GIS methodology for local tsunami risk assessment

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RAPSODI project / CONCERT-Japan Resilience Against Disasters

Meeting @ PARI, November 2014

Background

Three tsunami vulnerability and risk analyses performed. GIS model being adapted to the available information

1. **Bridgetown, Barbados**: possible future tsunami scenario, *much information available*
   - Topography, population from local partners
   - Field survey for building use and vulnerability
2. **Batangas, The Philippines**: possible future scenario, *little information available*
   - Internet and other sources of information
3. **American Samoa**: *hindcast* of 2009 South Pacific tsunami *for validation* of the tsunami vulnerability and risk model

Attribute tables with vulnerability scores

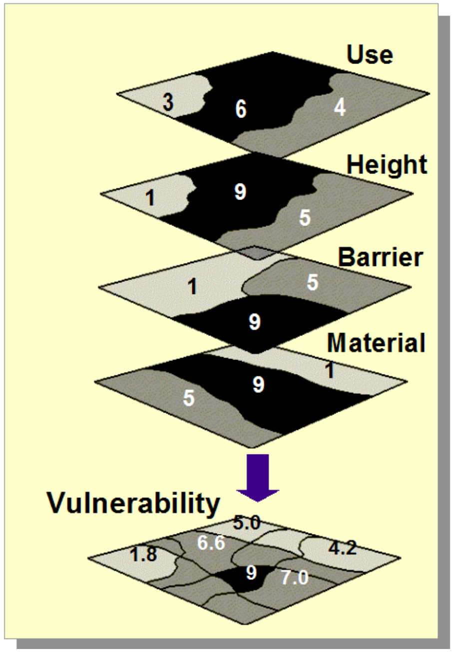
Height code	**Height Vulnerability**	Description
1	4	Only one floor
2	2	2 floors
3	1	3 or more floors

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

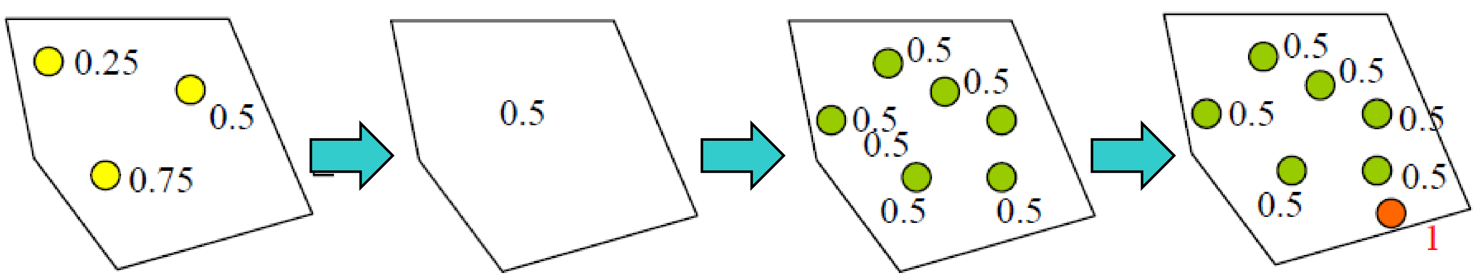
Barrier code	**Barrier Vulnerability**	Description
1	4	No barrier
2	3	Low/narrow earth embankment
3	2	Low concrete wall
4	1	High concrete wall
5	2	Low stone wall
6	1	High stone wall

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 building vulnerability



- Field survey covered only 10% of the buildings
- Manual digitalization using satellite image (QB VHR)
- Identification of ”homogeneous” regions
- Each region must contain surveyed buildings
- Computation of average residence building vulnerability scores for each of 3 vulnerability factors within each region
- Specific information about each surveyed building is kept



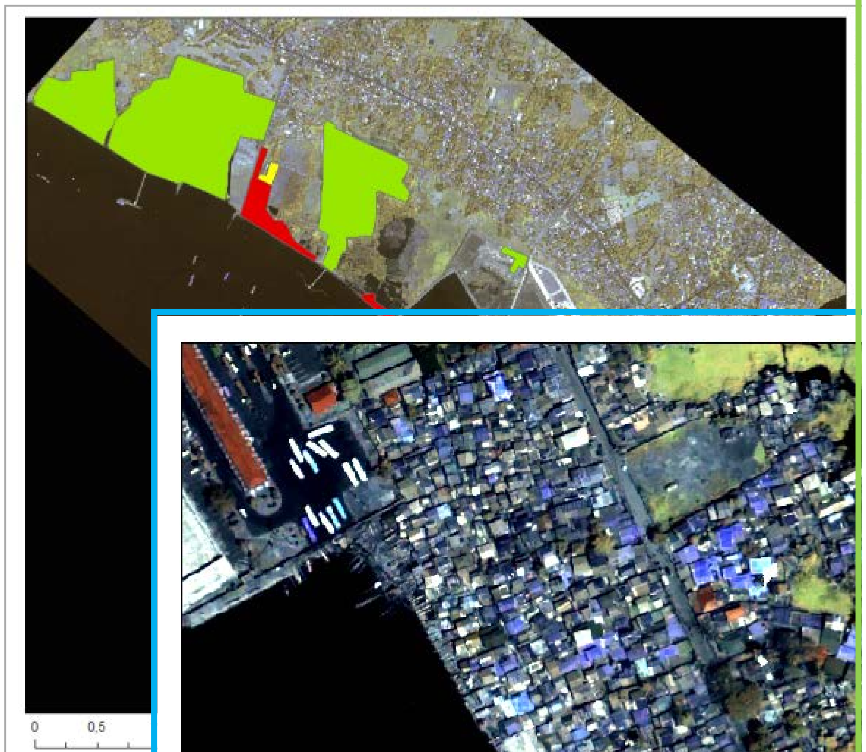
Structural building vulnerability - Batangas

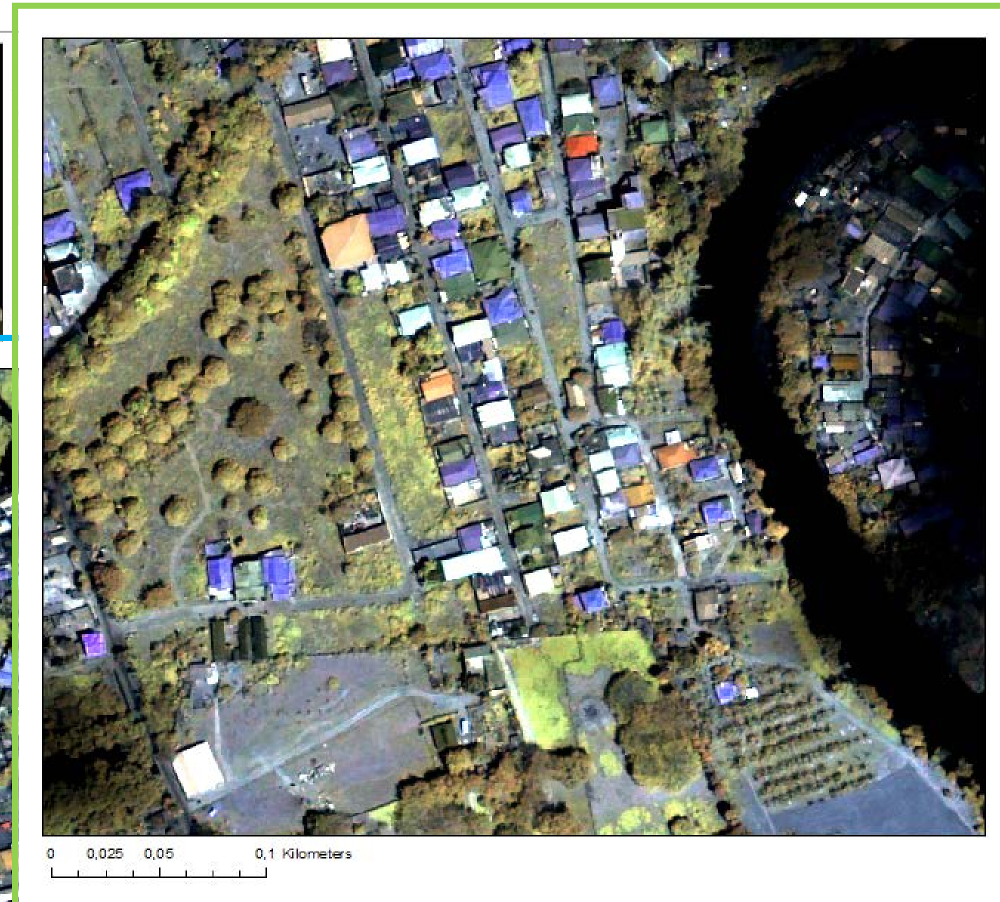
Total structural building vulnerability was assessed using publicly available photographic imagery available on GoogleEarth

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

Image credit: GoogleEarth, users: batangas, Romeo E. Barcena, samuel006, Teban

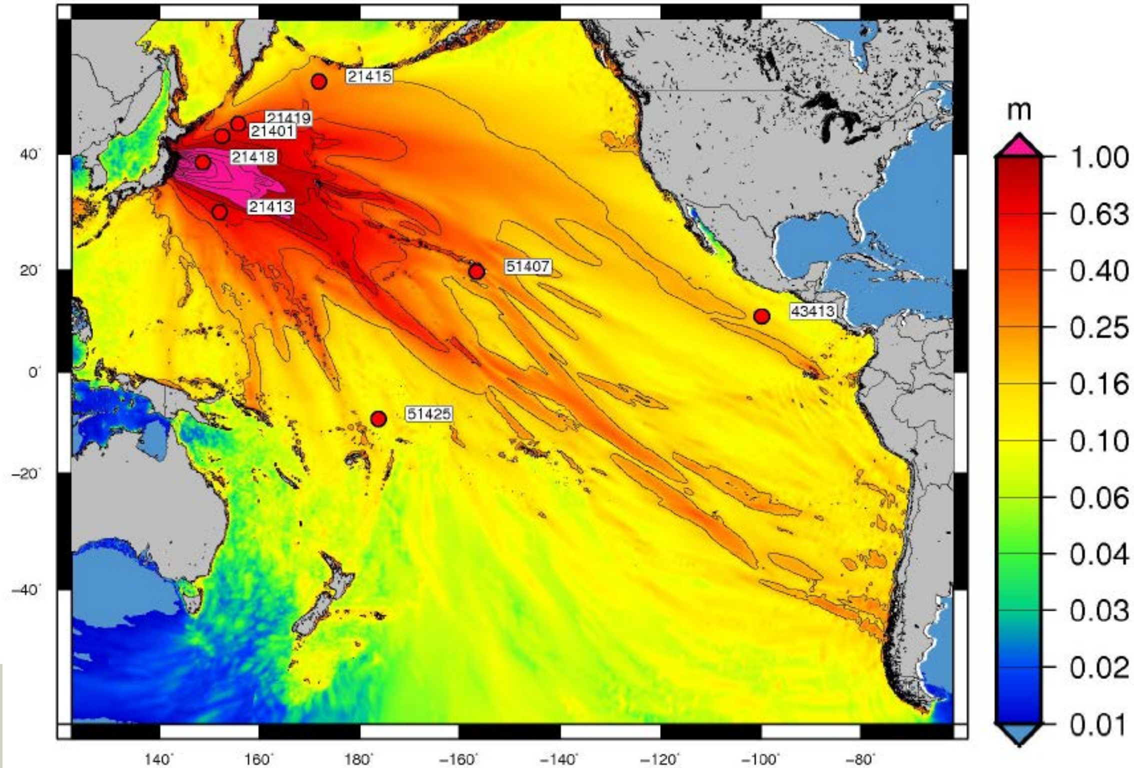
Structural building vulnerability - Batangas





Motivation within RAPSODI

Use GIS-methodology to *hindcast* 2011 Tohoku earthquake tsunami disaster *for validation* of the tsunami vulnerability and risk model.



Løvholt et al. 2012.
doi:10.5194/nhess-12-1017-2012

From risk modelling to enhanced resilience

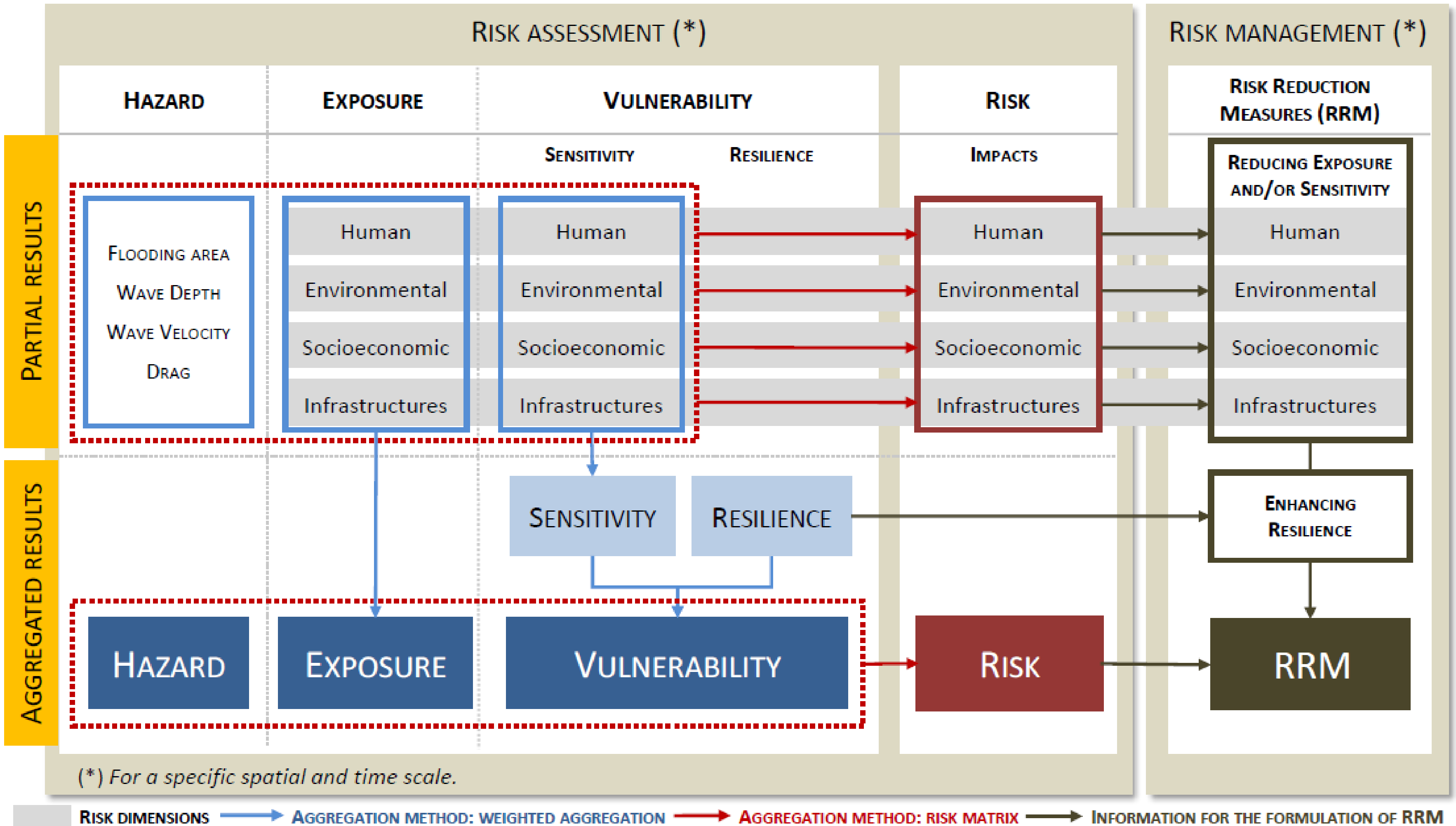


Figure 1. Structure of the risk assessment and different kind of results to be obtained (RRM = risk reduction measures).

González-Riancho, P. et al. doi:10.5194/nhess-14-1223-2014

Used parameters

GENERAL

Risk = Hazard * Consequence

Hazard = maximum tsunami flow depth related to a certain probability of occurrence

Consequence described by *exposure* and *mortality*

SITE DEPENDENT

Exposure; density of population

Mortality; function of flow depth and building vulnerability

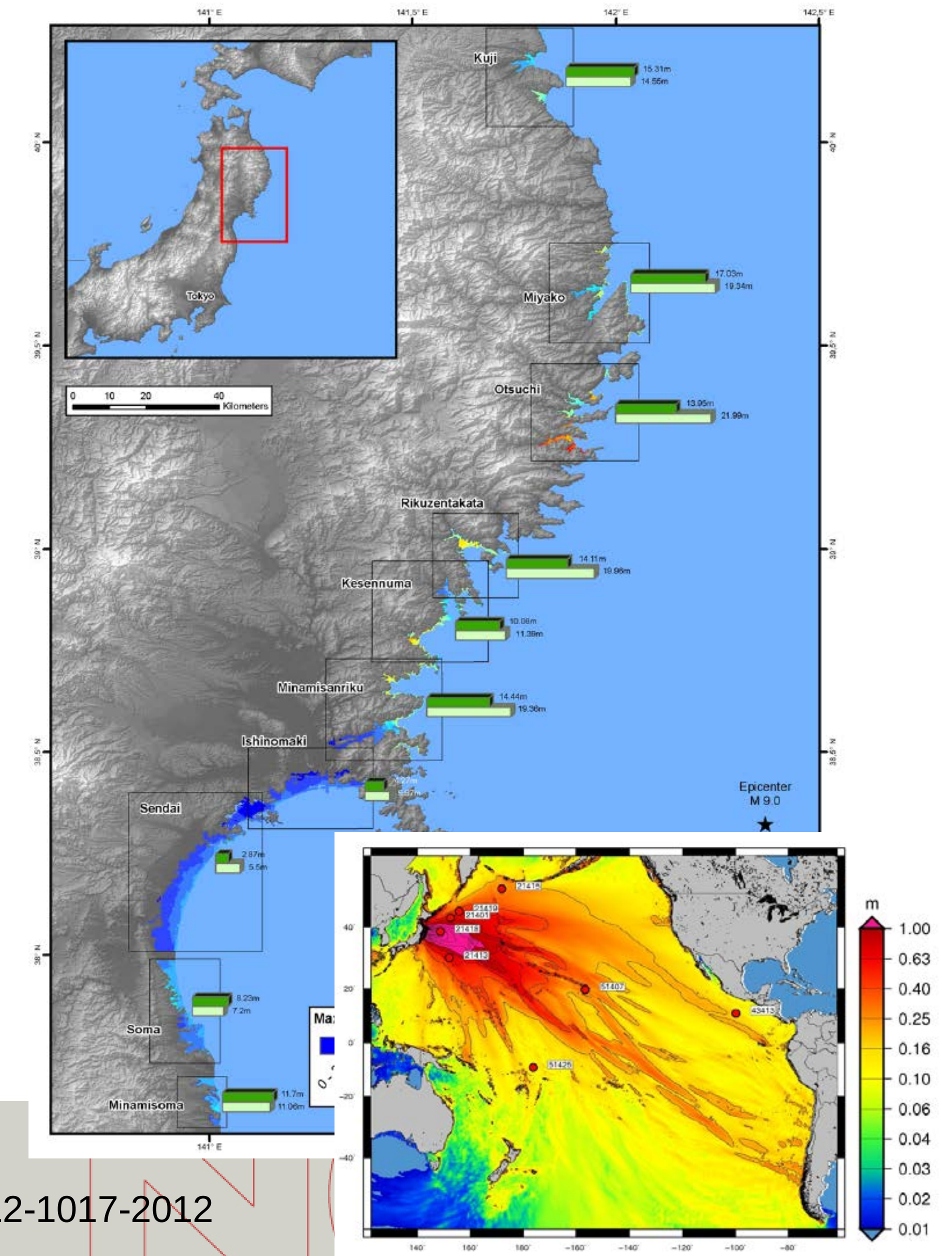
→ 4 factors describing the buildings:

height – material – barrier – use

2011 Tohoku event

Intentions:

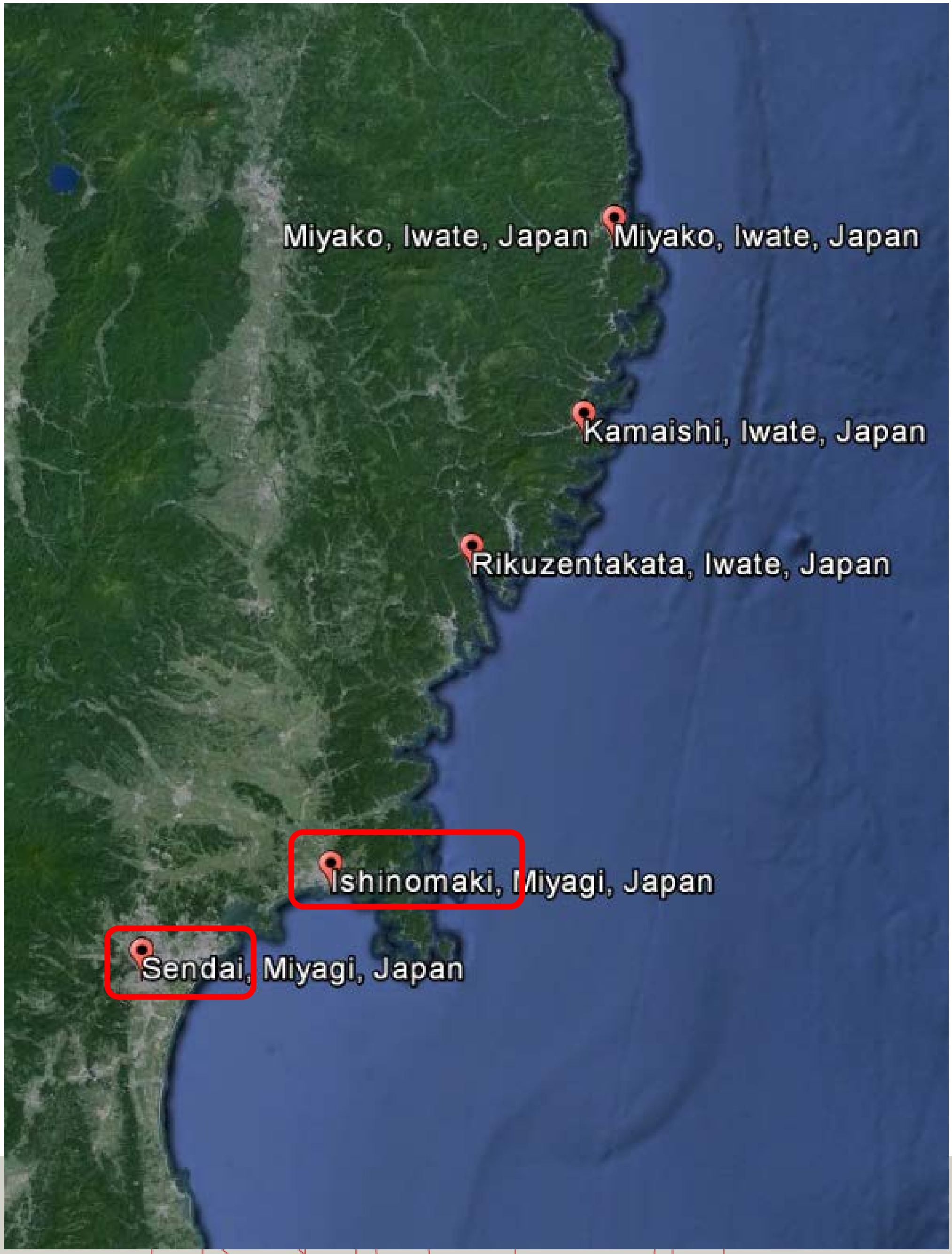
- Validating the GIS model approach for building vulnerability and mortality by hindcast event
- Maximum flow depth was obtained by back calculating the 2011 Tohoku earthquake and tsunami
- Potentially a lot of data available on population, building types, infrastructure, inundation, flow depth, damages, and death tolls



Løvholt et al. 2012.
doi:10.5194/nhess-12-1017-2012

Envisaged sites

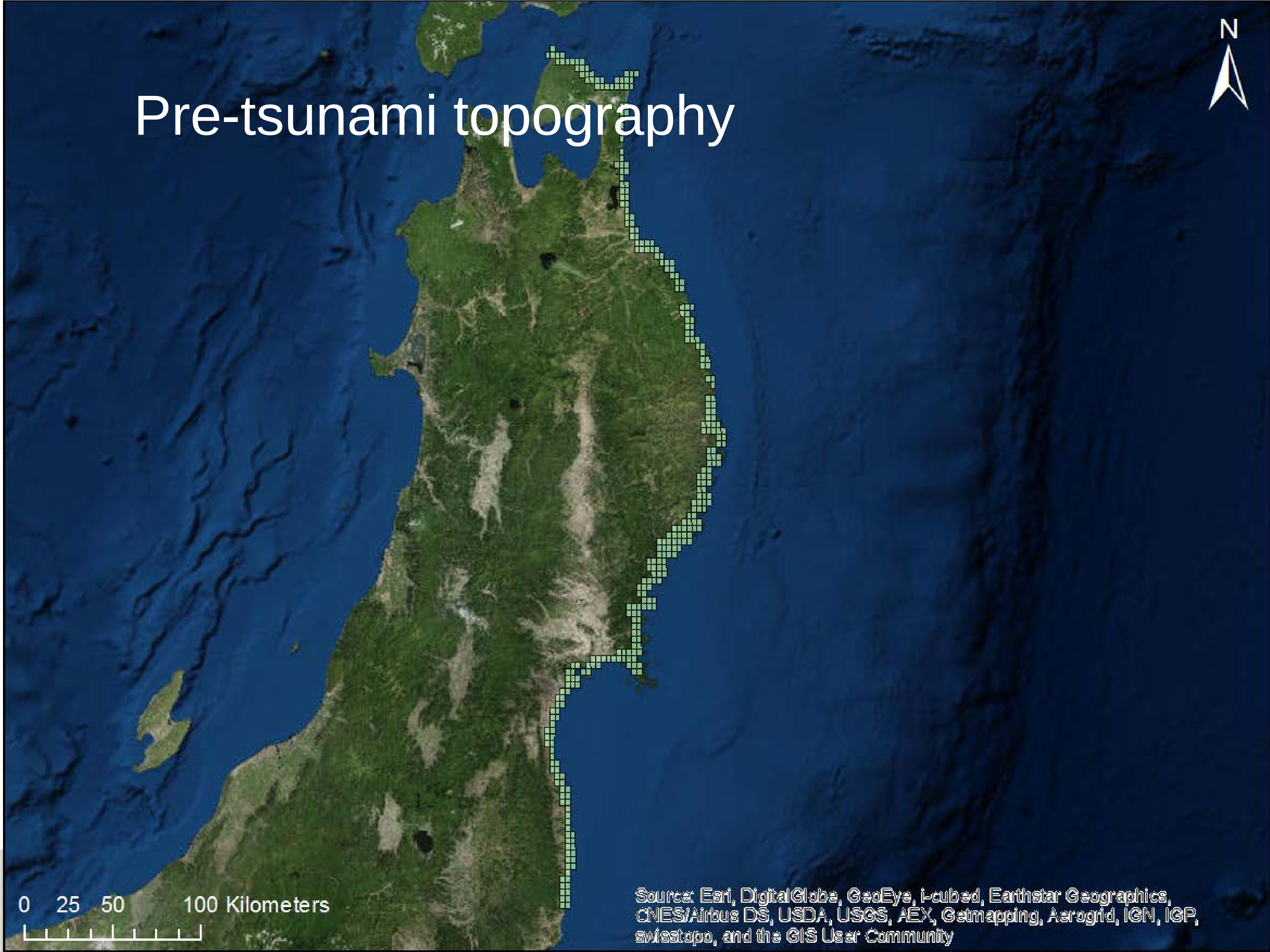
a) Sendai and Ishinomaki (flat, less topography)
b) Miyako Bay (seawall)
c) Rikuzentakata
d) Site with evacuation modelling data: Kamaishi bay



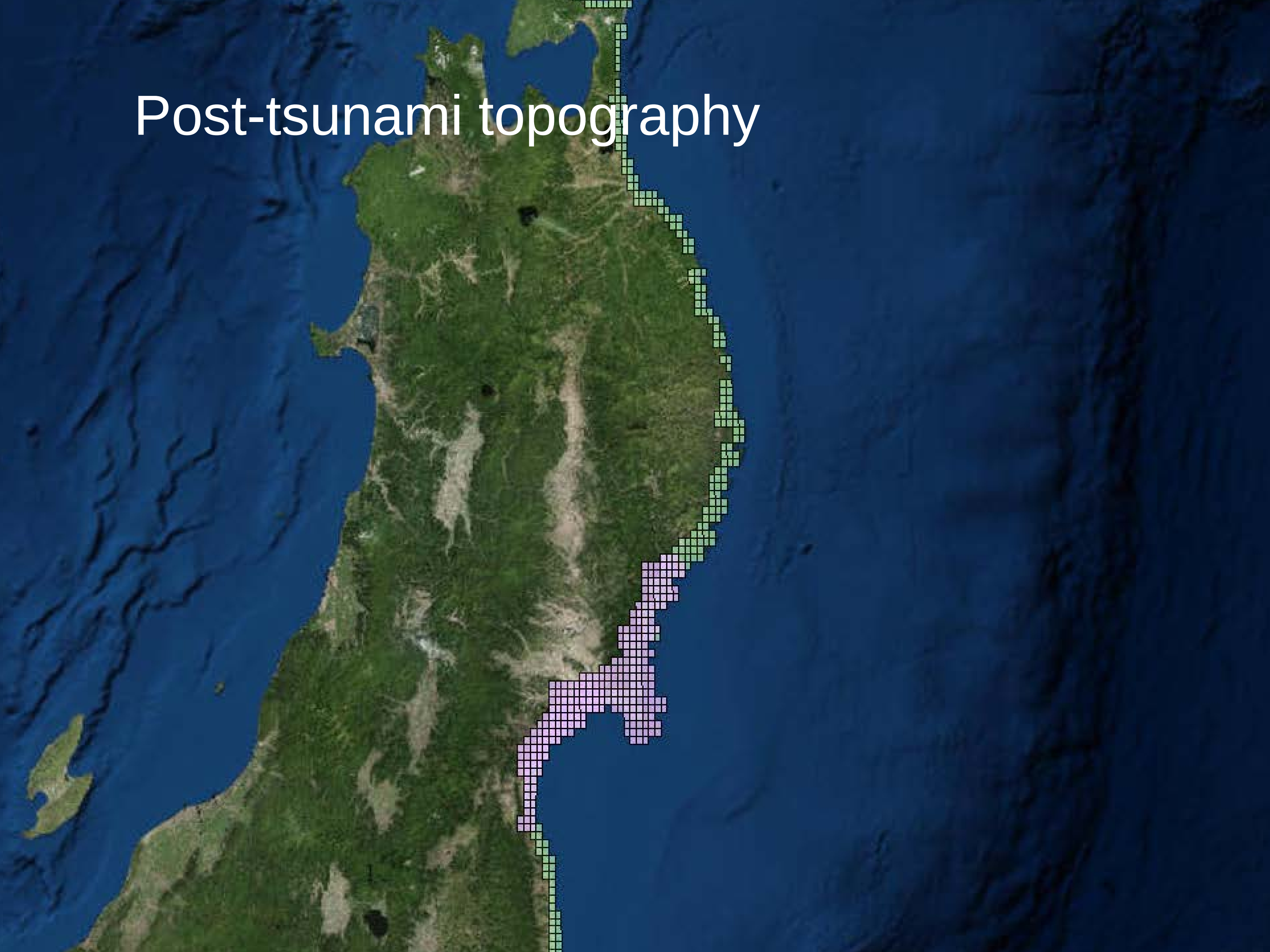
Data

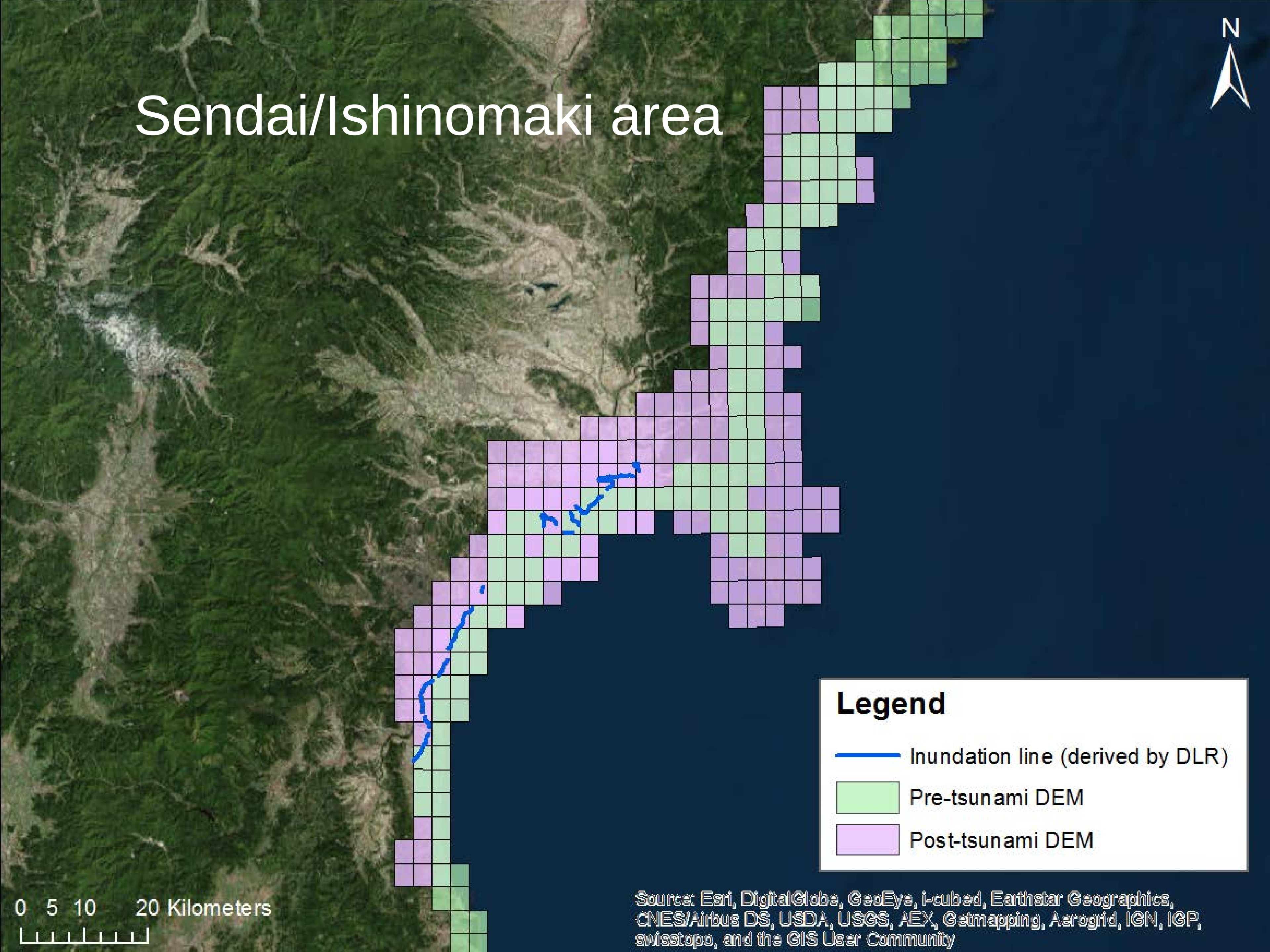
- Very high resolution digital elevation model – VHR DEM, pre-tsunami and post-tsunami data (received from Dr. Arikawa)
- Post-tsunami field data (water mark measurements, data on structural building vulnerability, etc.) available on http://fukkou.csis.u-tokyo.ac.jp/
- Census data aggregated by geographical units from the Portal Site of Official Statistics of Japan: http://www.e-stat.go.jp/SG1/estat/eStatTopPortal.do

Maruyama, Y., Tanaka, H., 2014. Evaluation of building damage and human casuality after the 2011 off the Pacific coast of Tohoku earthquake based on the population exposure. International Conference on Urban Disaster Reduction, Sept. 28.-Oct.1, 2014, Boulder, Colorado, US.

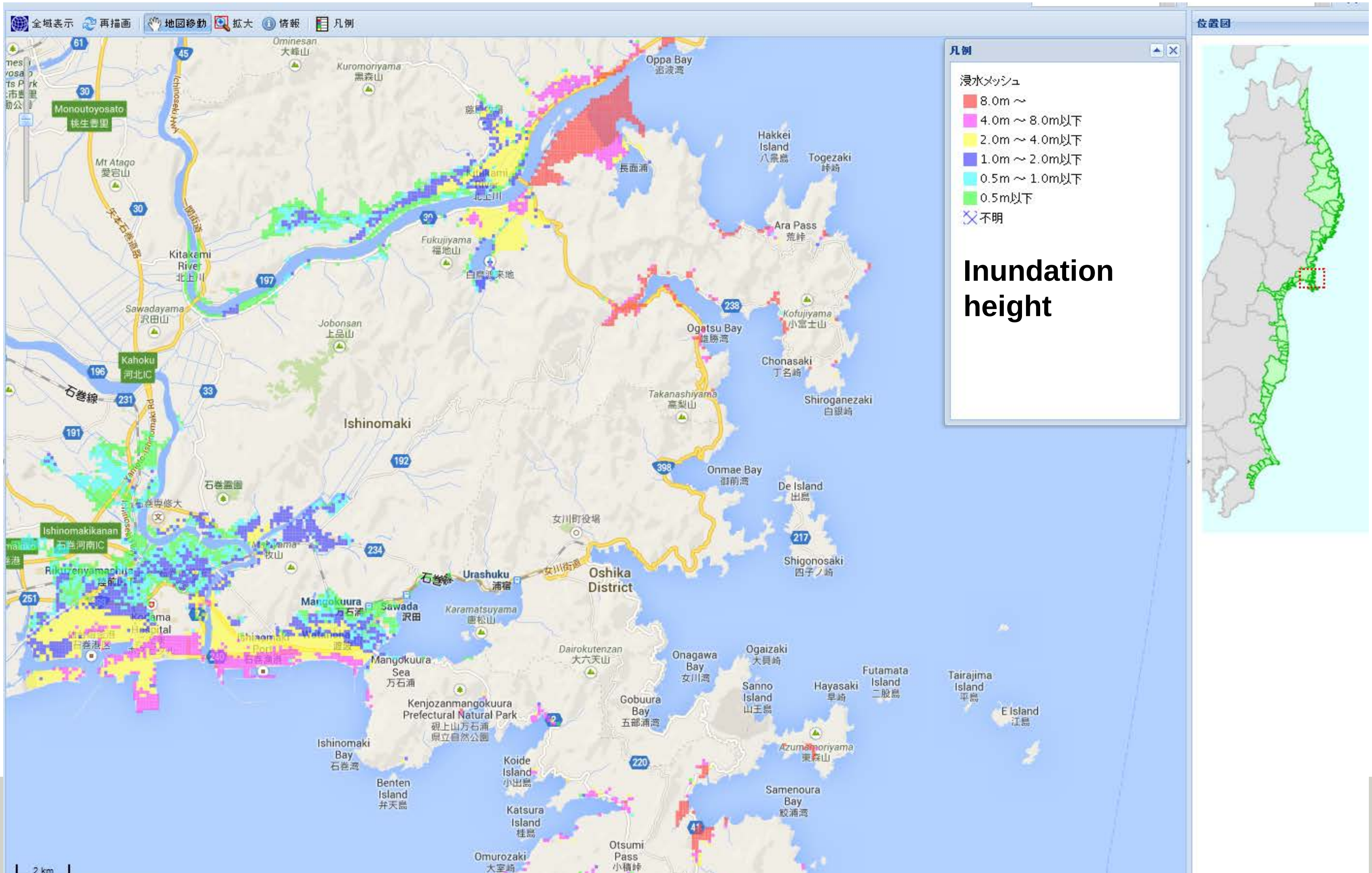

Pre-tsunami topography
N
0 25 50 100 Kilometers
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Post-tsunami topography



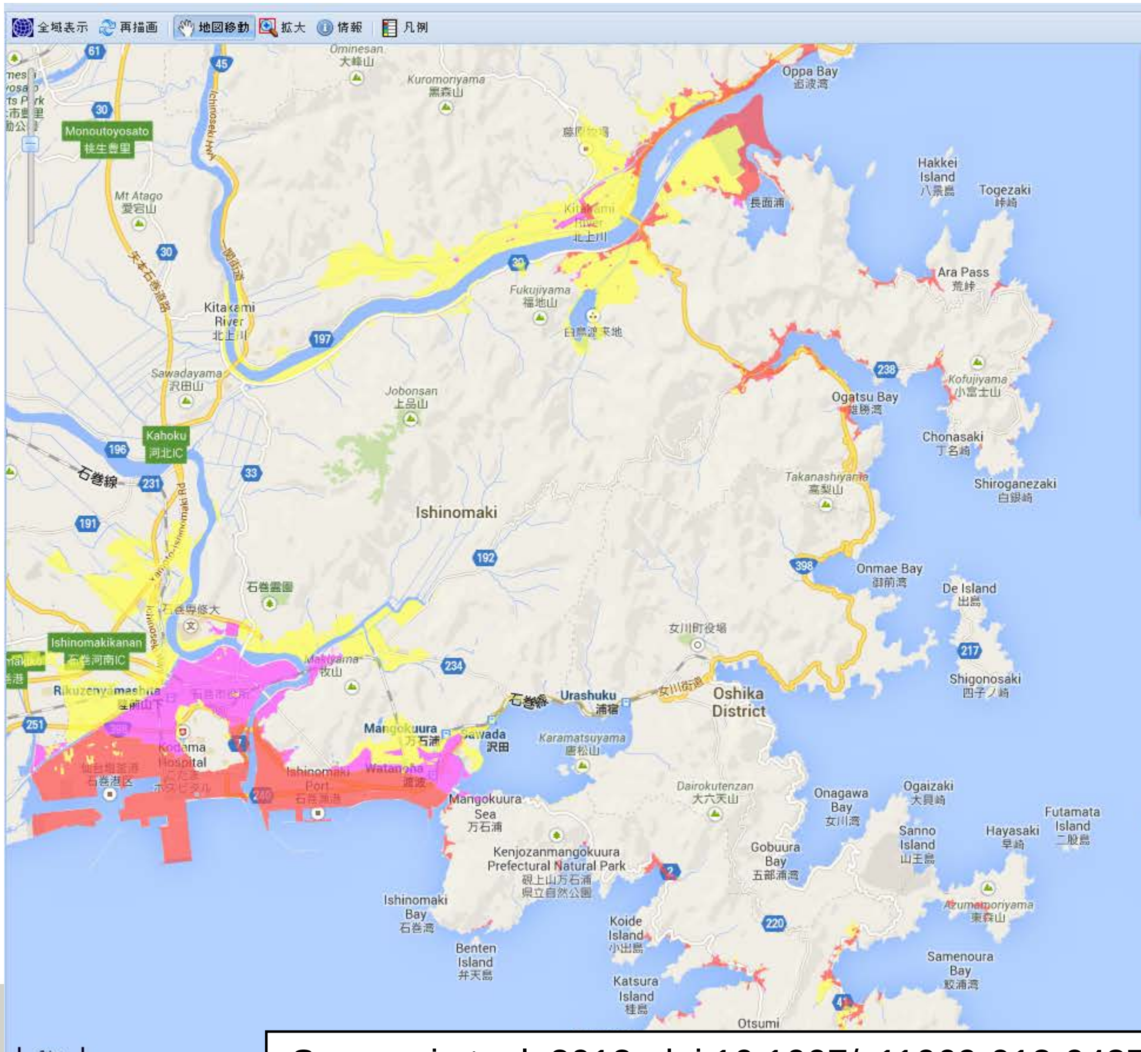

Sendai/Ishinomaki area
N
Legend
Inundation line (derived by DLR)
Pre-tsunami DEM
Post-tsunami DEM
0 5 10 20 Kilometers
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Post-tsunami field data: http://fukkou.csis.u-tokyo.ac.jp/



Post-tsunami field data

http://fukkou.csis.u-tokyo.ac.jp/



Building damage
Red: totally destroyed
Pink/yellow: partially destroyed
Blue: not destroyed
Crosses: no evidence

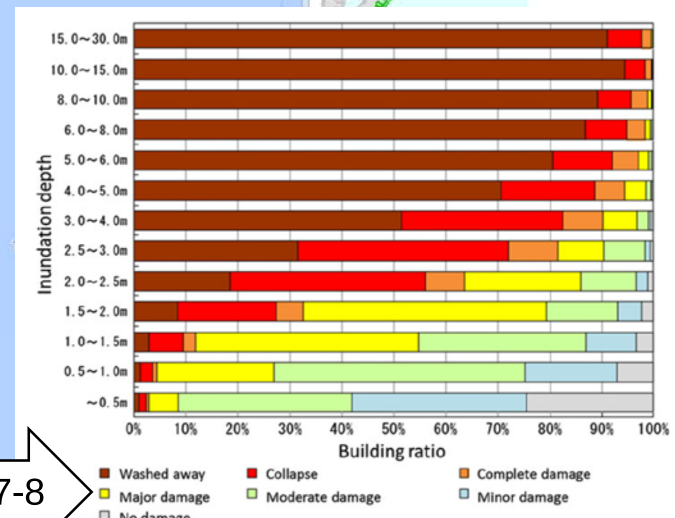


Fig. 2 Distribution of the total 251,301 building data surveyed by MLIT (2012)

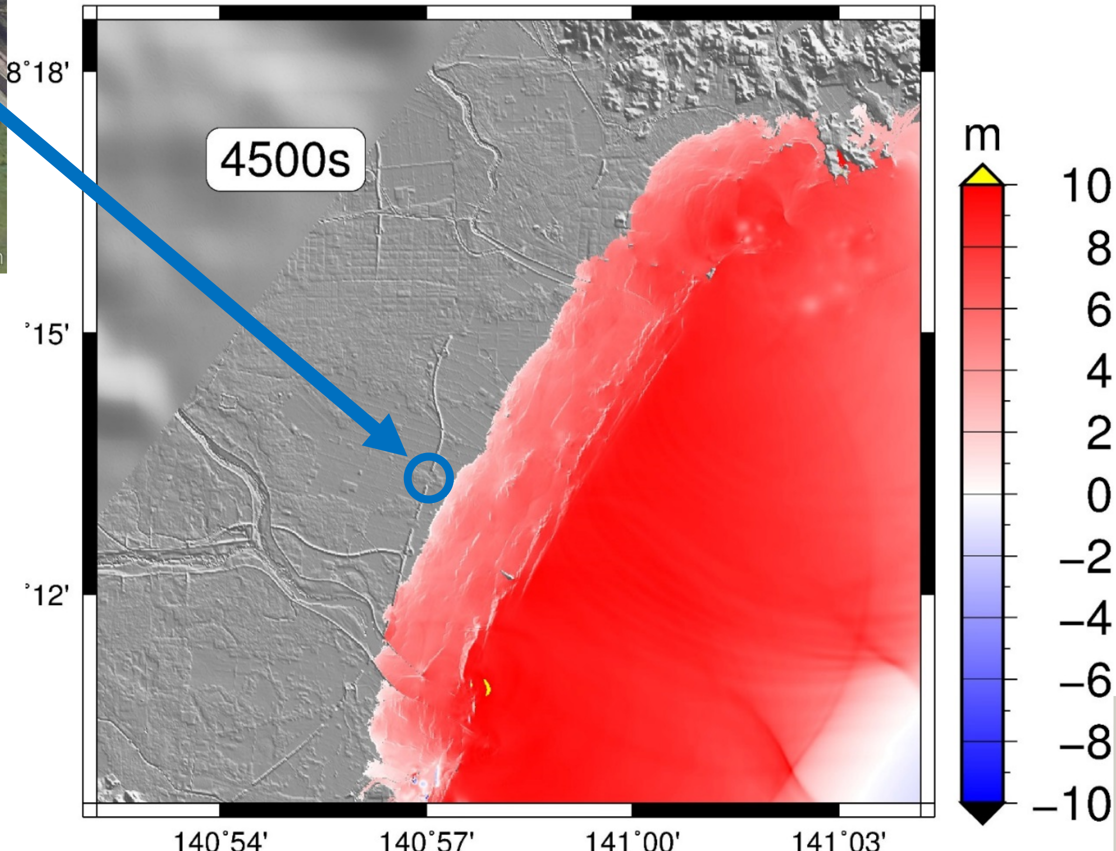
Suppasri et. al. 2013. doi 10.1007/s11069-012-0487-8

Data for tsunami inundation modelling

Bathymetry/topography is a combination of:

- High resolution topographical data
- GEBCO ‘08, 0.5 arcmin resolution (~900 m)
  - both on land and in sea
- For tsunami propagation, resolution 1 arcmin (~1800 m)
- For tsunami inundation; nested simulations on three grids (three levels), the finest resolution is about 20 m

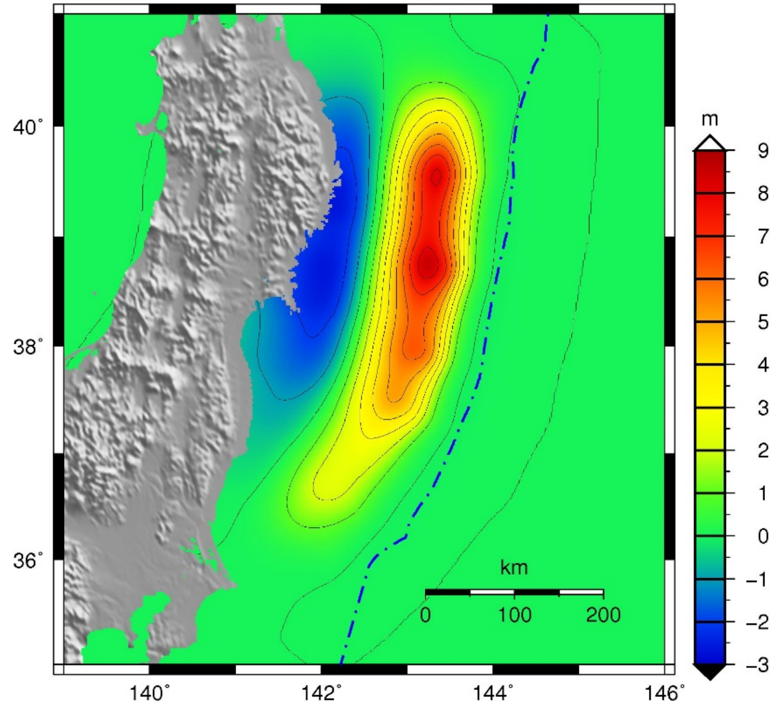
Comparing details in high-resolution data with StreetView in GoogleEarth

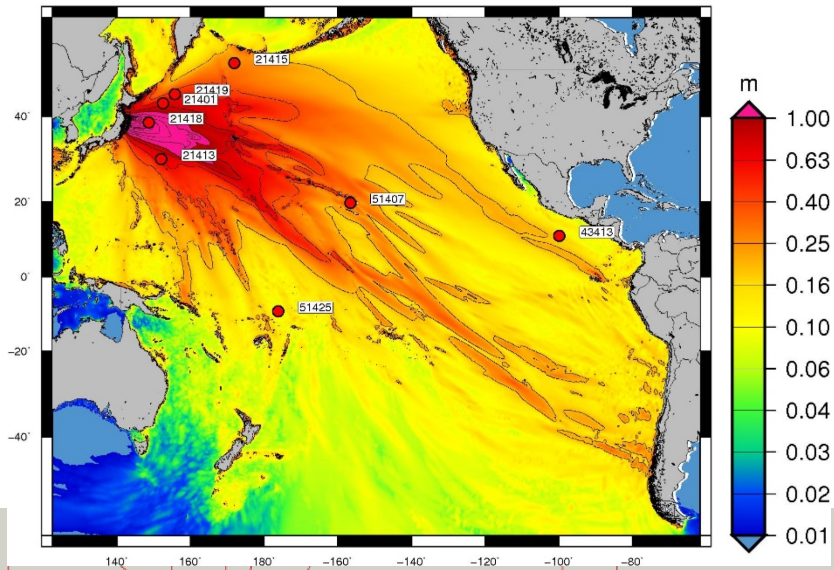


- Road protecting some areas (road higher than terrain around)
- Water may pass under bridge
- Bridge is removed in data (will give correct effect during inundation modelling)

Tsunami modelling: source refinement

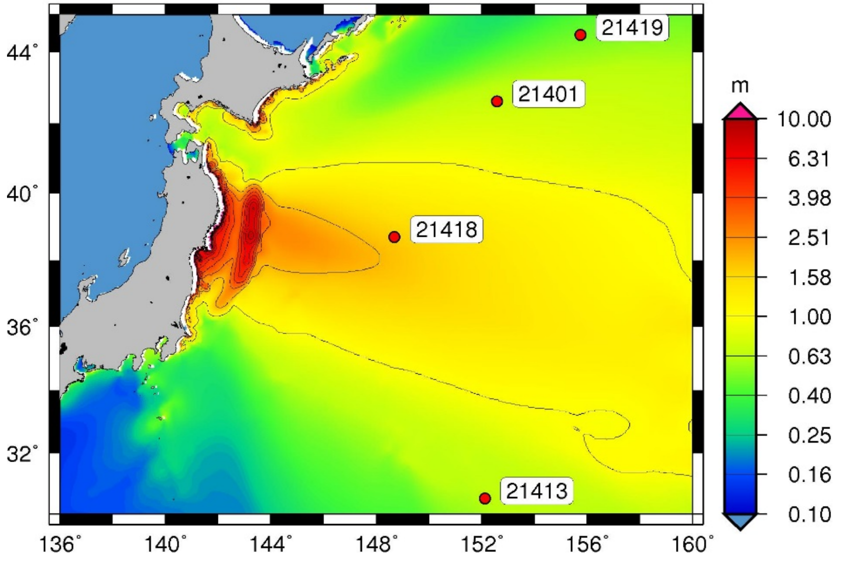
- Source based on knowledge of the 2011 earthquake
- Adjustments are made for best match at the DART bouys
- Sea bottom deformation by the Okada (1985) formula

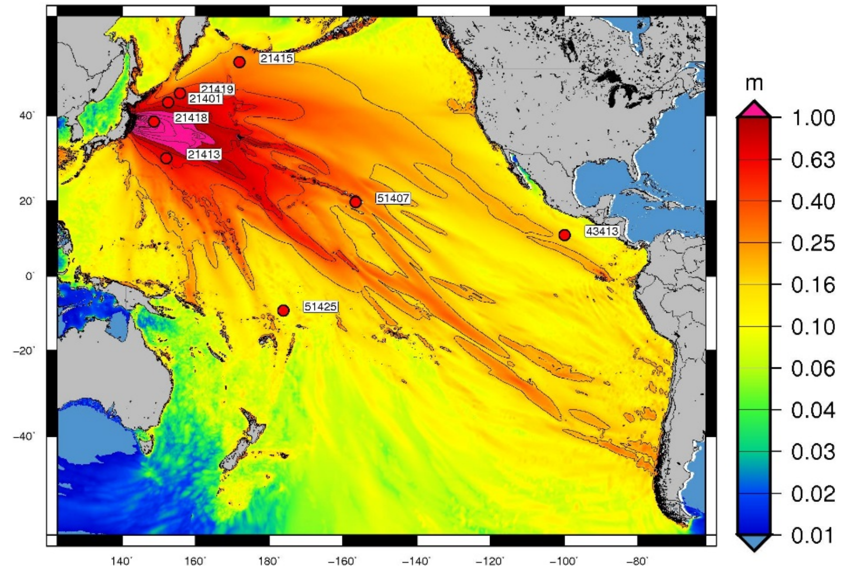


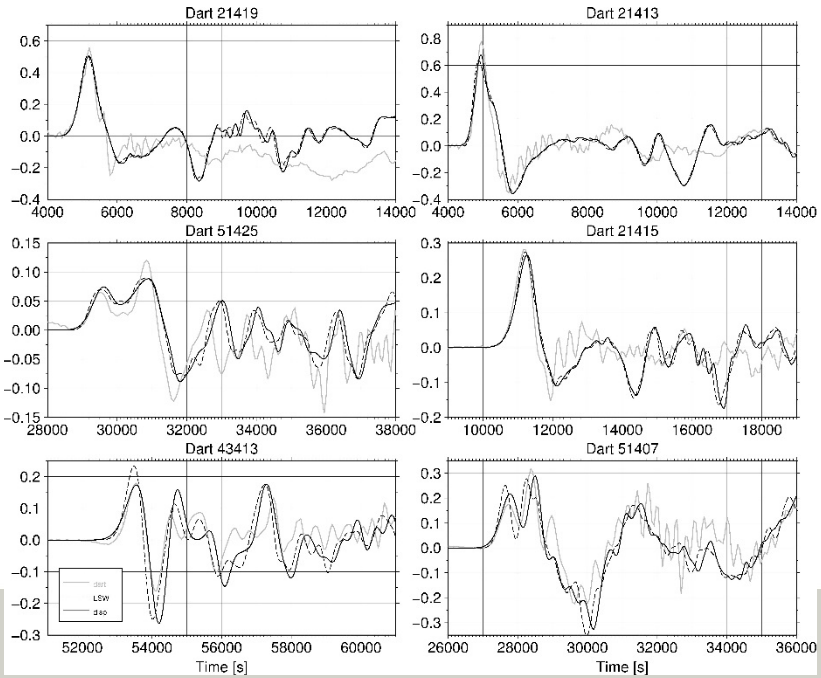


Tsunami propagation

- Locally (upper) and entire Pacific Ocean (lower panel)
- Observations at DART bouys
- Effect of dispersion for most distant bouys

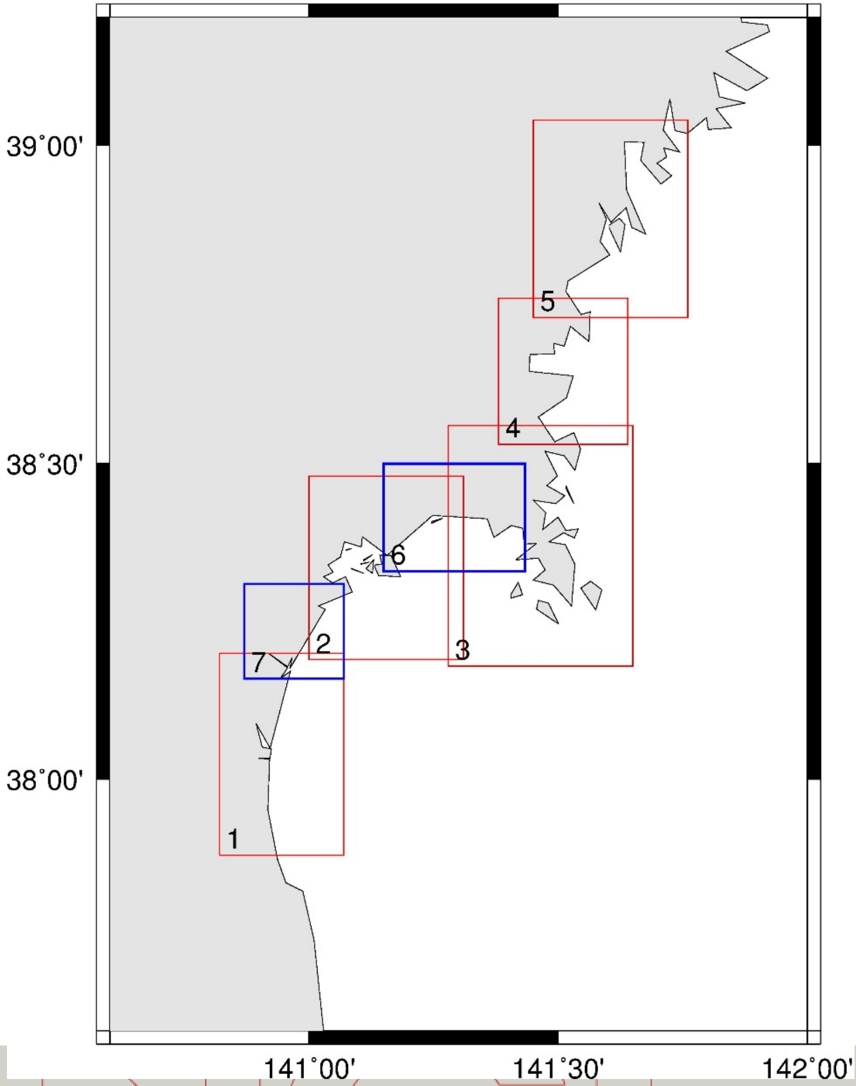






Tsunami inundation modelling

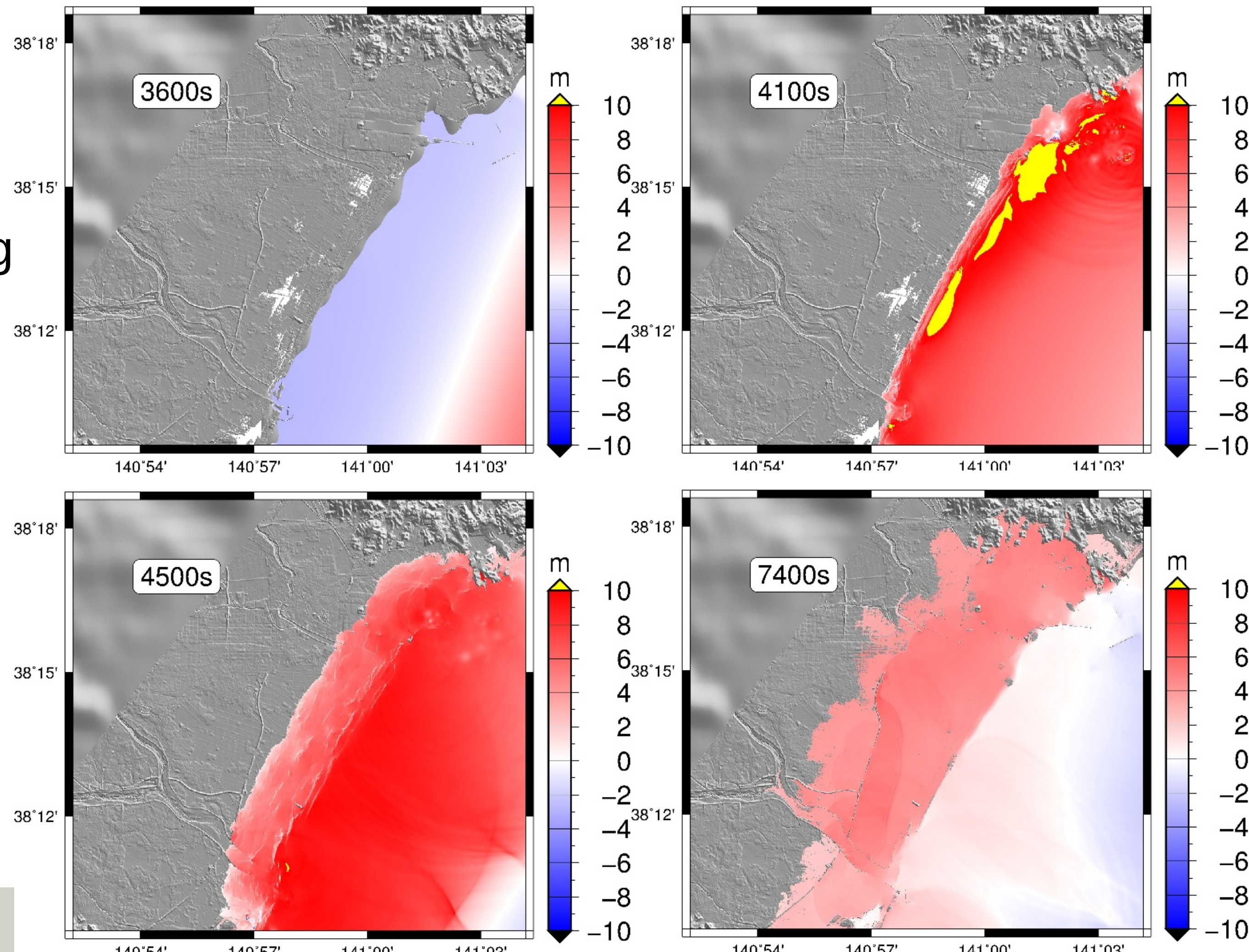
- Detailed inundation modelling from about 37.8º to about 39º N
- Results/examples from the simulations inside area 7 are shown (Sendai)



Surface elevation/water level during inundation

Snapshots of the surface elevation (in the sea) and water level (on land) during run-up at Sendai

Waves arrived at Sendai about 1 hour after the earthquake



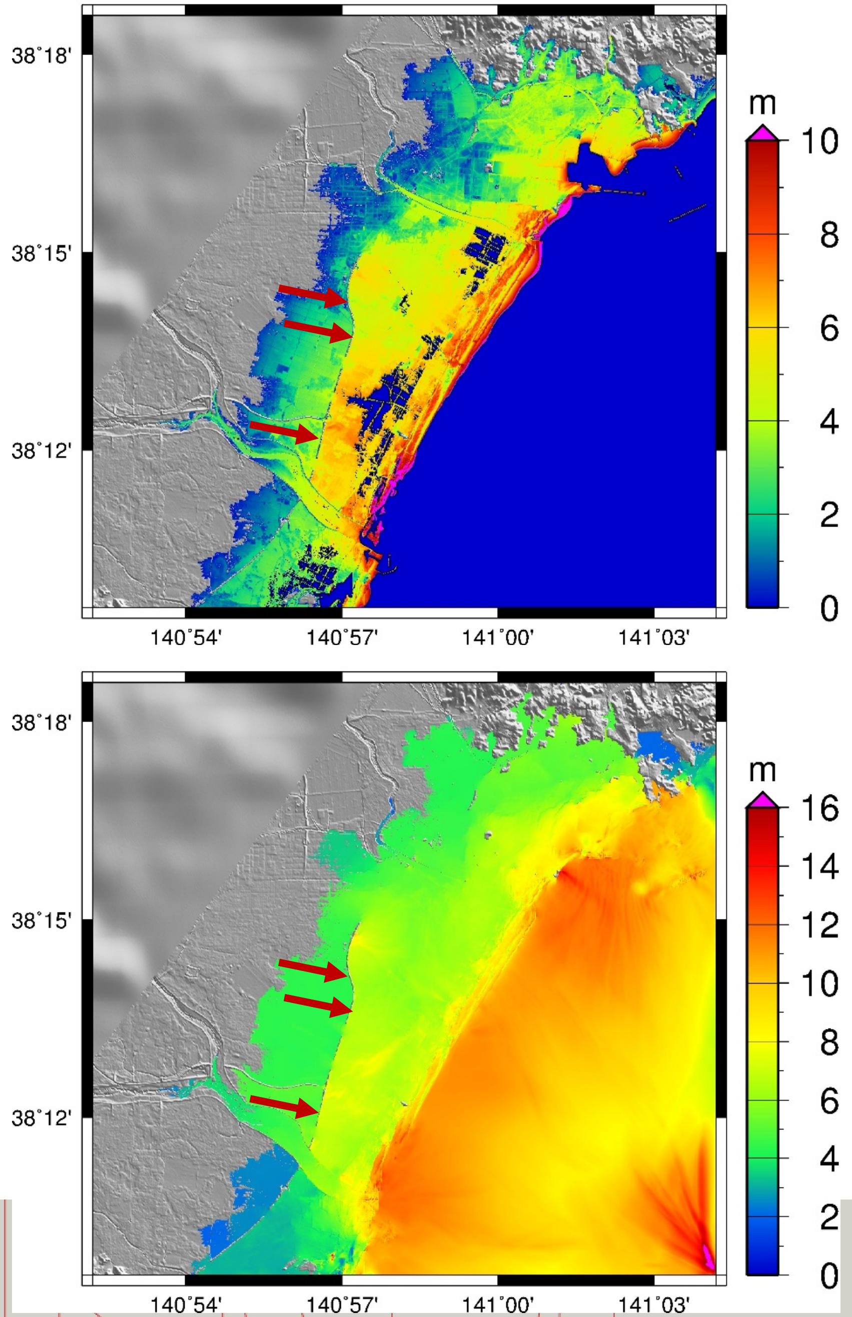
Maximum values

Maximum flow depth (upper panel):

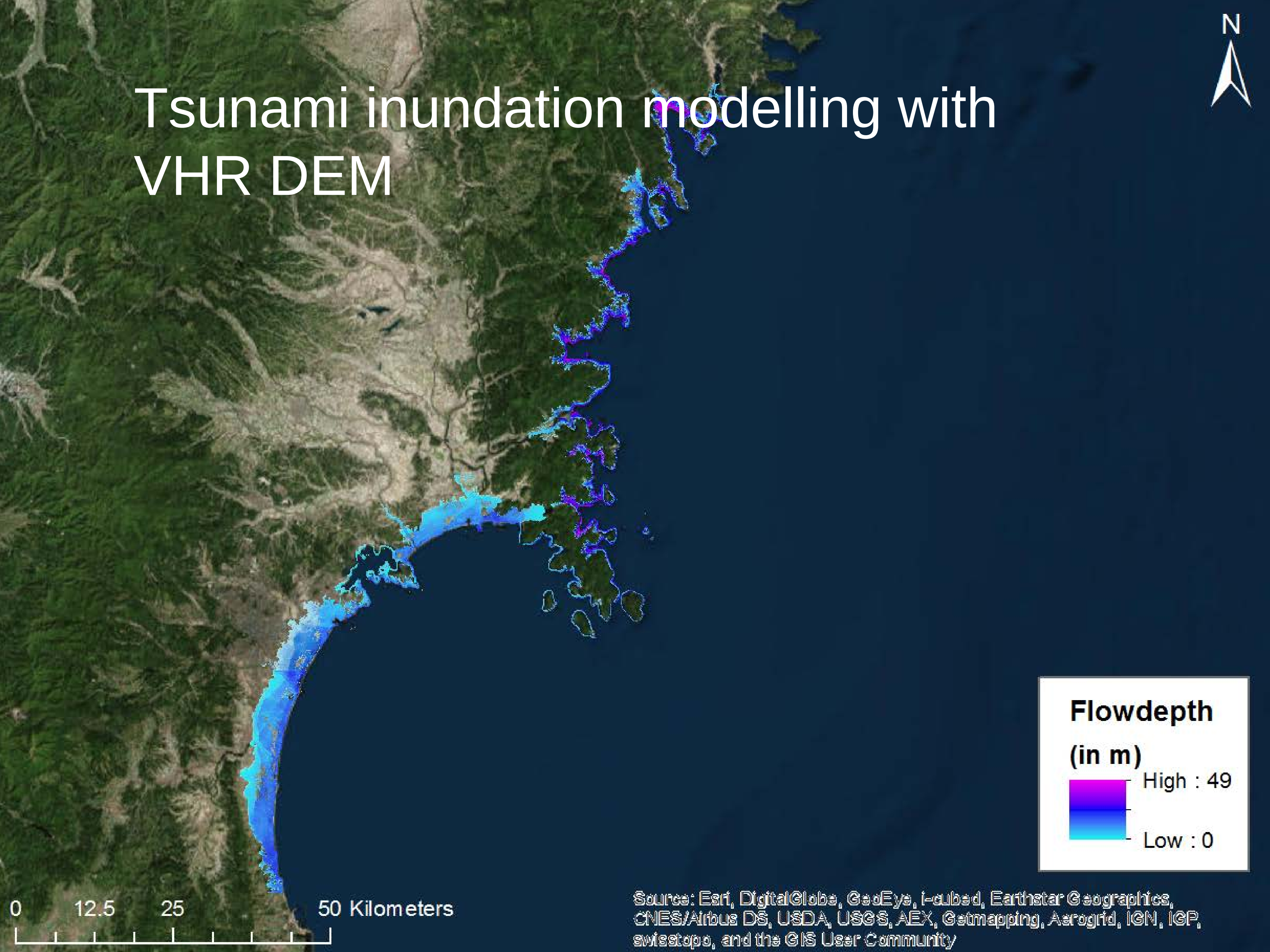
- > 10 m close to shoreline
- Road reduces the flow depth about 3 m (cf. red arrows)

Maximum surface elevation (and water level on land; lower panel)

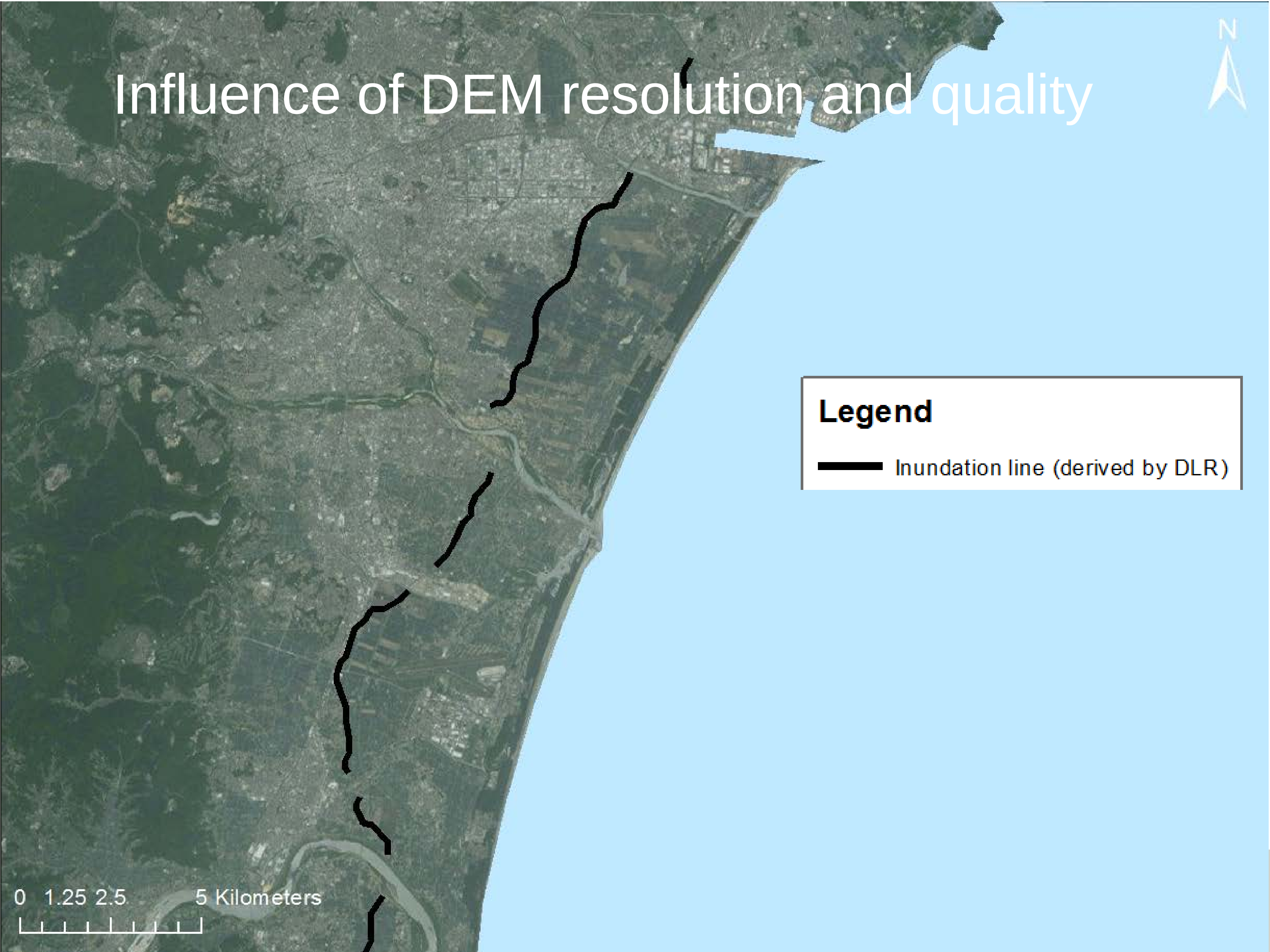
- > 10 m close to shoreline
- Down to about 3-4 m along the trimline (line of maximum inundation)



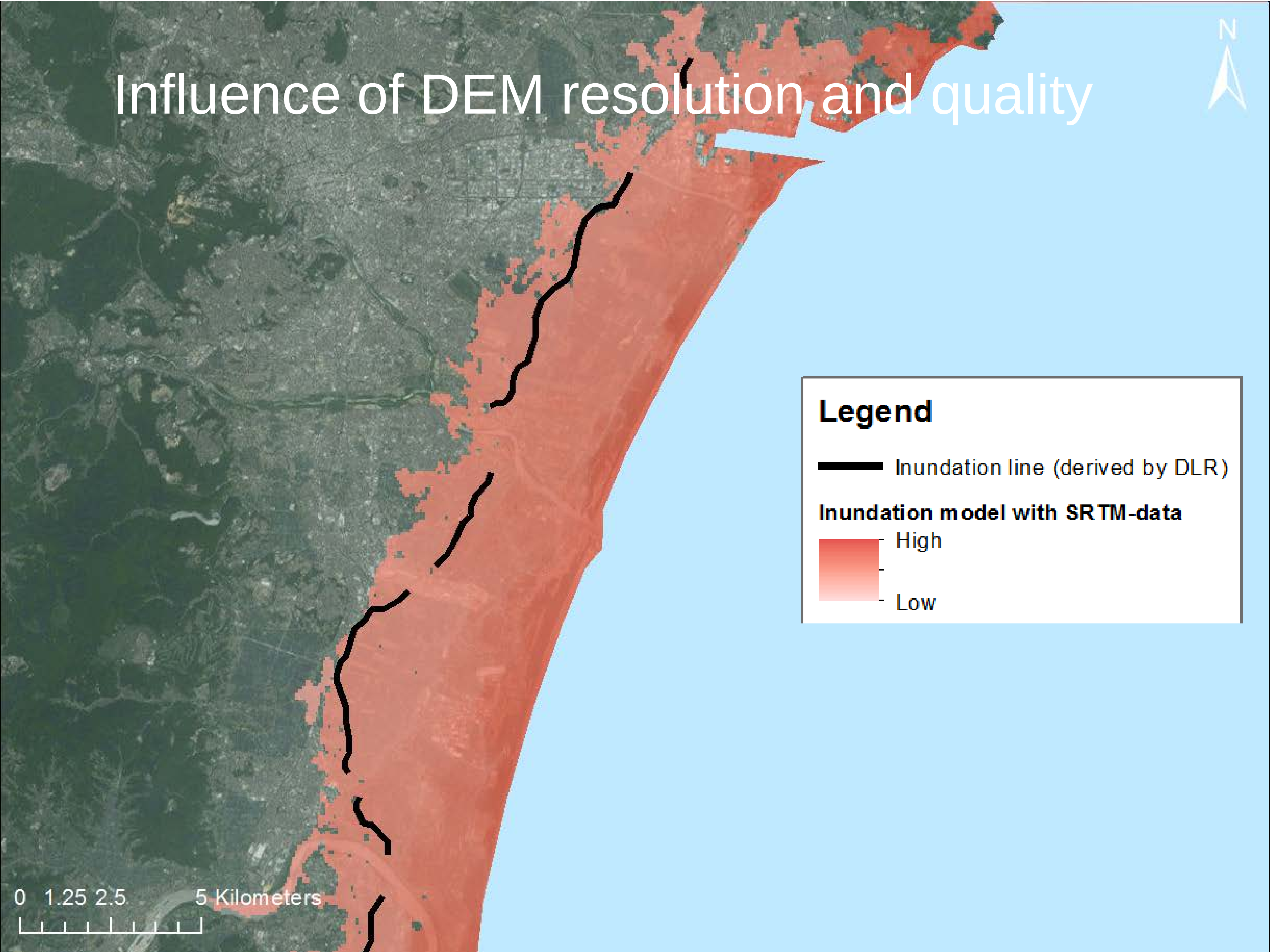
Tsunami inundation modelling with VHR DEM



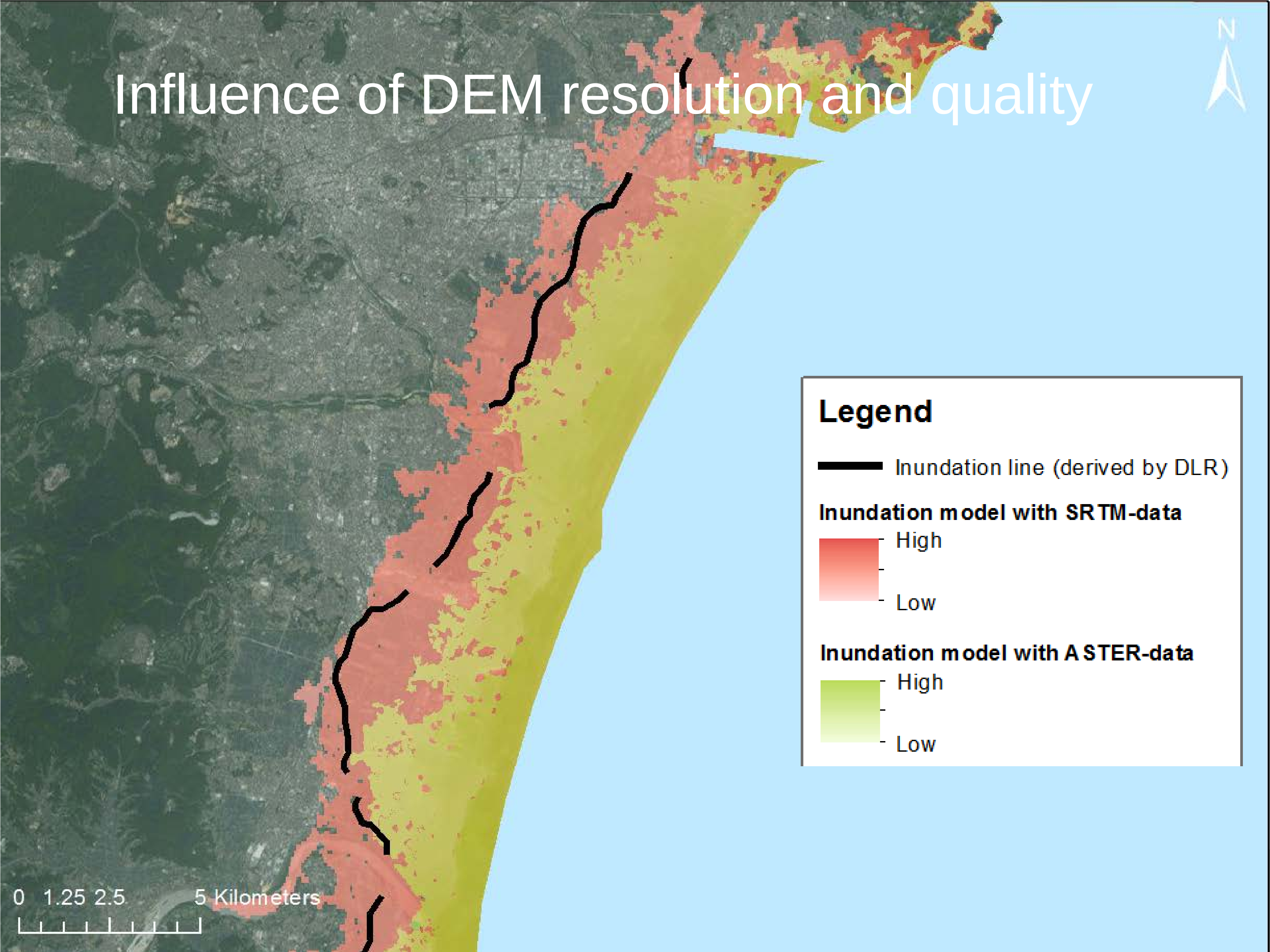
Influence of DEM resolution and quality



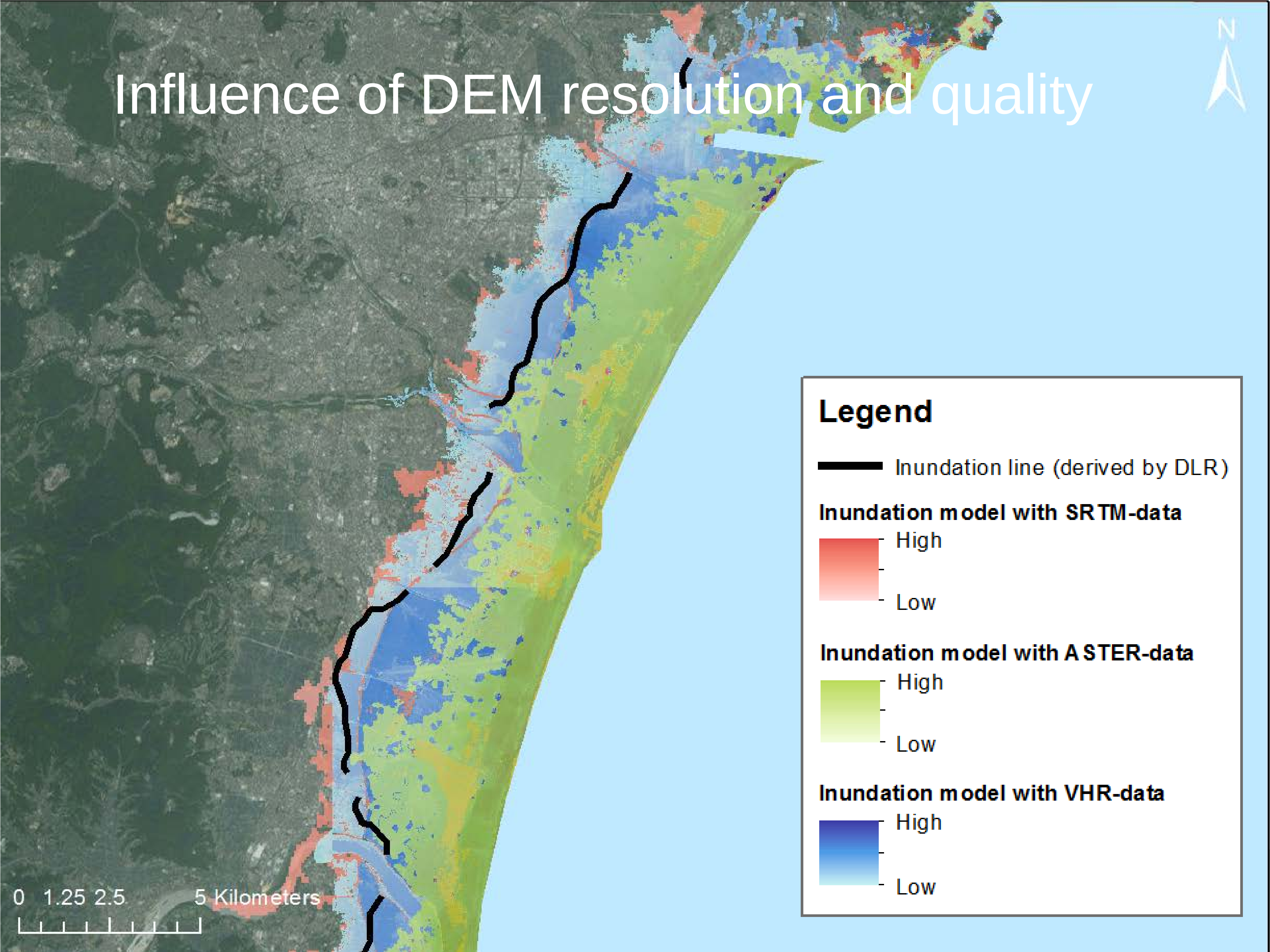
Influence of DEM resolution and quality



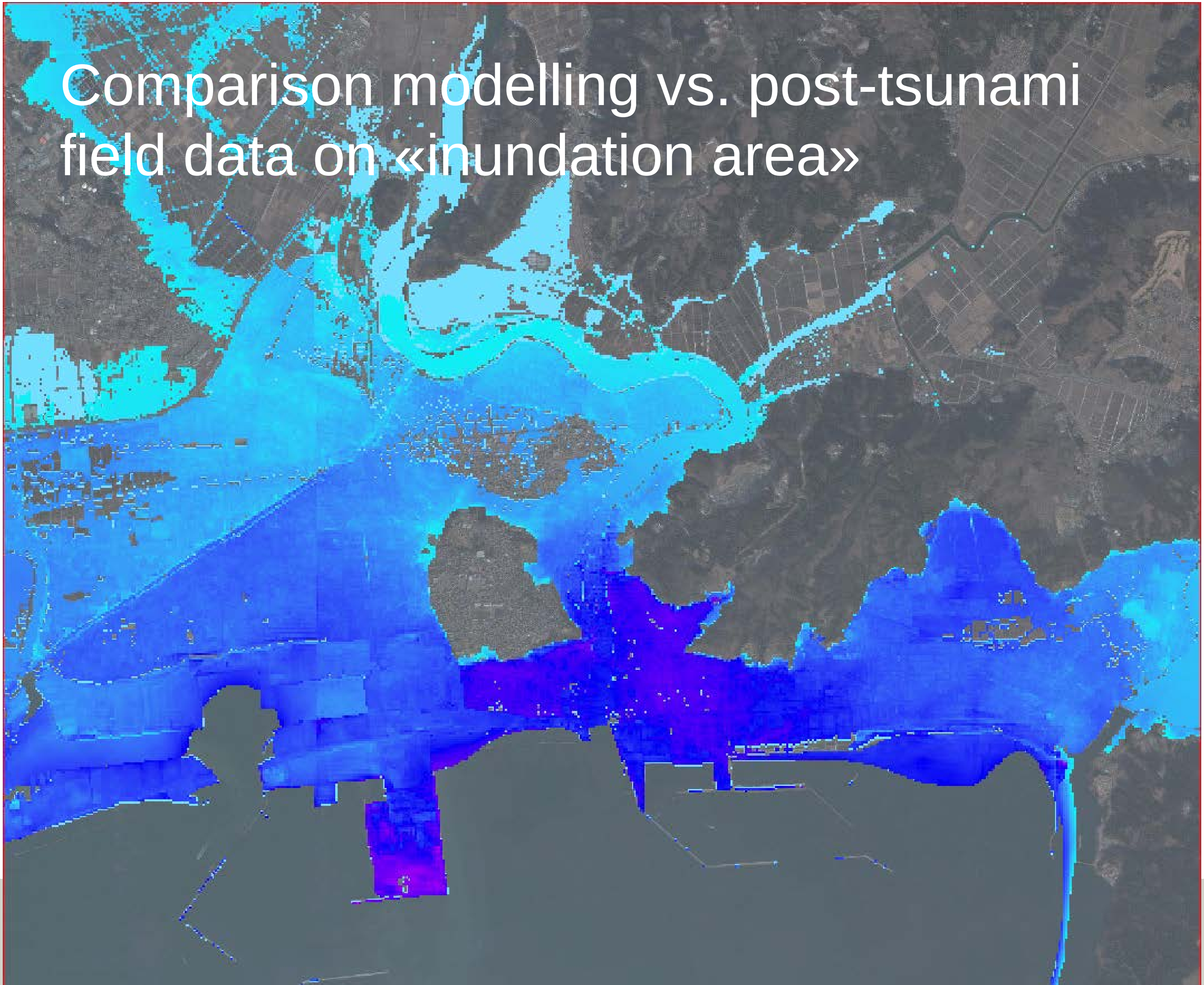
Influence of DEM resolution and quality



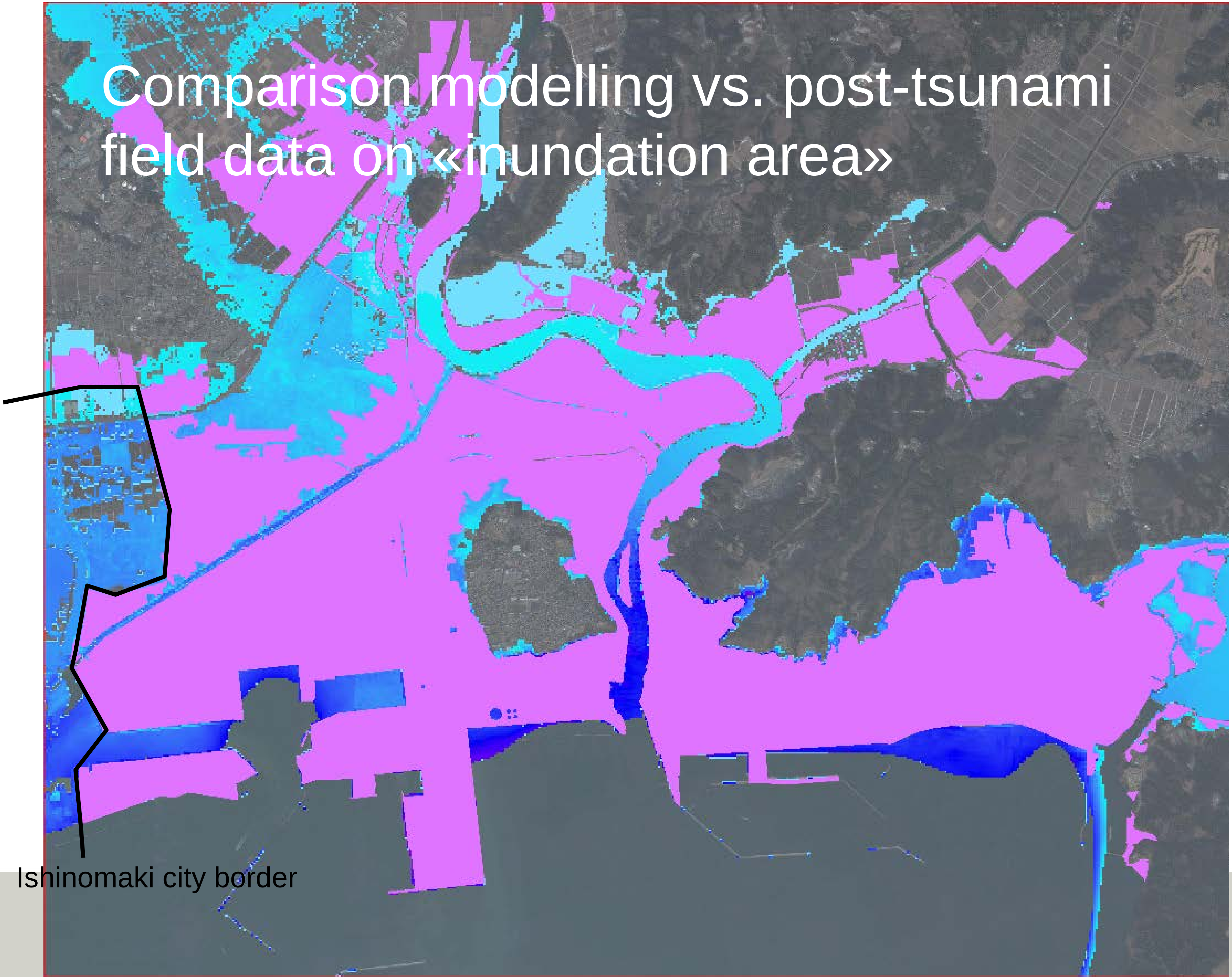
Influence of DEM resolution and quality



Comparison modelling vs. post-tsunami field data on «inundation area»



Comparison modelling vs. post-tsunami field data on «inundation area»



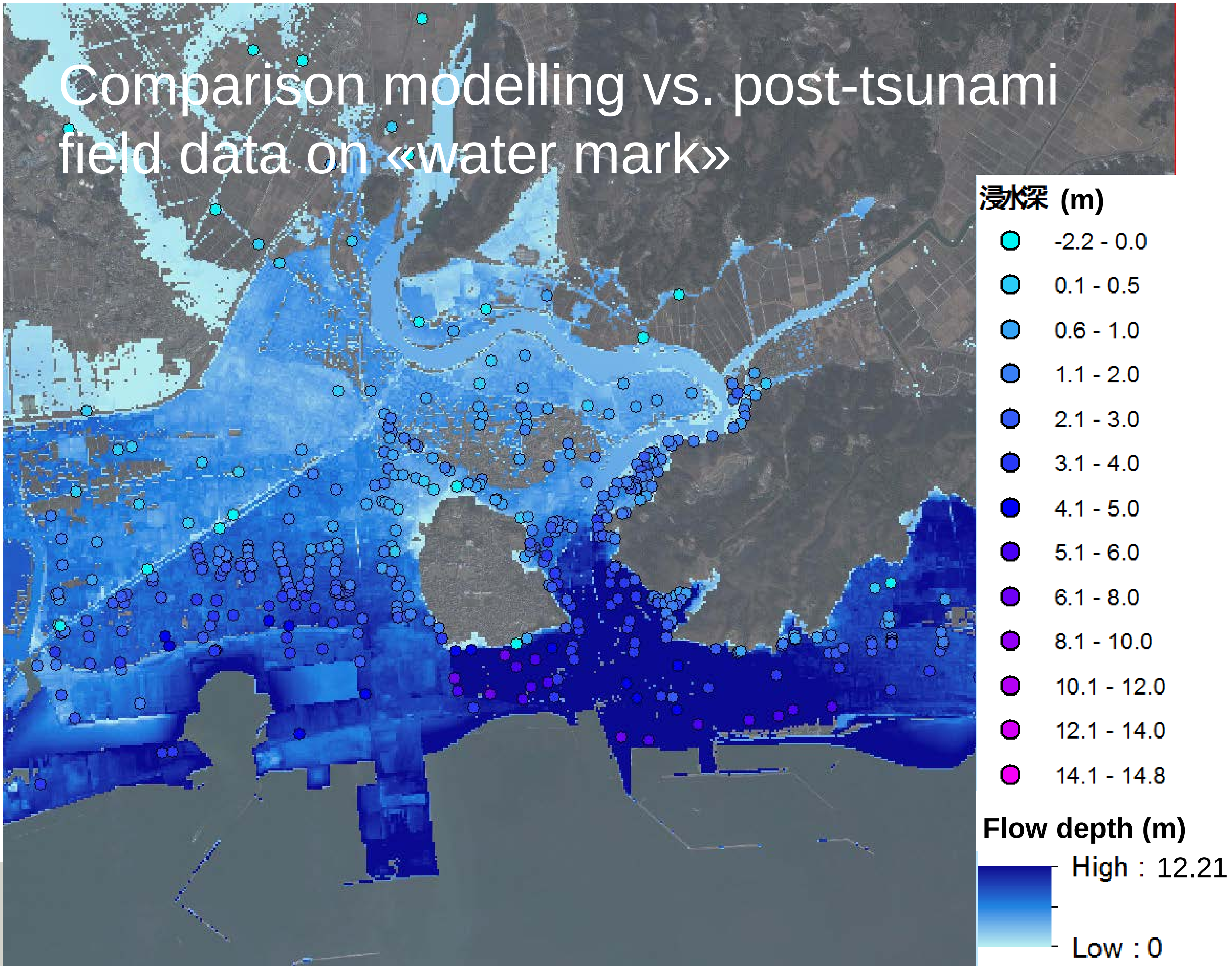
Comparison modelling vs. post-tsunami field data on «water mark»

撮影日時：2011-06-10 14:54:57
撮影地点:北緯38.19486東経
140.944286666667

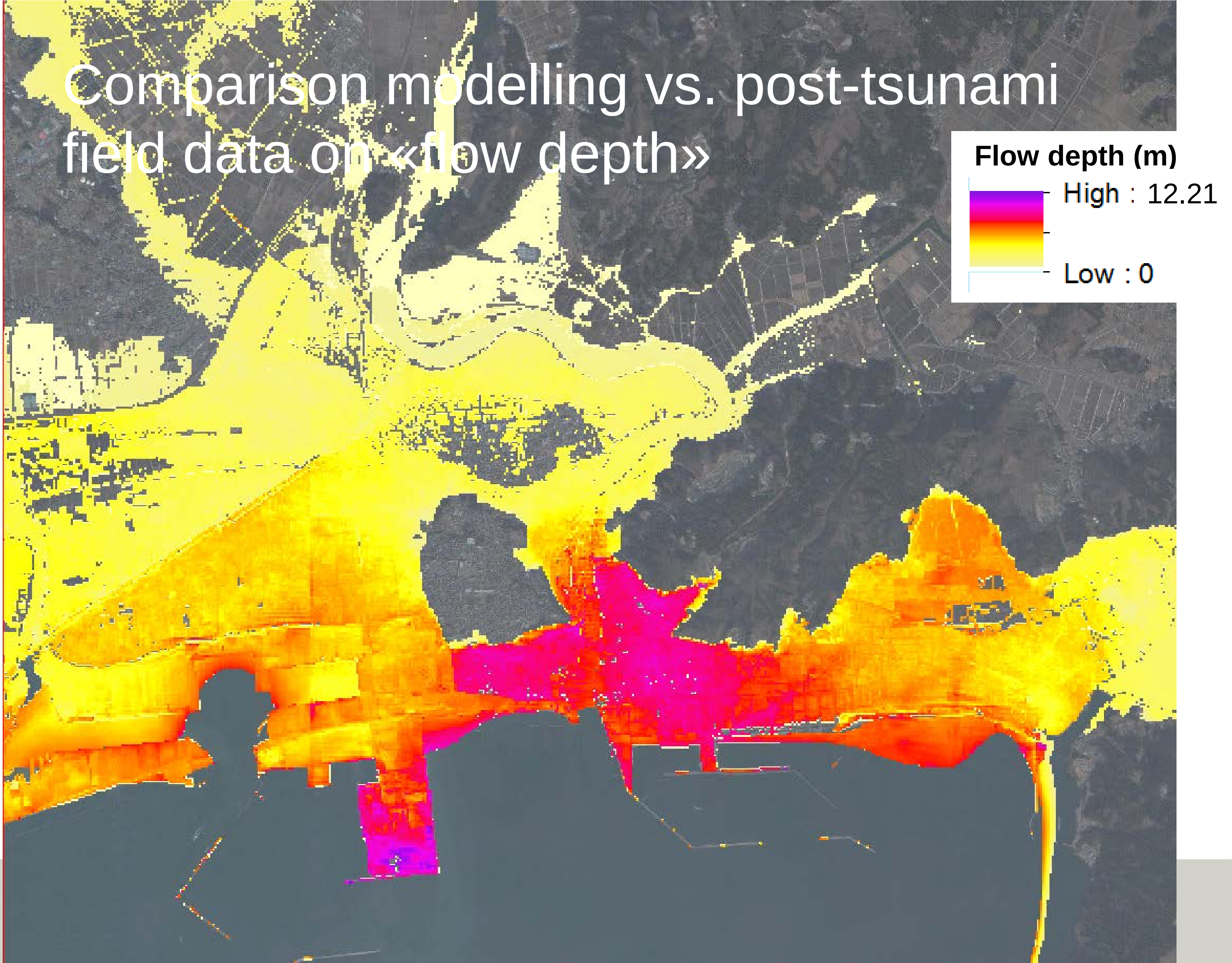
Examples from Sendai

撮影日時：2011-06-13 10:27:52
撮影地点:北緯38.277755東経
141.009456666667

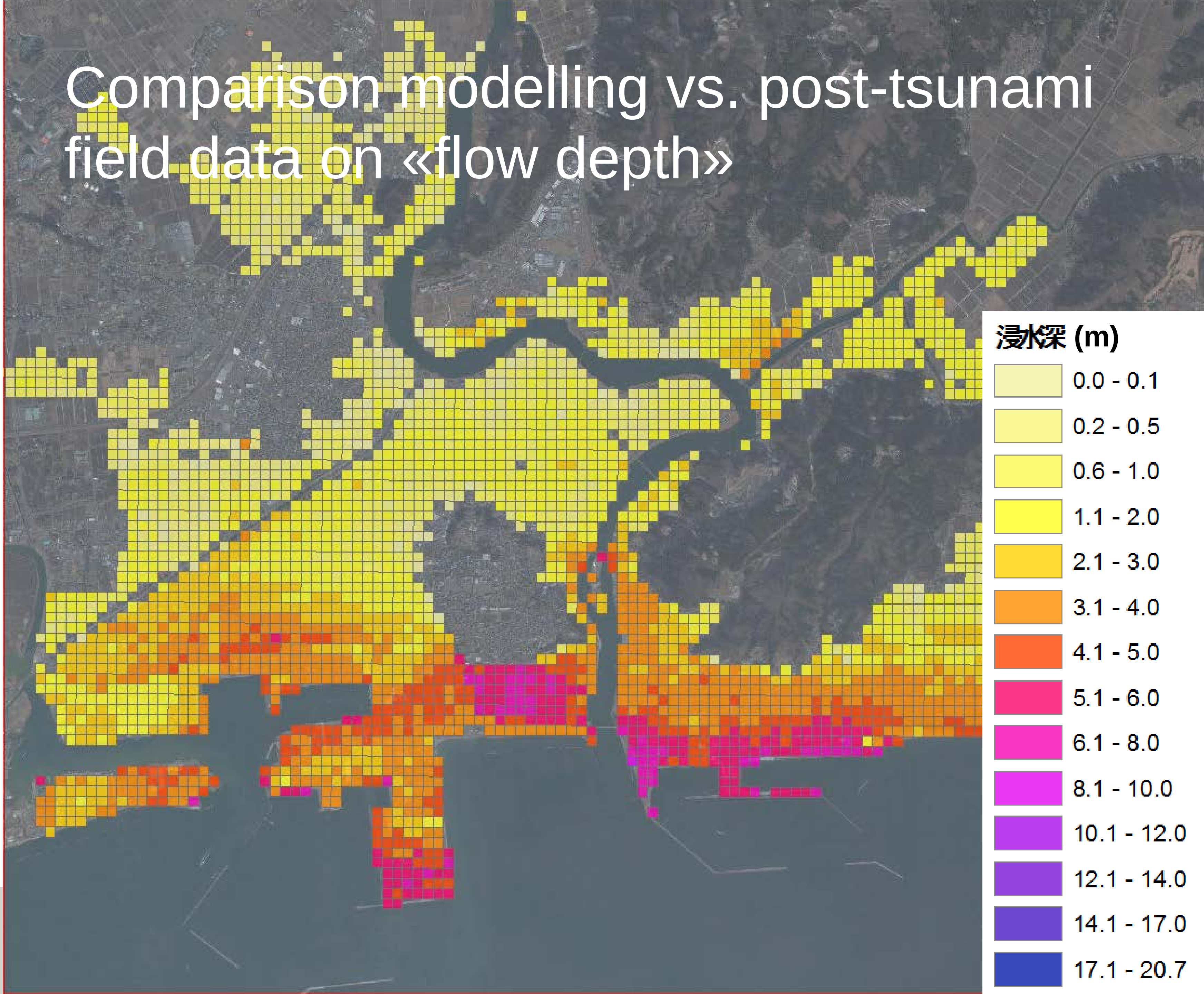
Comparison modelling vs. post-tsunami field data on «water mark»



Comparison modelling vs. post-tsunami field data on «flow depth»



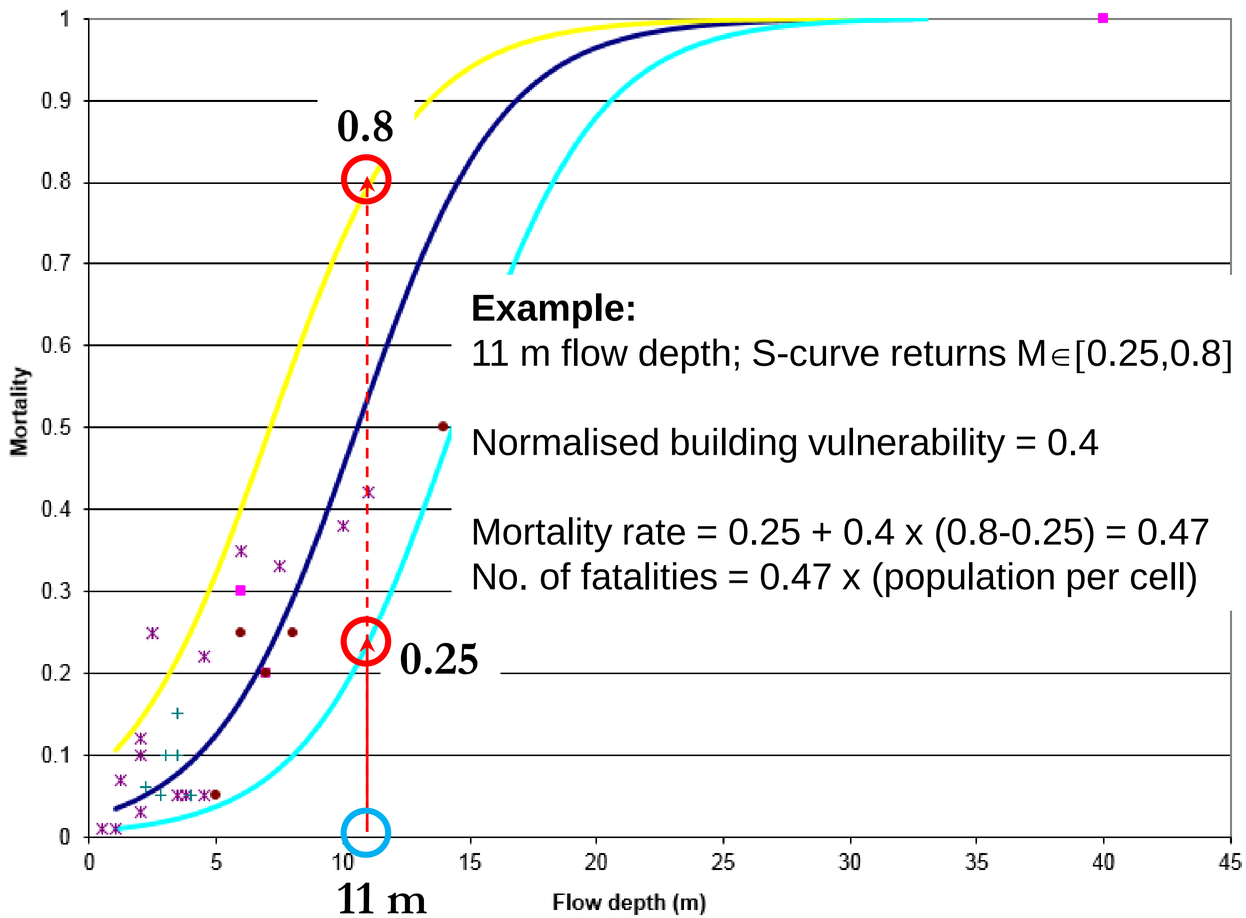
Comparison modelling vs. post-tsunami field data on «flow depth»



Total predicted mortality: concept

Convert all building vulnerability scores to [0,1]

Use vulnerability score to pick the ”correct” S-curve.

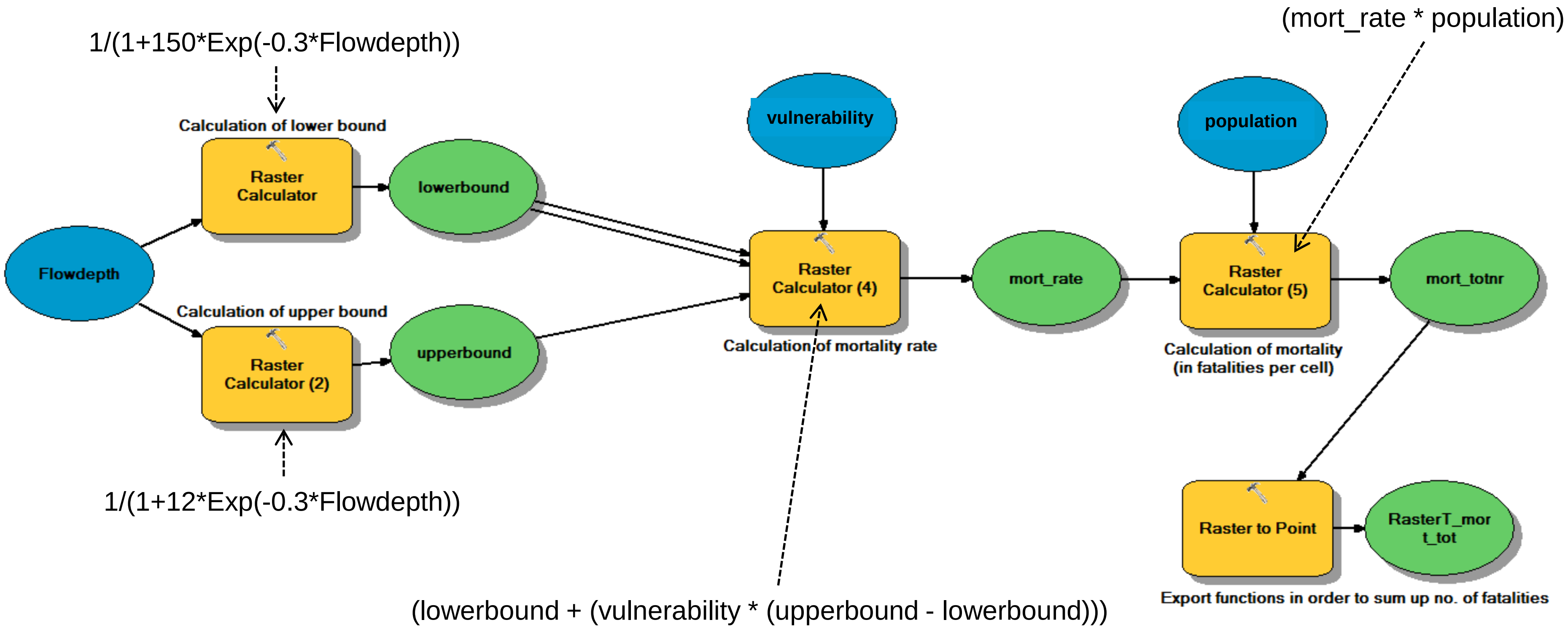


Example:
11 m flow depth; S-curve returns M∈[0.25,0.8]

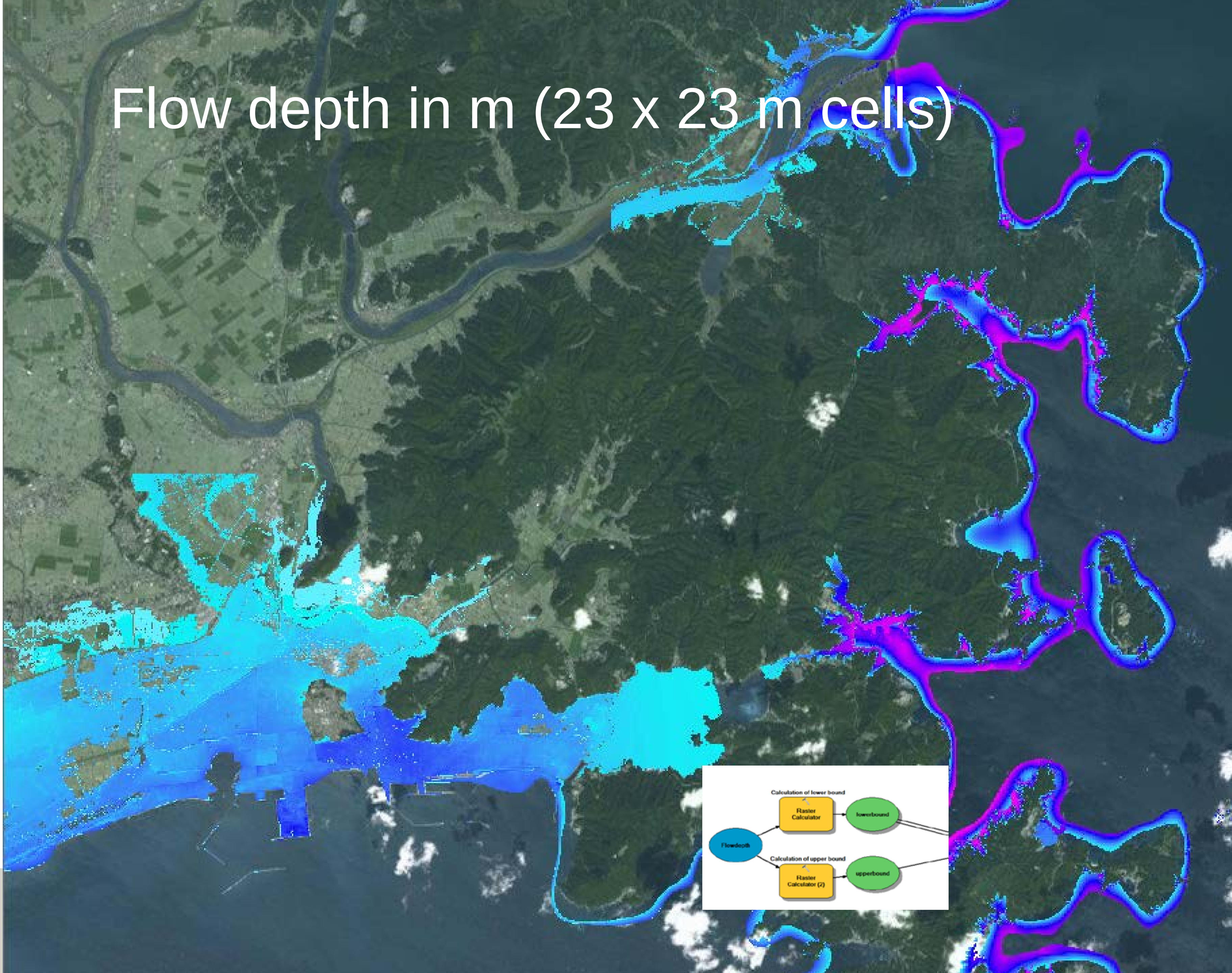
Normalised building vulnerability = 0.4

Mortality rate = 0.25 + 0.4 x (0.8-0.25) = 0.47
No. of fatalities = 0.47 x (population per cell)

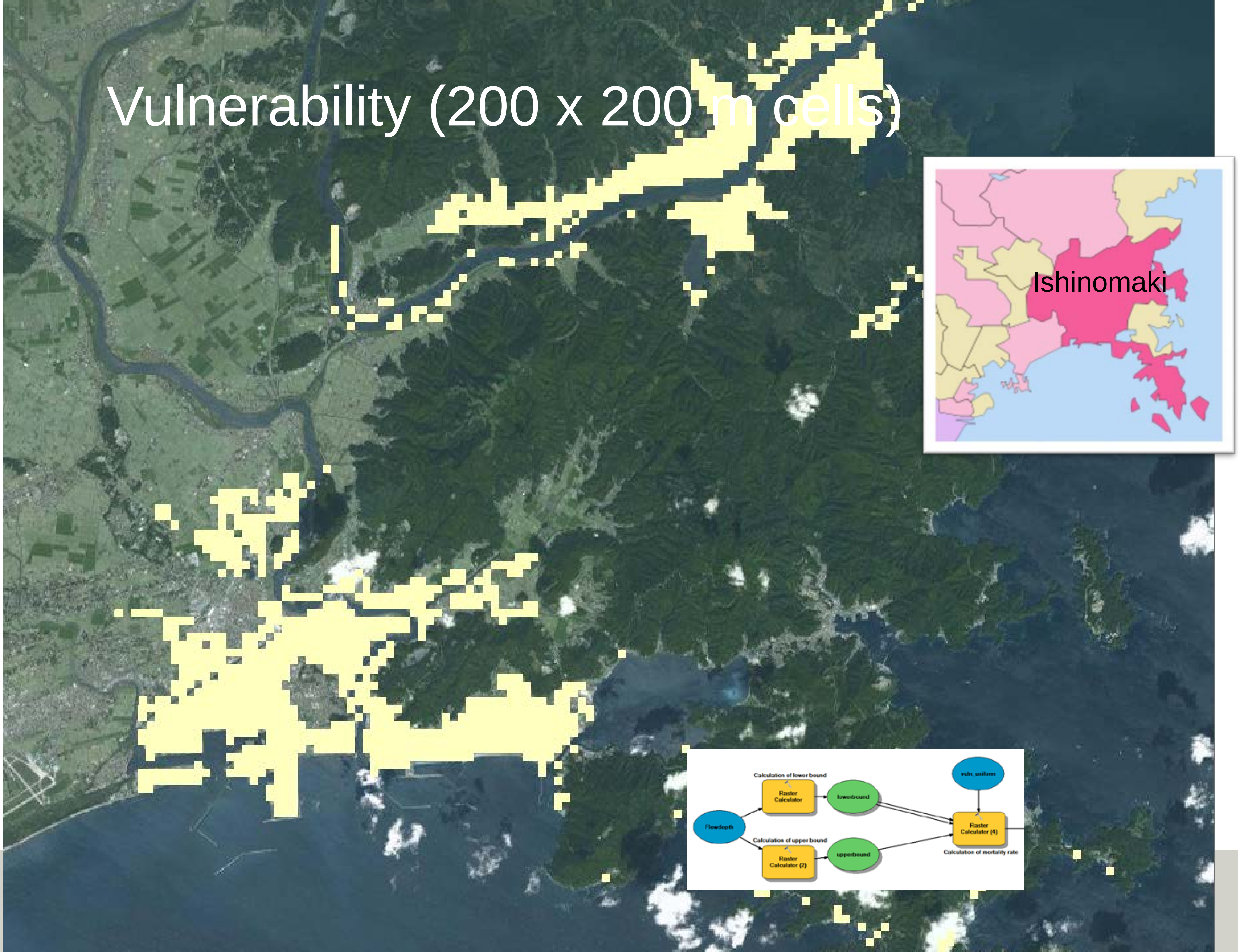
Total predicted mortality: computation



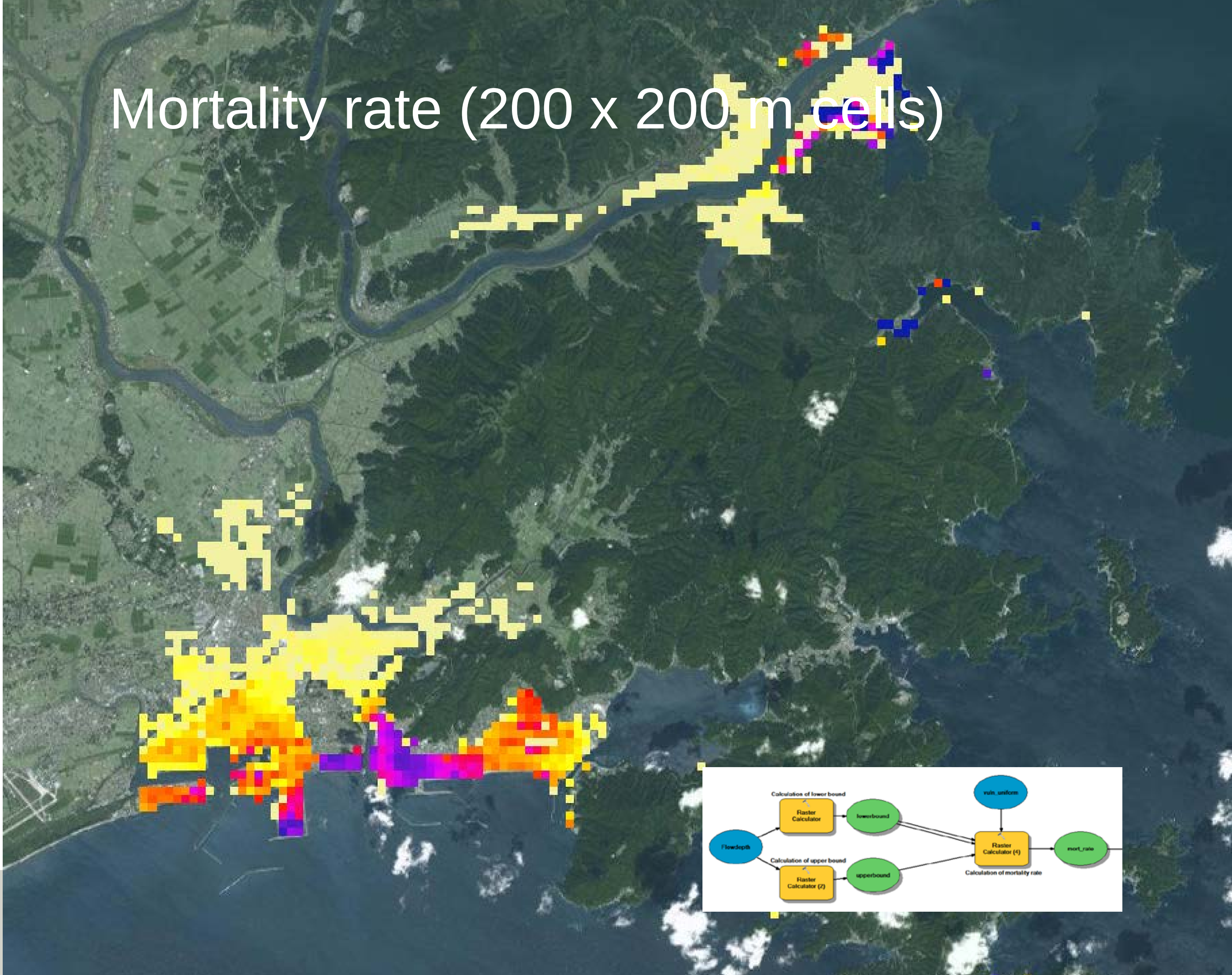
Flow depth in m (23 x 23 m cells)



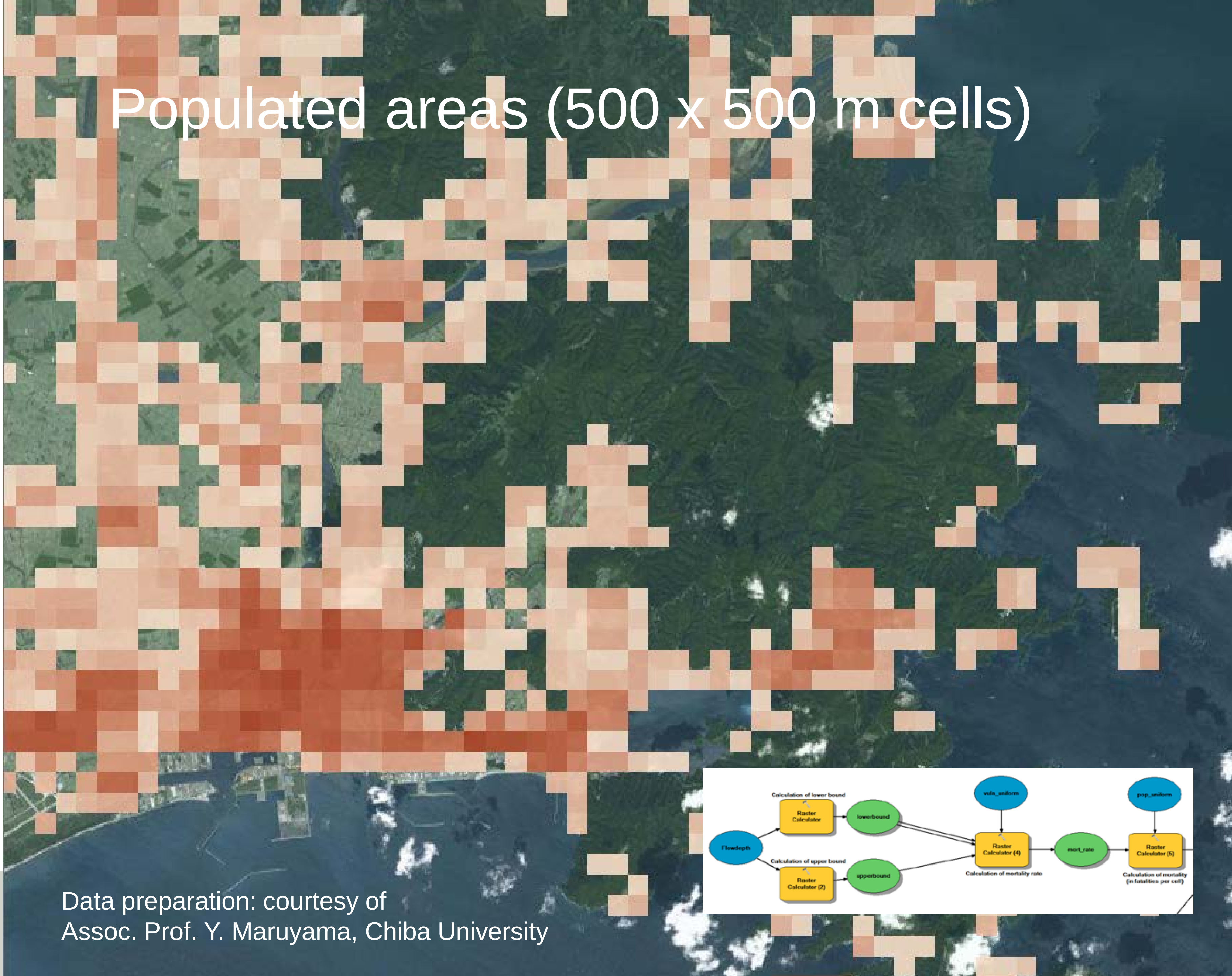
Vulnerability (200 x 200 m cells)



Mortality rate (200 x 200 m cells)

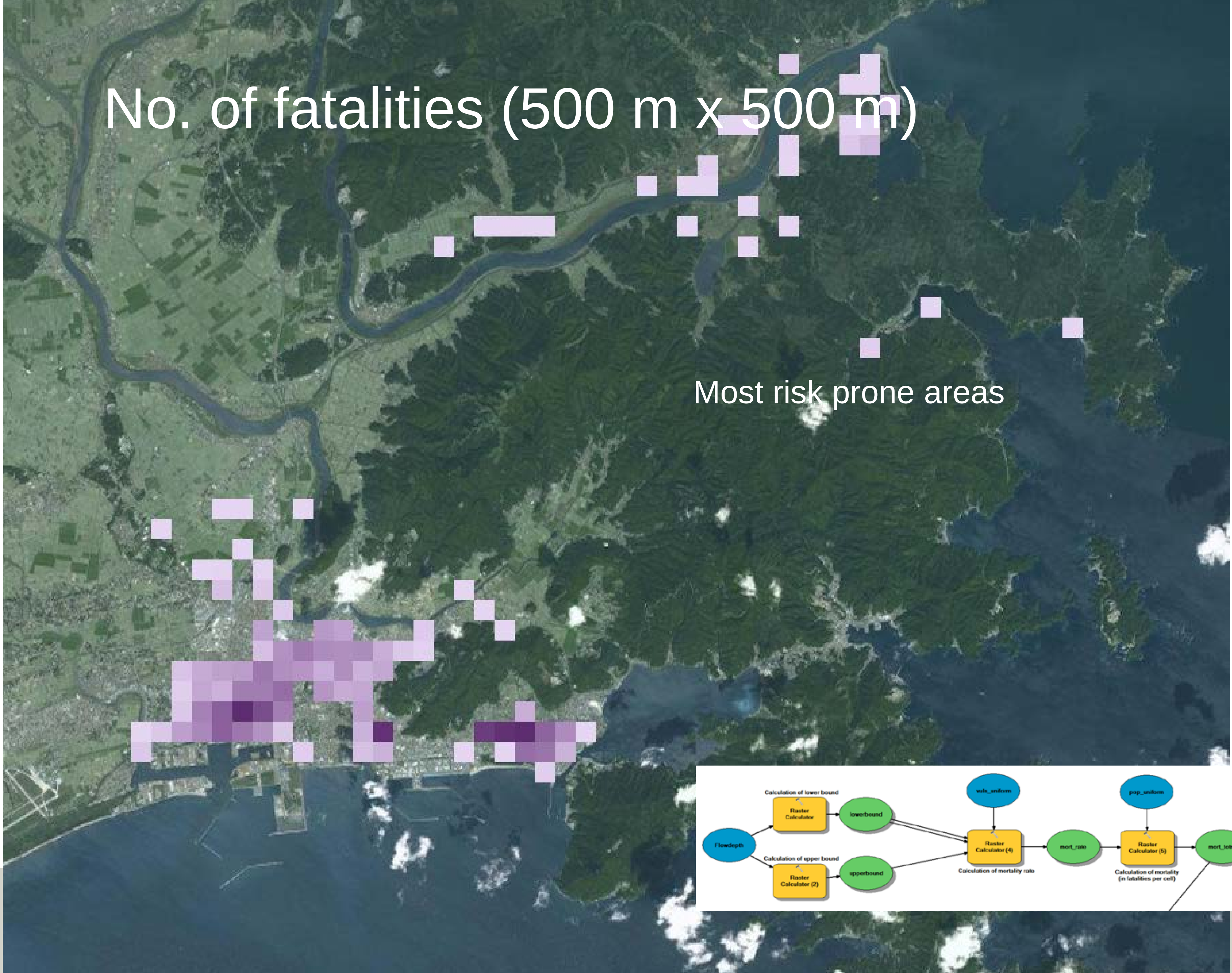


Populated areas (500 x 500 m cells)



Data preparation: courtesy of
Assoc. Prof. Y. Maruyama, Chiba University

No. of fatalities (500 m x 500 m)



Concluding remarks

- Maximum flow depth was obtained by back calculating the 2011 Tohoku earthquake and tsunami using very high resolution digital elevation data
- First runs for validation of GIS tsunami risk model
  - Using gridded population data from Portal Site of Official Statistics of Japan
  - Using uniformly distributed building vulnerability
- Potential for further development
  - In particular improvement of building vulnerability layer

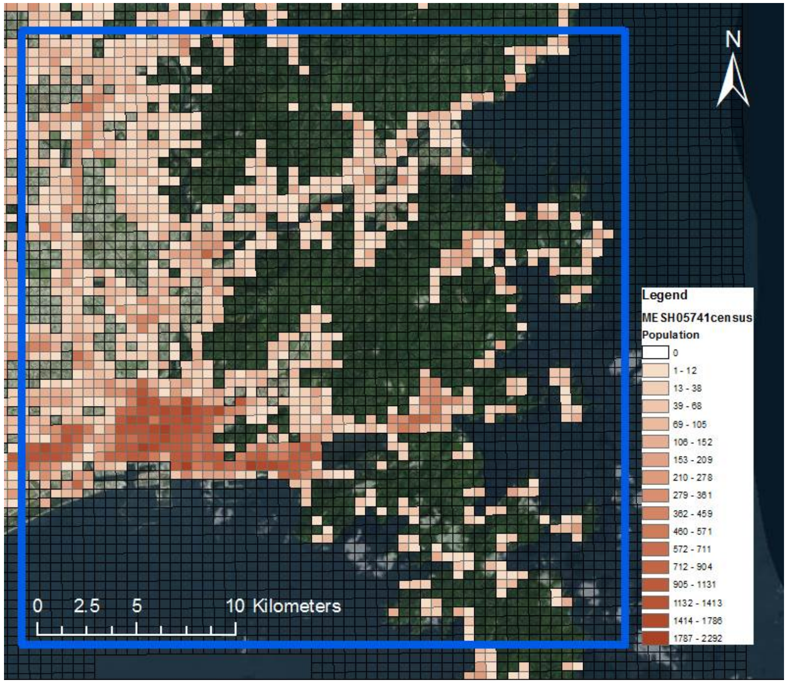
Thank you for your attention!

We acknowledge the help from:

- T. Arikawa, Y. Nakamura
- Y. Mayurama
- H. Fritz, B. Jaffe, Shona v Z de Jong, S. Koshimura, J. Melby
- USGS
- EERI reports
- American Samoa Department of Homeland Security
- Various internet sources (references given on slides)

And the funding from:

- The Research Council of Norway – CONCERT Japan
- NGI/ICG/The Research Council of Norway
- US National Science Foundation (RAPID, PIRE)
- Vassar College



Rasteret som vi fikk fra Y. Maruyama fører altså opp 197'657 mennesker i dette området. Så det er ikke urimelig at vi lander på høyere tall enn når vi bruker en uniform fordelt befolkning over 163'000 mennesker.

Sammenlignet med rapportere tall spiller jo følgende faktorer inn:

Når det snakkes om Ishinomaki city i kildene på internett: hvilket område er da ment?

Hvor mange personer pendler inn til byen/ut av byen for å jobbe?

Hvor mange pendler internt i byen til/fra tsunami utsatt område?

Hvor mange arbeidere var ved anleggene ved havn da tsunamien kom (midt på en arbeidsdag)?