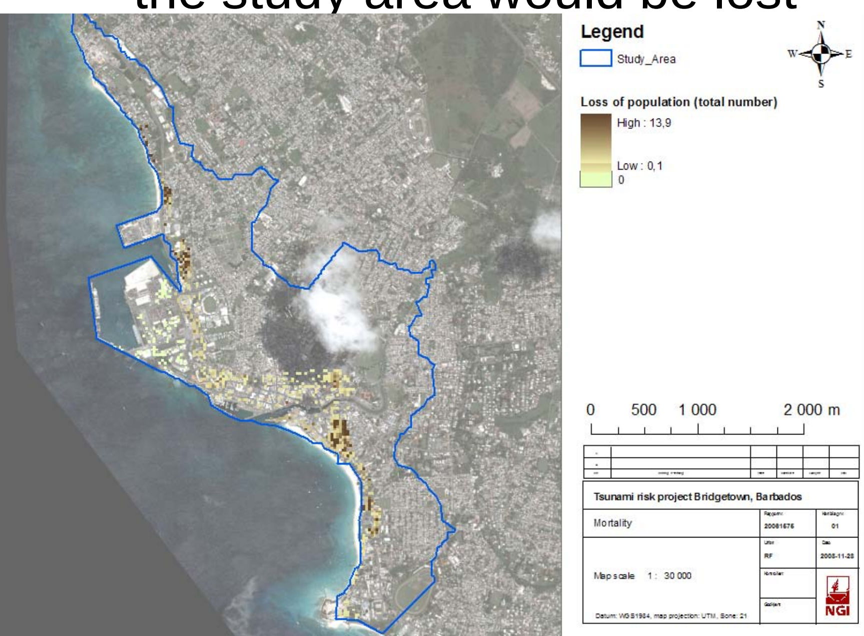
# Local mortality risk - Bridgetown, Barbados

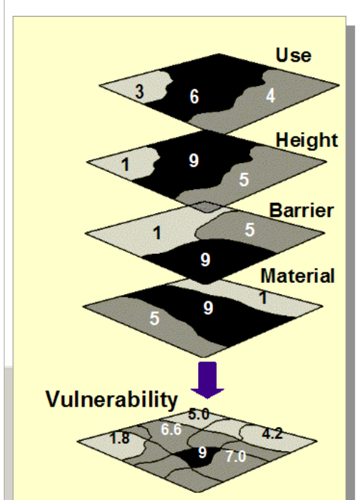
- Inundation
- Population density
- Building vulnerability
- Weighting
- Mortality function
- ⇒ Mortality risk map
  – ca. 130 out of about 30 000 residents (2000 census) in the study area would be lost

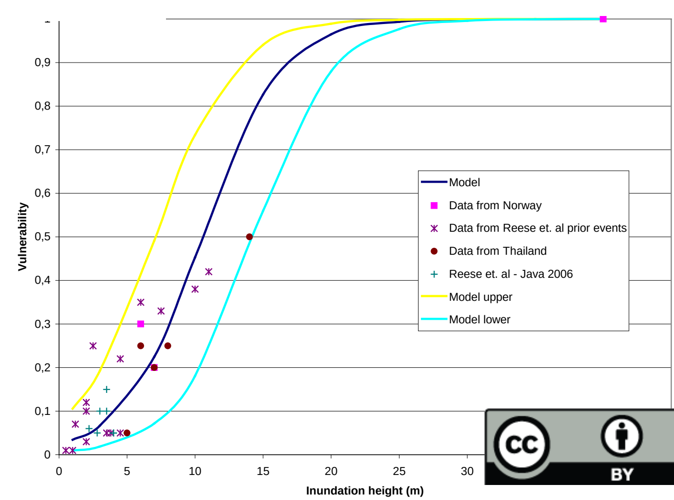






# Other considerations:

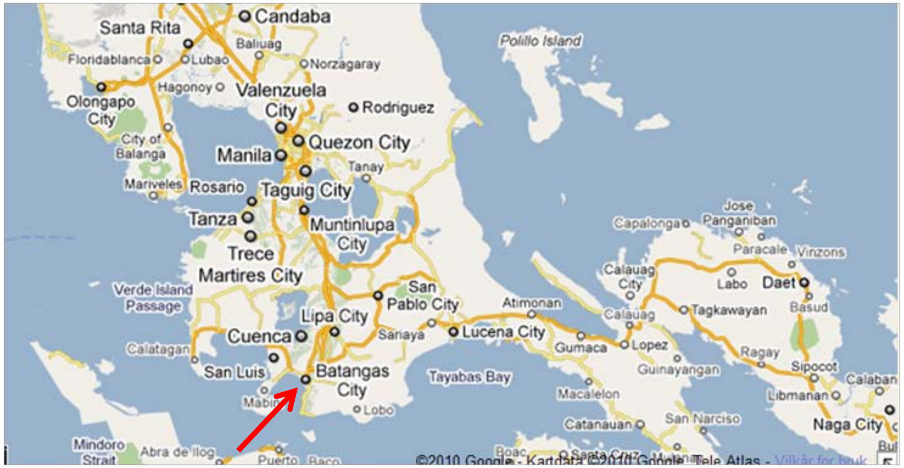
- **Vulnerability also depends on:**
  - Education, knowledge, awareness
  - TEWS
  - Other mitigation measures
    - evacuation plans and routes
    - safe elevated areas
    - barriers, …
  - Age of population
  - Differences in night and day use of buildings, etc.
  - ….

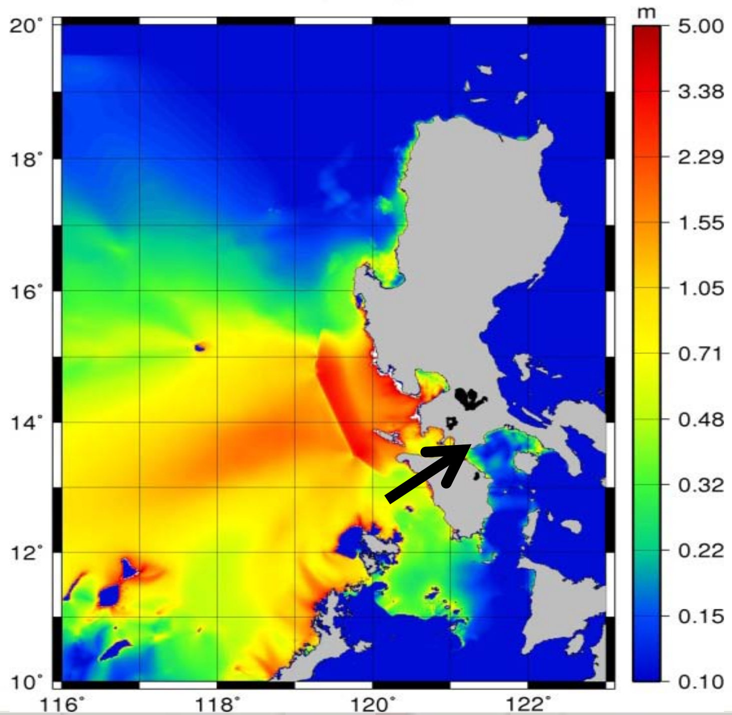
- **Other risks than mortality are not considered**
  - Economic loss
  - Ecological
  - Reputation

- **Perceived risk**
- ….

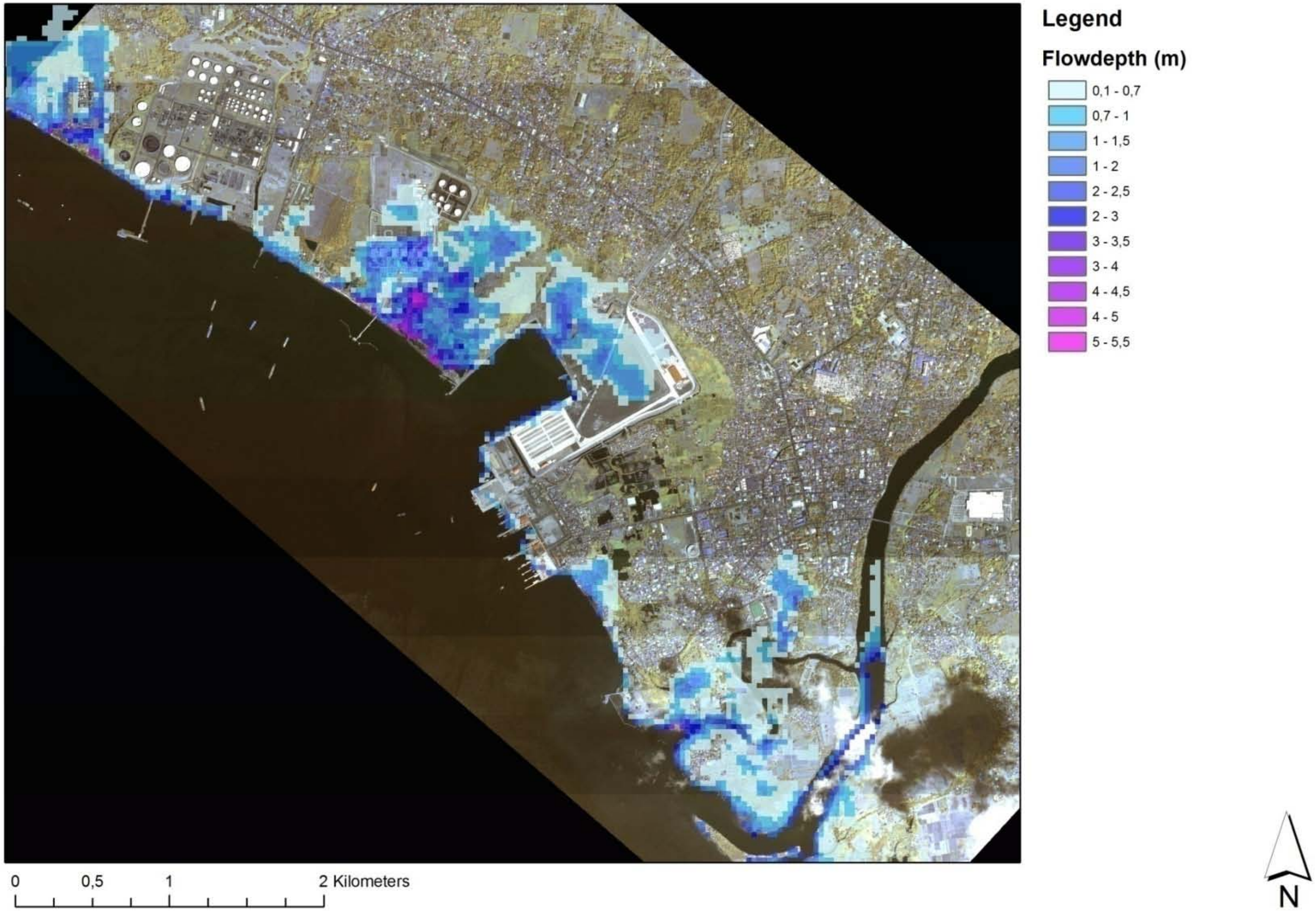
# Batangas City, The Philippines – Local tsunami risk assessment

- Local <u>demonstration</u> project
- Mw 8.2 Southern Manila Trench scenario
  - Lower bound return period 120 years
- + 1 m tide and sea level rise
- Limited amount of data from local partners
- So everything was found on the internet or studied from "the sky", i.e. from google maps and the purchased *quick bird* image



# Hazard (flow depth)

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# Structural building vulnerability

- Total structural building vulnerability was assessed using publicly available photographic imagery available on GoogleEarth

| ID | Assigned Vulnerability | Description |
|---|---|---|
| 1 | 0,25 | concrete-stone, several floors |
| 2 | 0,5 | concrete-stone-wood, one or two floors |
| 3 | 0,75 | stone-wood, one or two floors |
| 4 | 1 | wood-corrugated iron, one floor |
| 5 | 0,25 | Large industrial plants |

Credit: GoogleEarth, users: batangas, Romeo E. Barcena, samuel006, Teban

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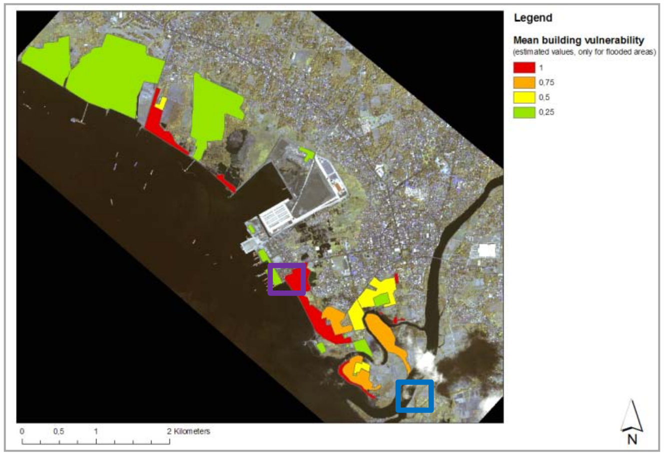
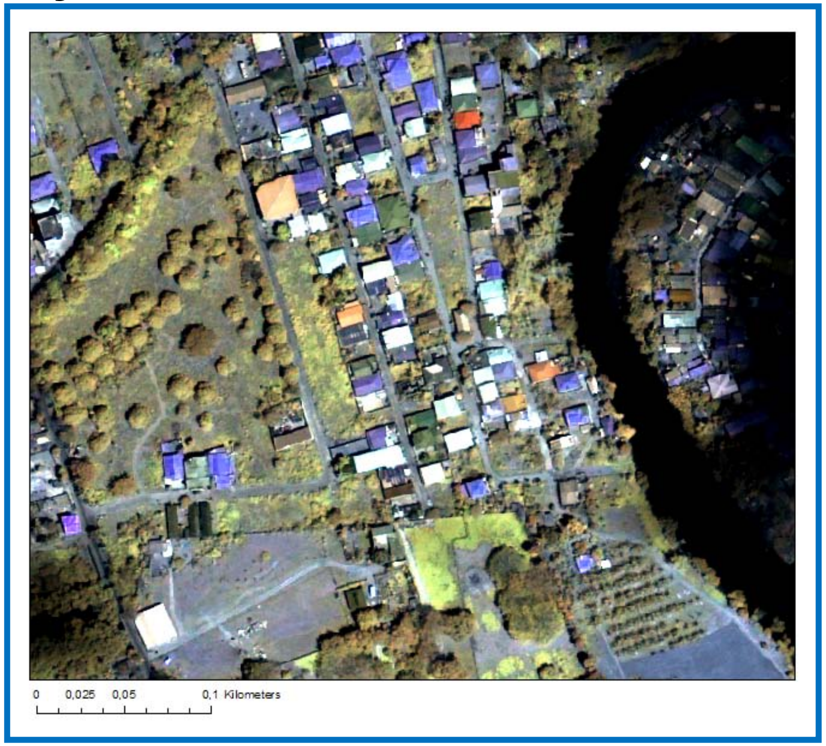
# Structural building vulnerability

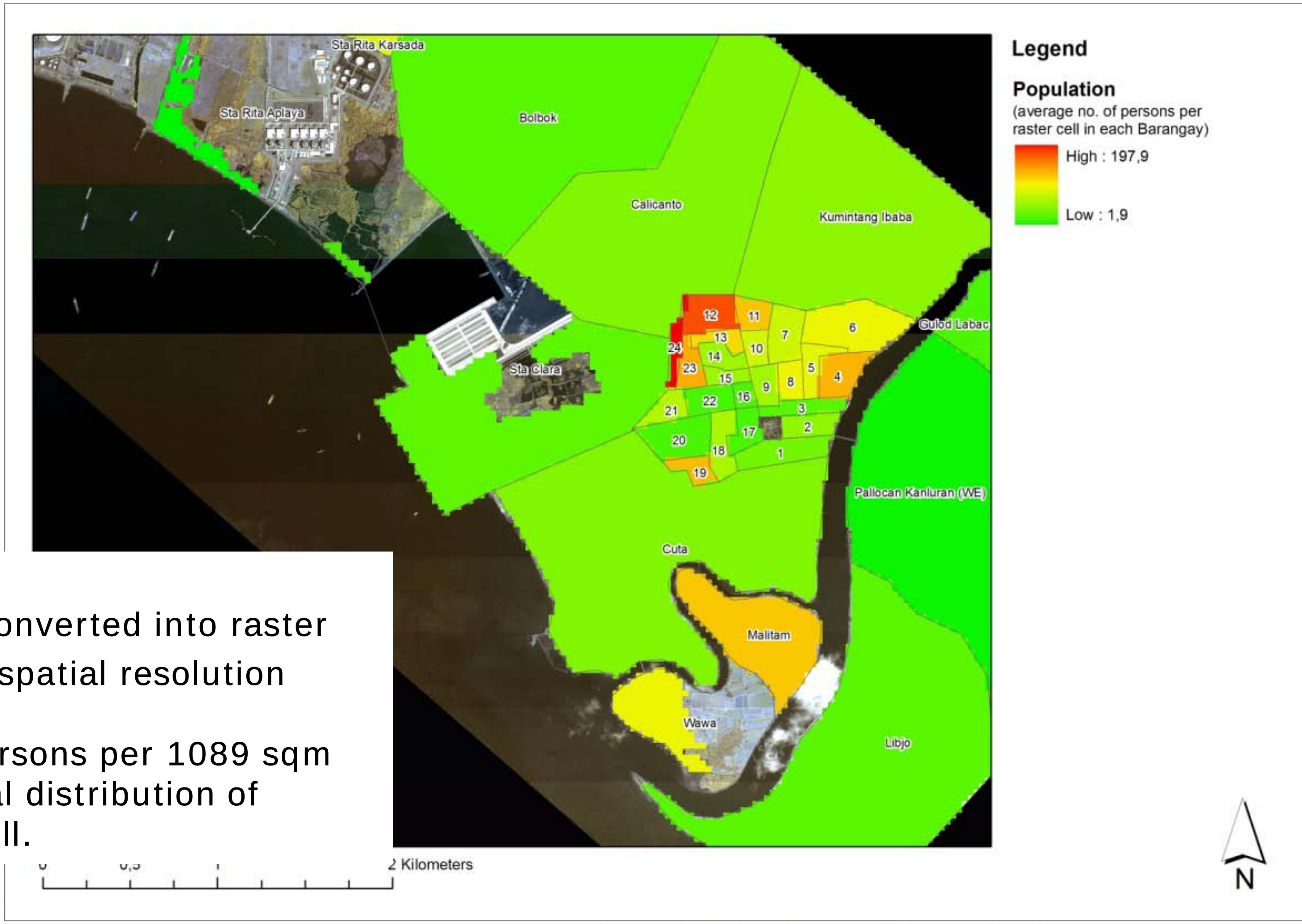




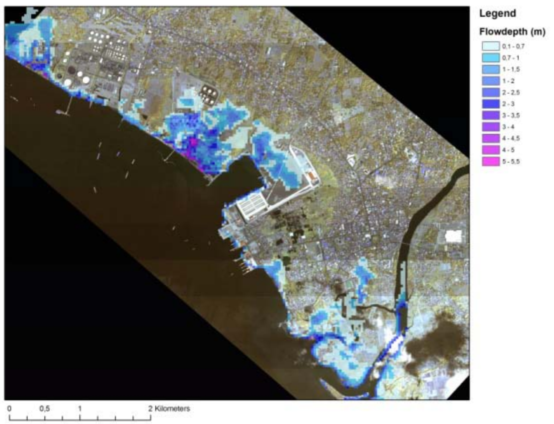
Quickbird images were used to classify buildings into vulnerability classes

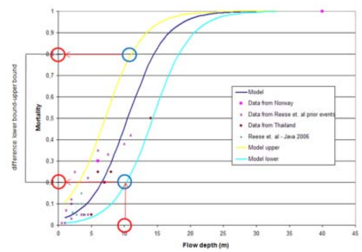
# Exposure: Population density from enumeration district population data (census year 2007)

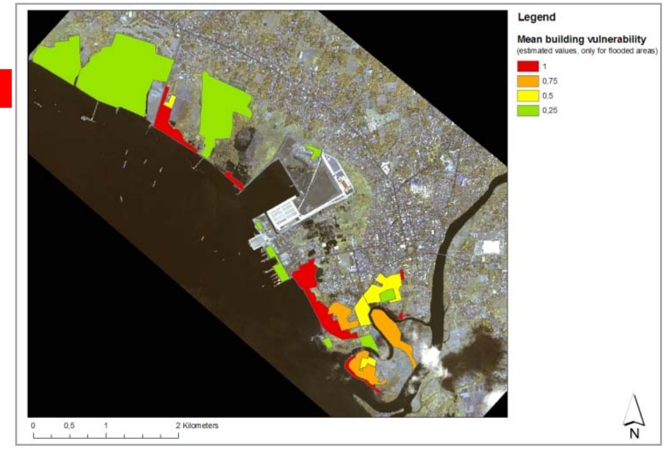


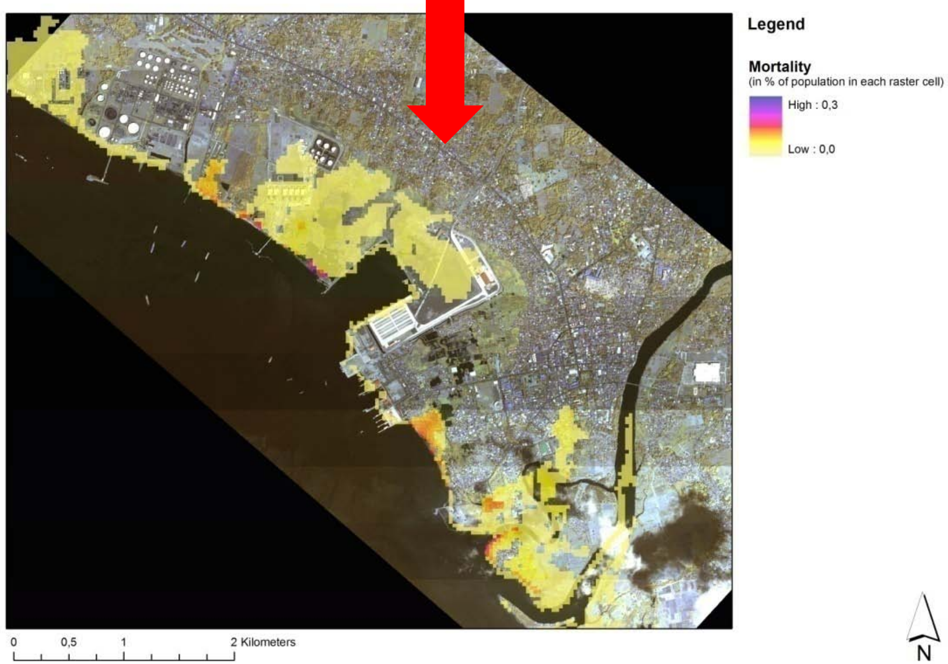

- Vector information converted into raster information, with 33 m spatial resolution (can be altered)
- Average number of persons per 1089 sqm
- NB: Assumption: Equal distribution of people in each raster cell.

# Bringing it all together: mortality risk map

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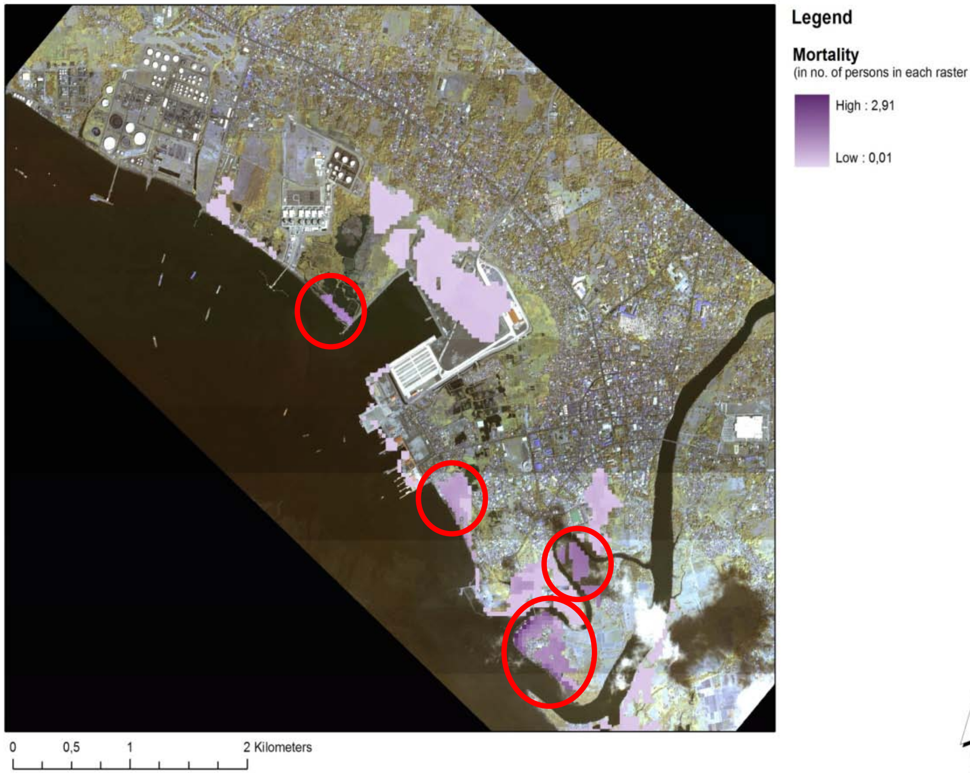
# Final product: Mortality risk map

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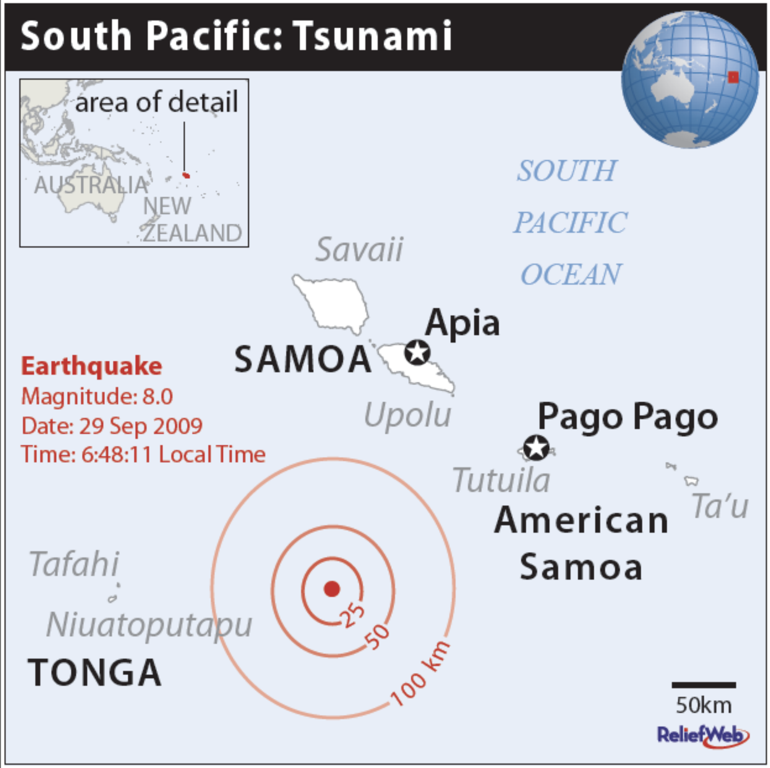
Results for southern Mw8.2 Manila Trench scenario:

- 500-600 lives might be lost due to the tsunami
- Most affected areas revealed
- The high number of fatalities in all these areas results from a combination of
  - dense population
  - high building vulnerability
  - medium high flow depth

# 2009 South Pacific tsunami in American Samoa

- On September 29th 2009 at 6:48 AM local time, a series of earthquakes generated near the Tonga trench (15.509°S, 172.034°W) triggered a tsunami that reached the shores of Tonga, the Independent State of Samoa, and American Samoa.
- Devastation was widespread, resulting in 9 fatalities in Tonga, 149 in the independent State of Samoa and 34 in this study's region of focus, American Samoa, which was selected mainly because of better data availability.
- Pago Pago, the capital on the main island of Tutuila, was especially affected by the tsunami because of its natural deep water harbor.
- Leone, located on the southwest coast of the island, was hit directly by waves propagating northeast from the earthquake's epicenter.




**29 Sep 2009** - Sixty eight confirmed dead with numbers expecting to rise after a series of tsunamis triggered by an earthquake hit Samoa, American Samoa and northern Tonga. A state of emergency was declared in Niuatoputapu, a state of disaster declared in Samoa and a major disaster declared in American Samoa.

Map Sources: Europa Technologies, Gov't. of USA, UNCS, USGS.
Reference: OCHA. *Samoan Tsunami Situation Report #2*. 30 Sep 2009.
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Map created on 30 Sep 2009 – *www.reliefweb.int*

# Hindcast of 2009 South Pacific tsunami for American Samoa

- Normally a certain future tsunami scenario with a corresponding return period is applied for vulnerability and risk assessment
- However, in this study the maximum flow depth was obtained by back calculating the 2009 South Pacific earthquake and tsunami, *aiming at validating the GIS model approach for building vulnerability and mortality only*
- Following the disaster, teams from several nations evaluated damages and inundation levels
- We gathered information on population, building types, infrastructure, inundation, flow depth, damages, and death tolls
- The GIS model was adapted for optimal use of the available data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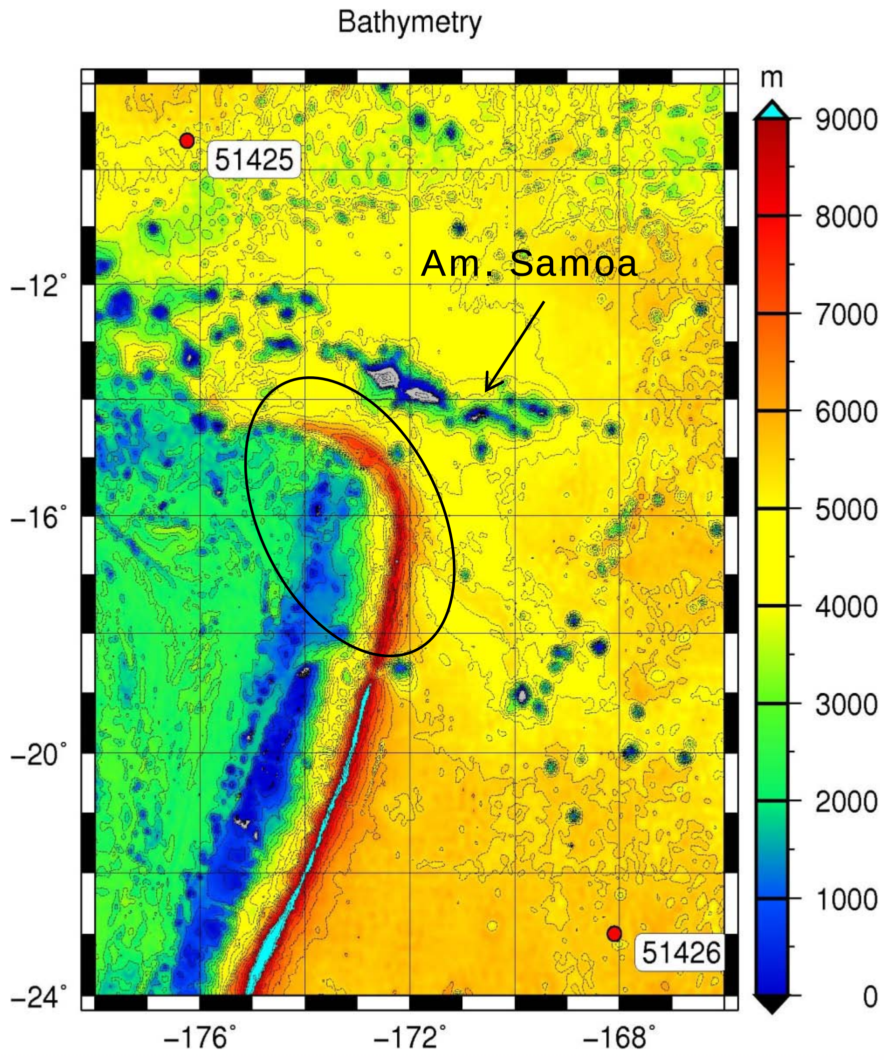
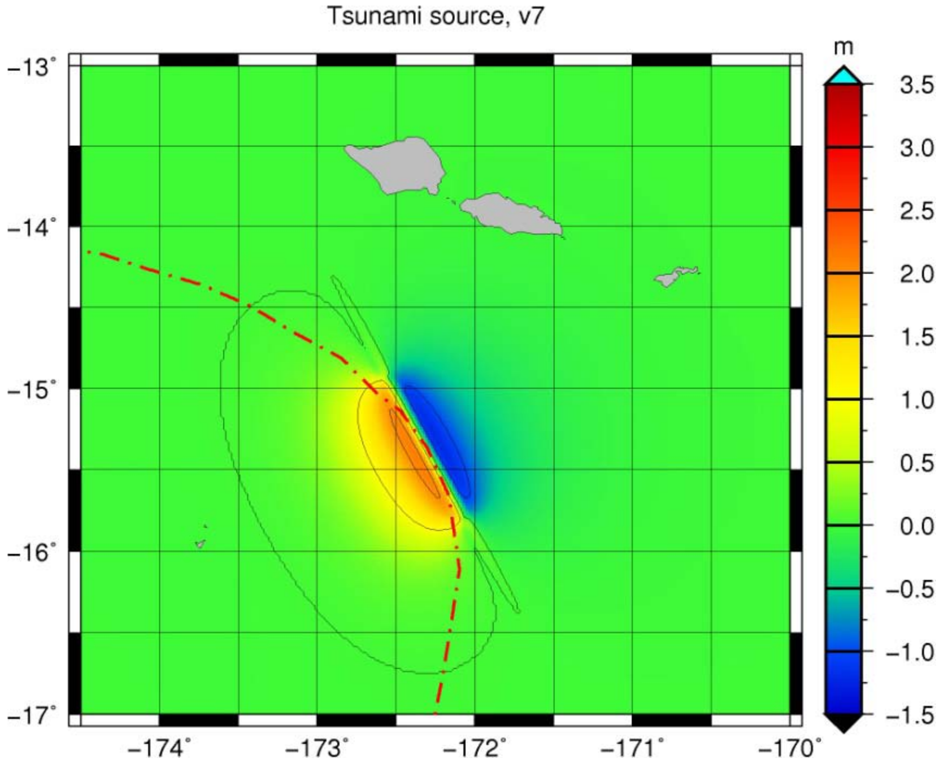
# Tsunami simulations



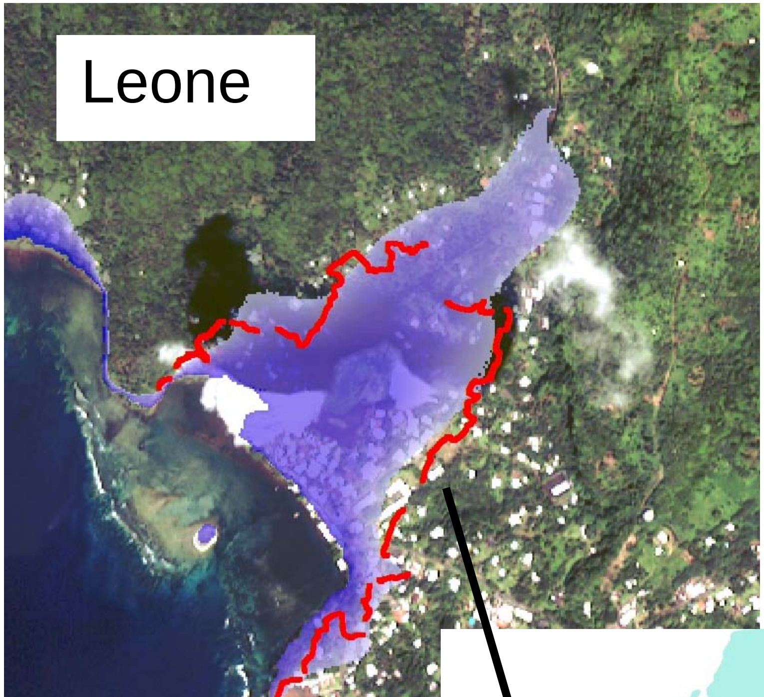

- Earthquake located south-west of Am.Samoa
- Sea depth 5000-9000m
- Surface elevations observed at DART gauges (51425 and 51426) and a GCOS station outside Pago Pago
- Depth data: GEBCO 1’
- Nearshore: NOAA DEM

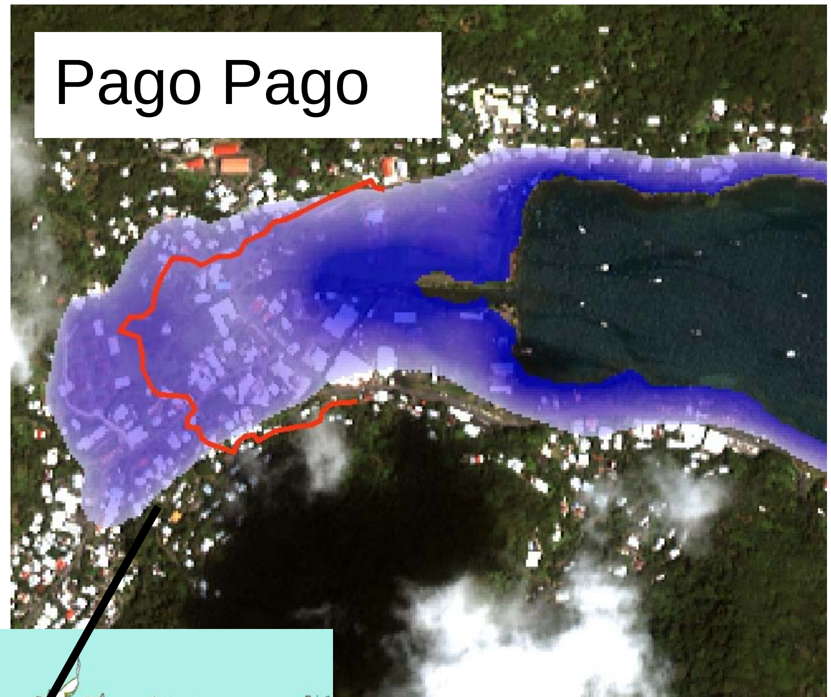
# Sources

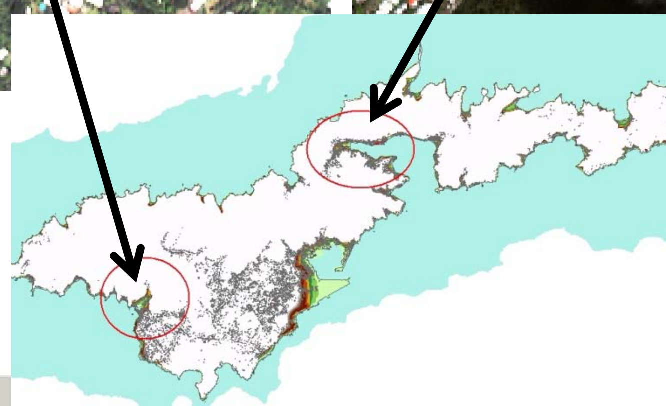
- Location and earthquake parameters tuned to match both observed inundation and mariograms from gauges (totally 7 different sources)
- Example shown for version 7 (“v7” with Mw8.1)



# Comparison to trimlines ("v7")

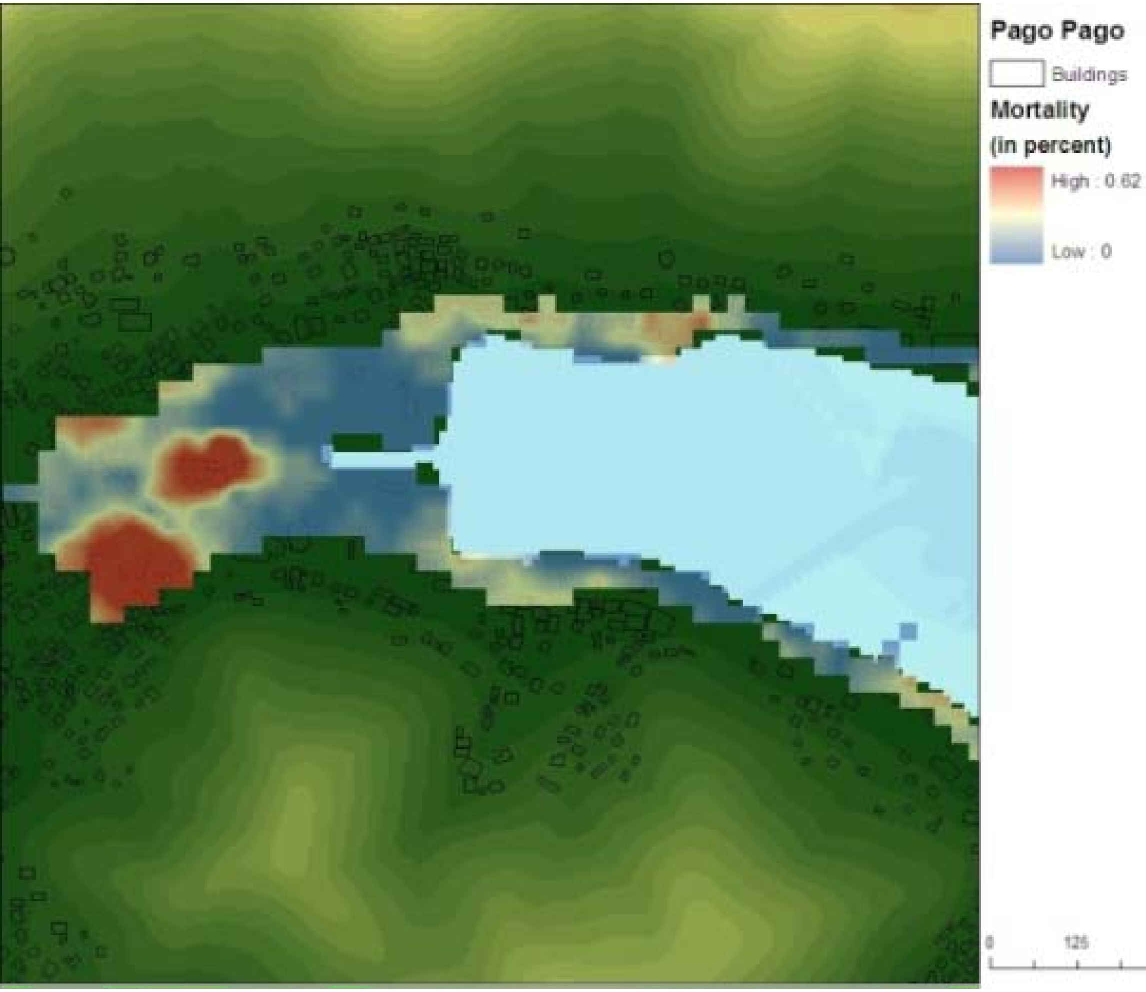


Buildings and infrastructure not included in the simulations (may reduce the run-up)

# GIS model validation




- Maximum flow depth was obtained by back modeling the 2009 Samoa event, aiming at validating the GIS model for building vulnerability and mortality only
- Journal papers, reports, newspaper articles, internet, personal communication with local agencies, photos, aerial views, and satellite images applied to deduce population density,
- and building vulnerability
- Our model predicted 48 and 37 deaths in Pago Pago and Leone, respectively (total 85)
- There were 34 recorded deaths
- Death tolls somewhat overestimated – as could at best be expected

# Why are death tolls overestimated?

- Early morning- **People were awake, but still at home**, noticed initial drawdown
- Minimal infrastructure damage- **accessible roads** → access to high ground
- **Education-** September in American Samoa is emergency awareness month- people were informed of the correct procedures for the situation
- Strong multi-story buildings allowed for **vertical evacuation**
- **Coastal protection structures** performed relatively well
- Many people risked their own safety to **assist others**
- **Shelter** for evacuees
  - The close familial ties of villagers meant that everyone had an alternative place to stay and no one was left alone
- Rapid **cleanup**

# Concluding remarks

- Method for quantitative tsunami risk assessment developed
- Flexibility with regard to amount and type of data at hand
- Two assessments + 1 validation successfully performed
- Local partners of high importance for collection of field data and later use of the results
- Potential for further development (distribution of people night/day, indoors/streets/public areas, importance of TEWS…)
- Very much can be done already!!

# Acknowledgements

- Information from:
  - H. Fritz, B. Jaffe, Shona v Z de Jong, S. Koshimura, J. Melby,
  - USGS
  - EERI report
  - American Samoa Department of Homeland Security
  - Much more downloaded from internet

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  - Vassar College


**Thank you!**