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Understanding tsunami hazard and risk in lakes:

the case of Western Lake Geneva

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Outline

1. Introduction
   - Tsunami in lakes
   - The context

2. Methods
   - NOC Scheme methods
   - From mathematical to geographical environment

3. Results
   - Tsunami wave propagation characteristics
   - Tsunami exposure assessment

4. Conclusion

Tsunamis in lakes

Why are these phenomena interesting:

- Lacustrine geographical environment: highly urbanized
- Closed vs open geometry
- Short arrival time of the waves
- Potential sources:
  - Earthquakes, landslides, rockfalls OR cascading effect

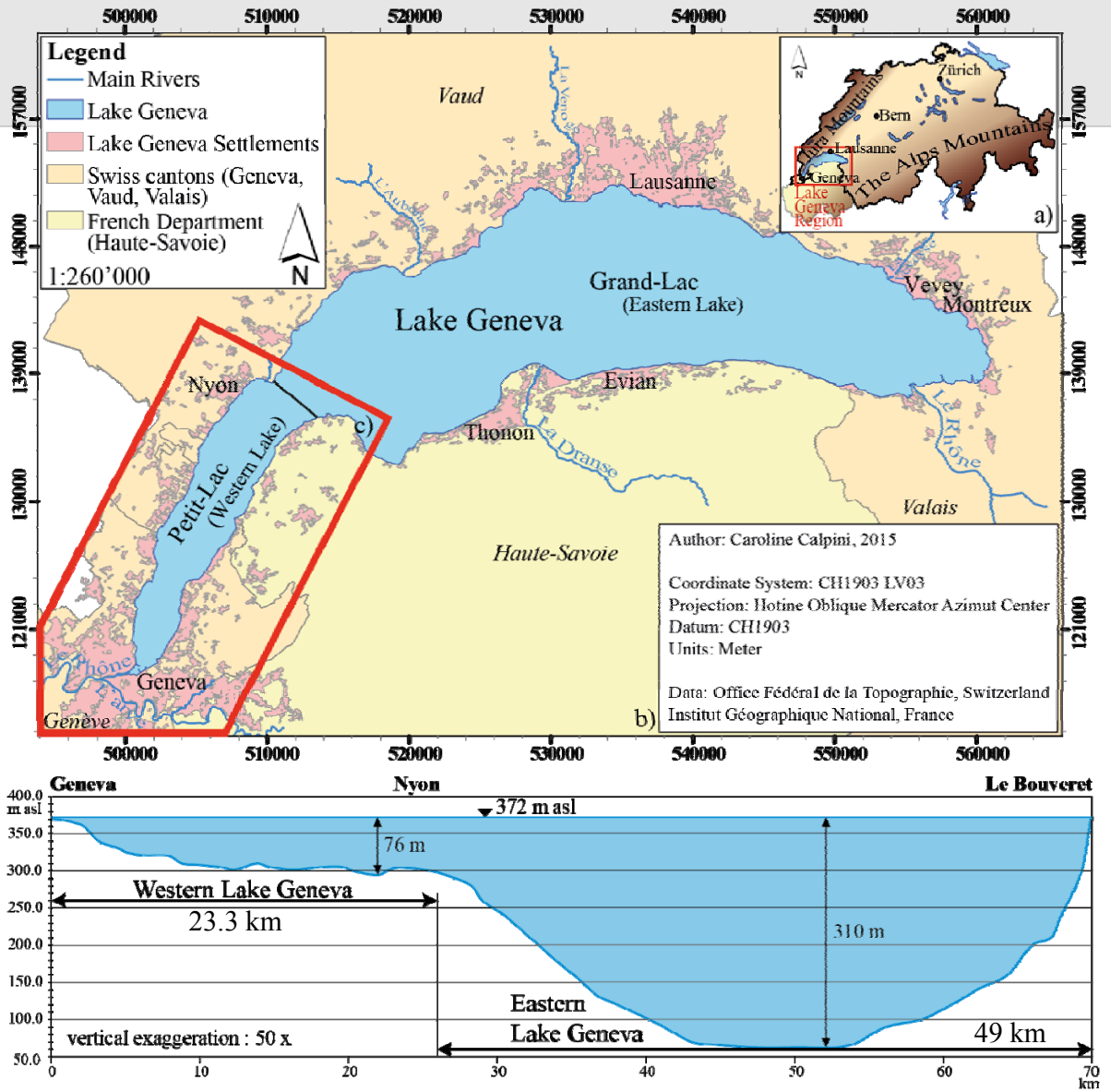
Historical prospect

1. 6 large mass-movement deposits (past 3'695 years)
   - ➢ 2 meter-sized tsunamis
   - ➢ 4 possible meter-sized tsunamis

2. Last major event: 563 AD (Tauredunum event)

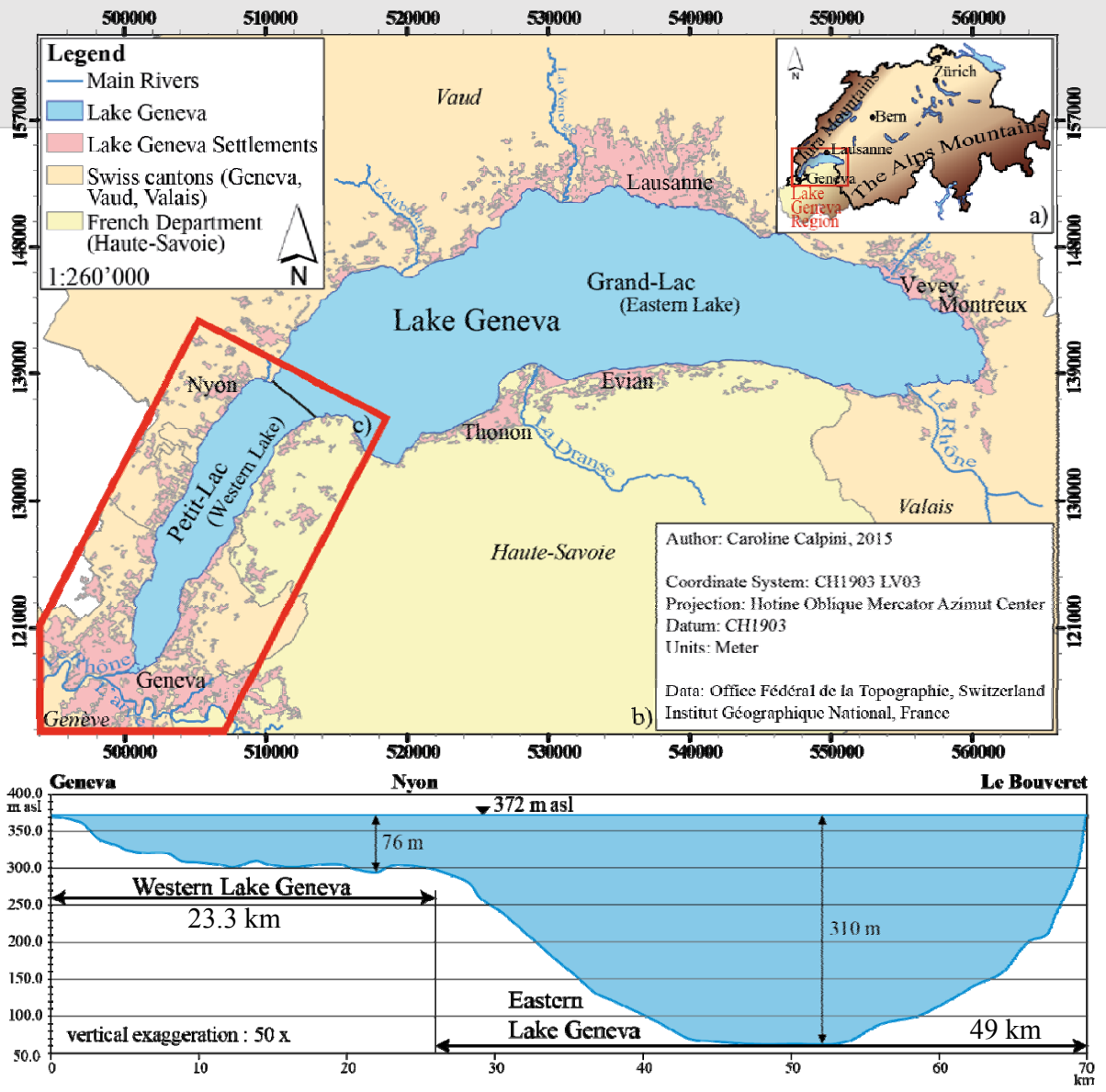
3. A tsunami associated with a large mass-movement event cannot be excluded in the next 500 years!

Source: Kremer et al., 2015



Socio-economical

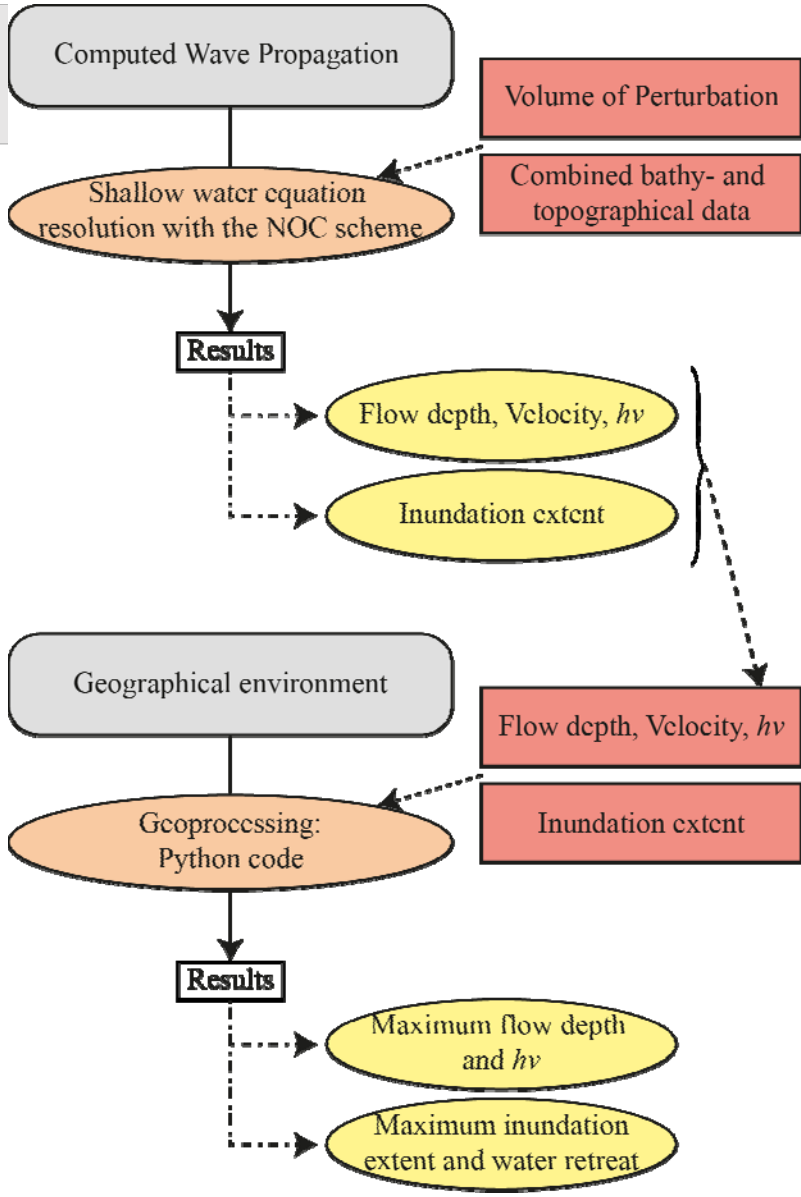
1. Encompassed 1.5 millions of inhabitants
2. Major economical region: 16 % of the Swiss PIB.
3. Only 3 % of the shore remains completely natural



Methods

1. Tsunami wave propagation path model:
   - Resolution of the shallow water equations with the non-oscillatory central differencing (NOC) scheme method
   - Grid size: 20 m x 20 m
   - Cells: 350 x 1’245

2. Tsunami hazard maps:
   - Geographical environment
   - Python code (transformation – extraction)

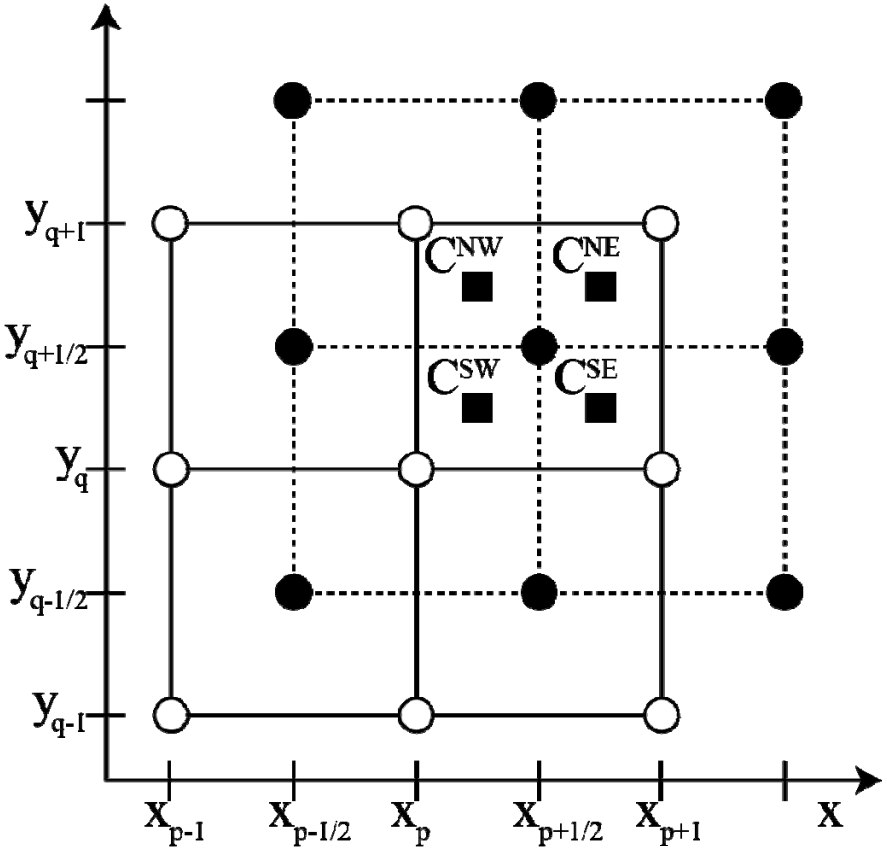


The non-oscillatory central differencing (NOC) scheme method :

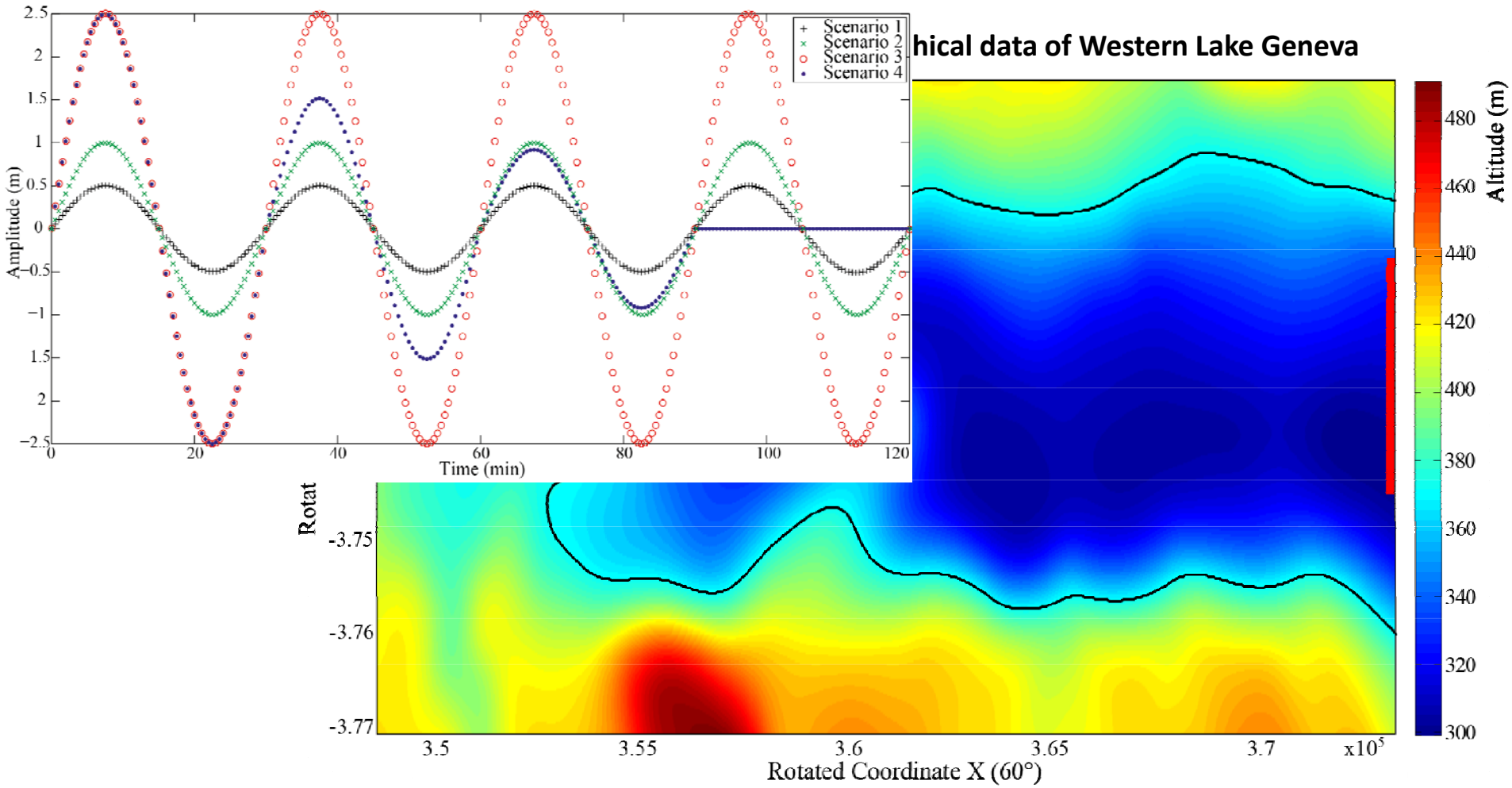
1. **Wet/dry boundary:** Avoid spurious non-physical oscillation (numerical instabilities)

2. **Cell value:** Predictor – Corrector method

3. **Stability :** use of a Total Variation Diminishing (TVD) limiter and Courant-Friedrichs-Lewy (CFL) stability condition

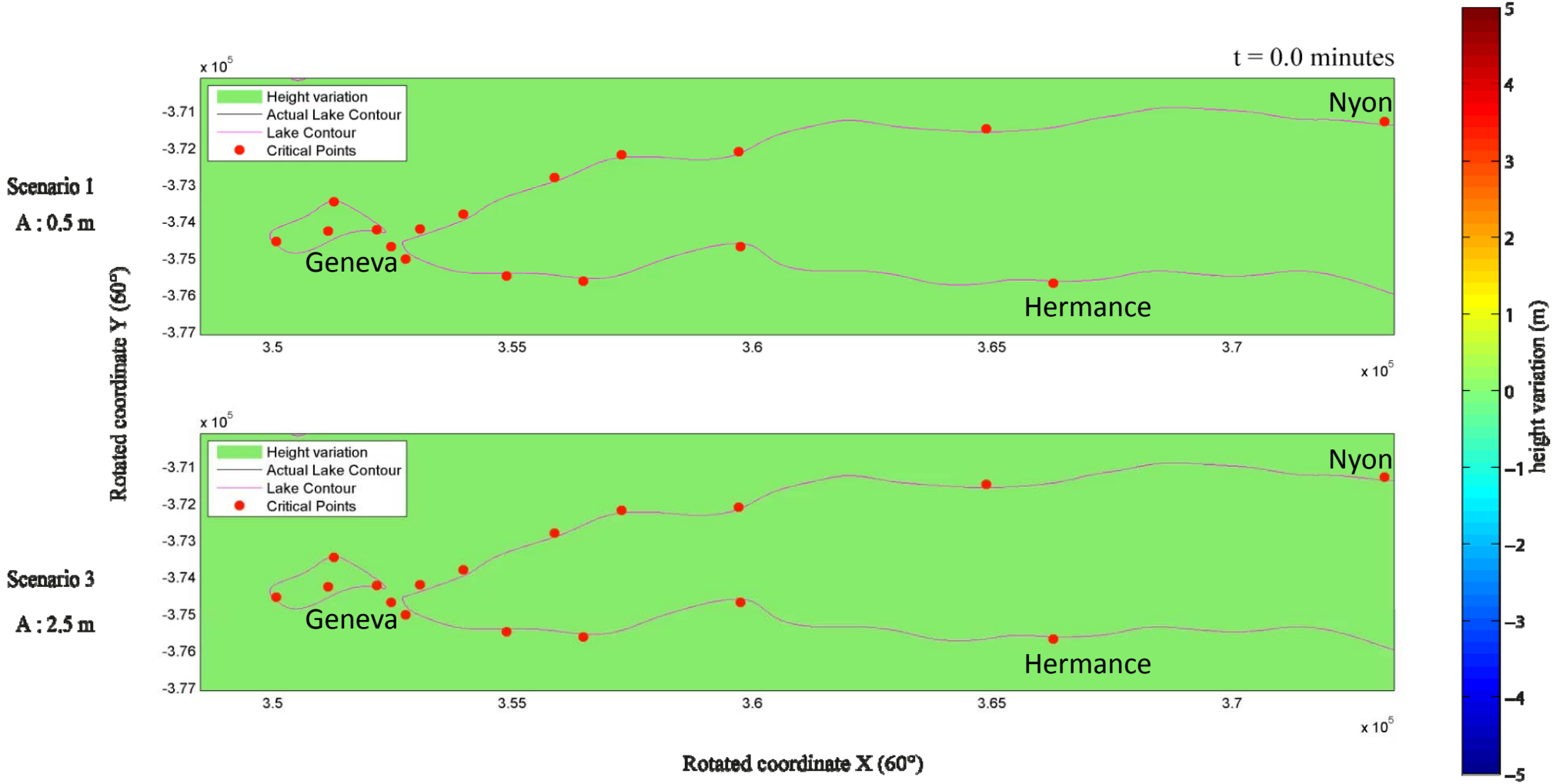


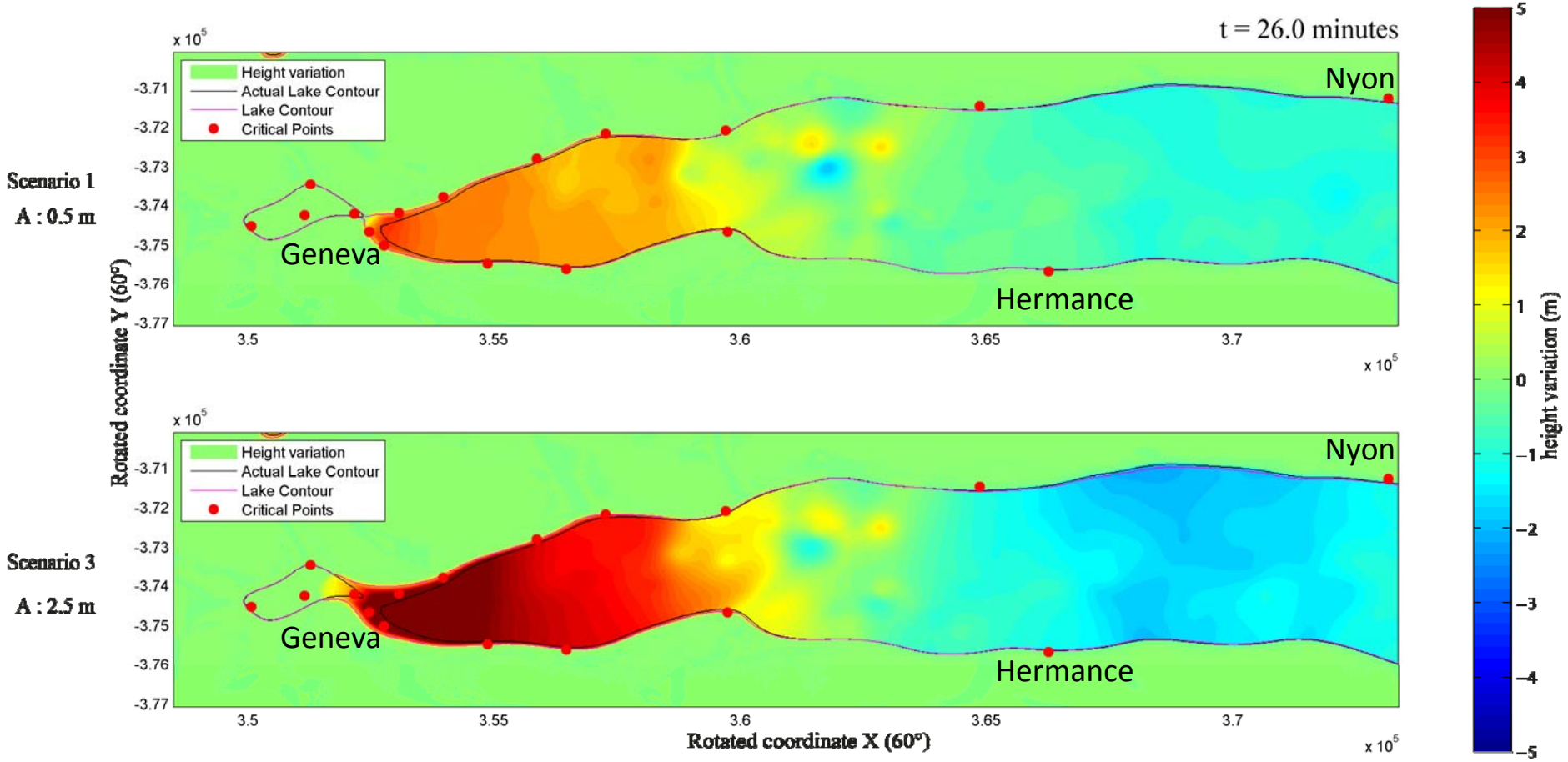
Source: Nessyahu and Tadmor, 1990; Zia and Simpson (in prep)



hical data of Western Lake Geneva

Results

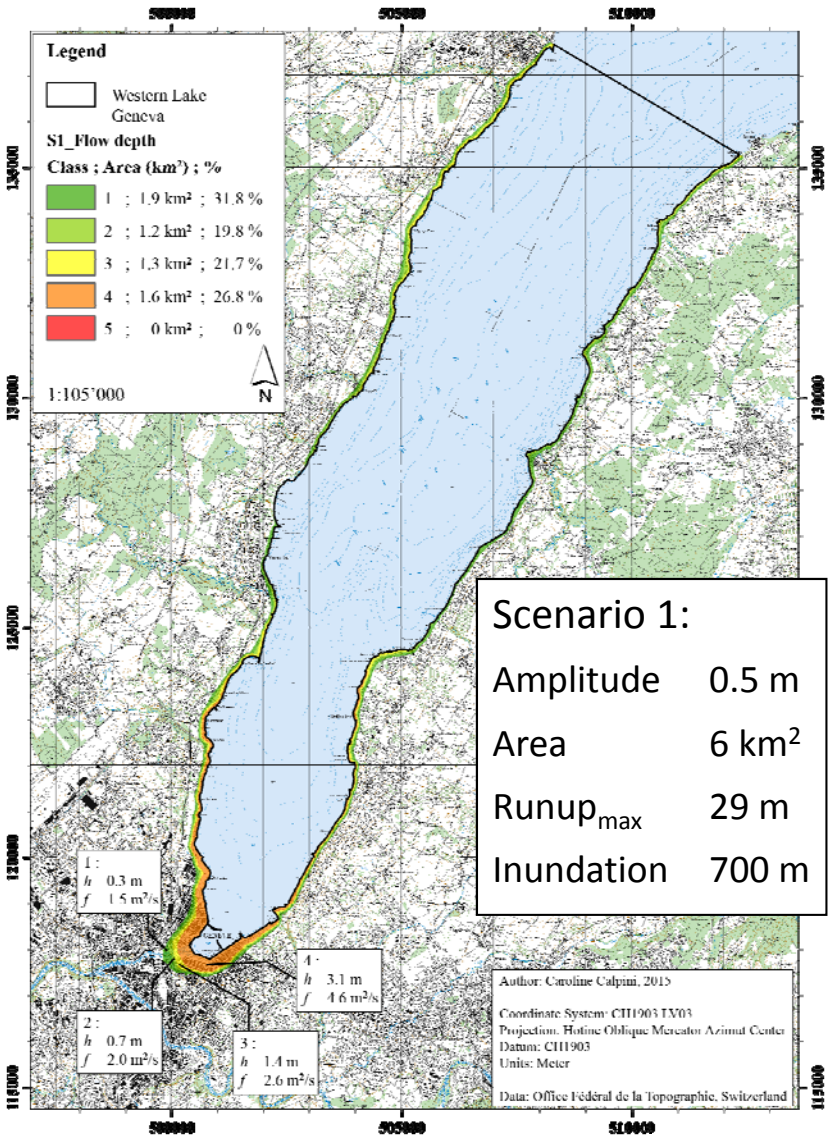

Scenario 1
A : 0.5 m
Scenario 3
A : 2.5 m
t = 0.0 minutes
Height variation
Actual Lake Contour
Lake Contour
Critical Points
Nyon
Geneva
Hermance
x 10^5
-3.71
-3.72
-3.73
-3.74
-3.75
-3.76
-3.77
3.5
3.55
3.6
3.65
3.7
Rotated coordinate Y (60°)
Rotated coordinate X (60°)
height variation (m)
5
4
3
2
1
0
−1
−2
−3
−4
−5



	Scenario 1	Scenario 3
Initial wave amplitude	0.5 meter	2.5 meters
First wave (Geneva City)	2 meters	6 meters
Greatest wave (Geneva City)	3 meters	9 meters

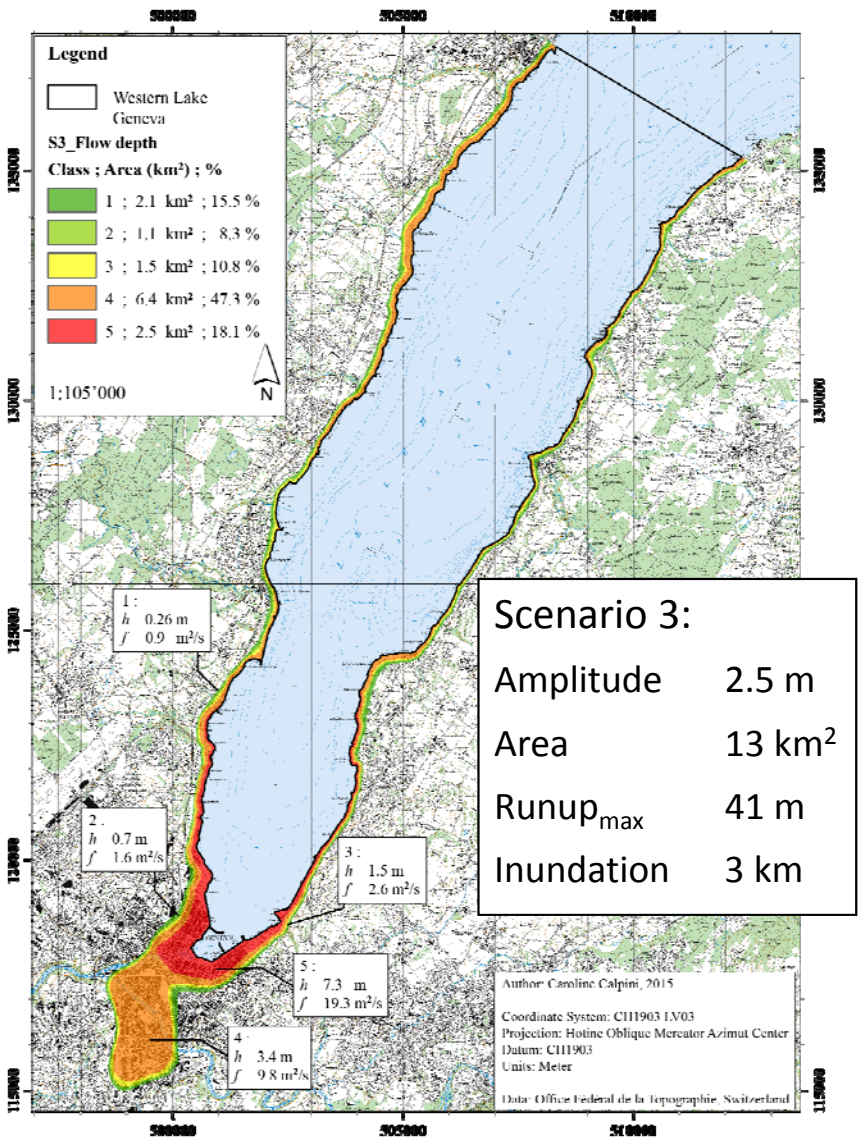
Class	Tsunami Flow depth [m]
1	< 0.5
2	0.5 – 1
3	1 – 2
4	2 – 5
5	> 5

Source: adapted from Lekkas et al., 2013



Scenario 1:

Amplitude	0.5 m
Area	6 km²
$Runup_{max}$	29 m
Inundation	700 m

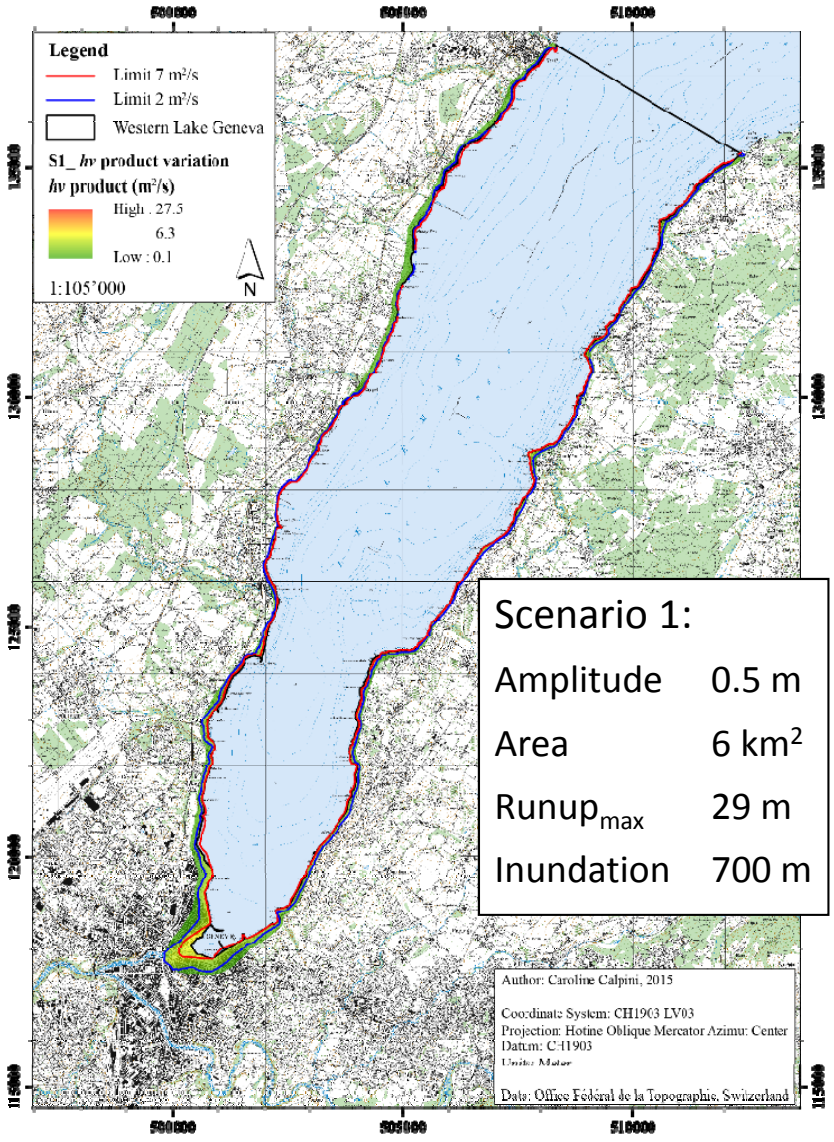


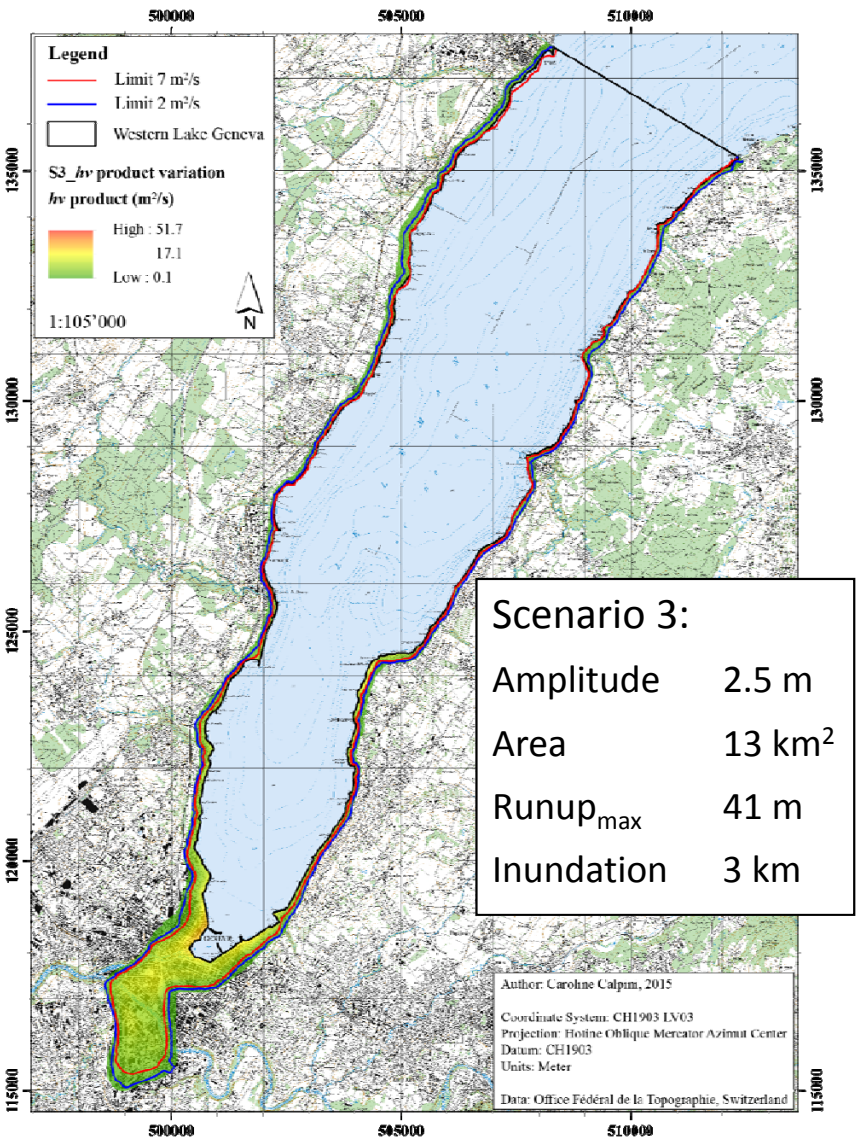
Scenario 3:

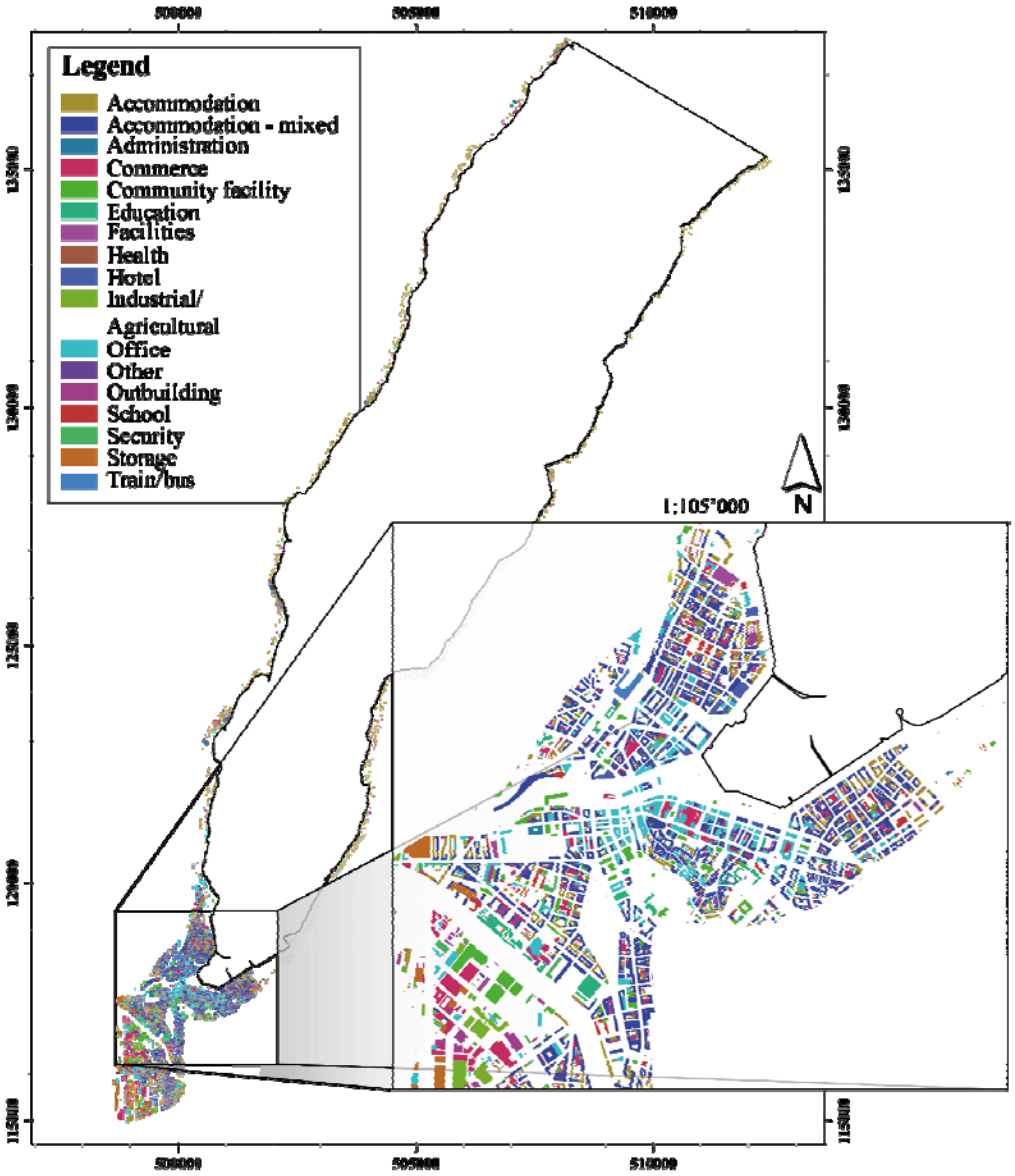
Amplitude	2.5 m
Area	13 km²
$Runup_{max}$	41 m
Inundation	3 km

	Critical *hv* of stability [m²/s]
Persons	2
Buildings	7

Source: REDSCDAM, 2001; Jonkman et al., 2008







Exposure assessment for the Western Lake Geneva

Scenario 1	Scenario 3
Population exposed (Swiss area)	
~ 30’000 persons	More than 100’000 persons
Buildings exposed	
~ 4’600 buildings	~ 10’600 buildings
Lifelines (roads) exposed	
~ 80 km	~ 200 km

Conclusion

1. Strength of the model
   - Model a moving wet/dry interface properly
   - Validity of the model
   - Over the real lake bathymetry

1. Wave propagation path
   - Wave amplification by the geometry of the lake
     - Scenario 1: factor of 6
     - Scenario 3: factor of 3.6
   - Geographical location
     - Perpendicular location more at-risk than parallel location
   - Tsunami physical parameters
     - Flow depth up to 9 meters (Scenario 3)
     - Flow depth x velocity product more than 51 m^2/s (Scenario 3)

1. First step towards understanding the risks associated with a tsunami occurring on Western Lake Geneva
   - Risk not negligible
   - Raising awareness
   - Mitigating measures

Credit: NOAA

Thank you !