Tsunami hazard assessment on the coast of the Caspian Sea

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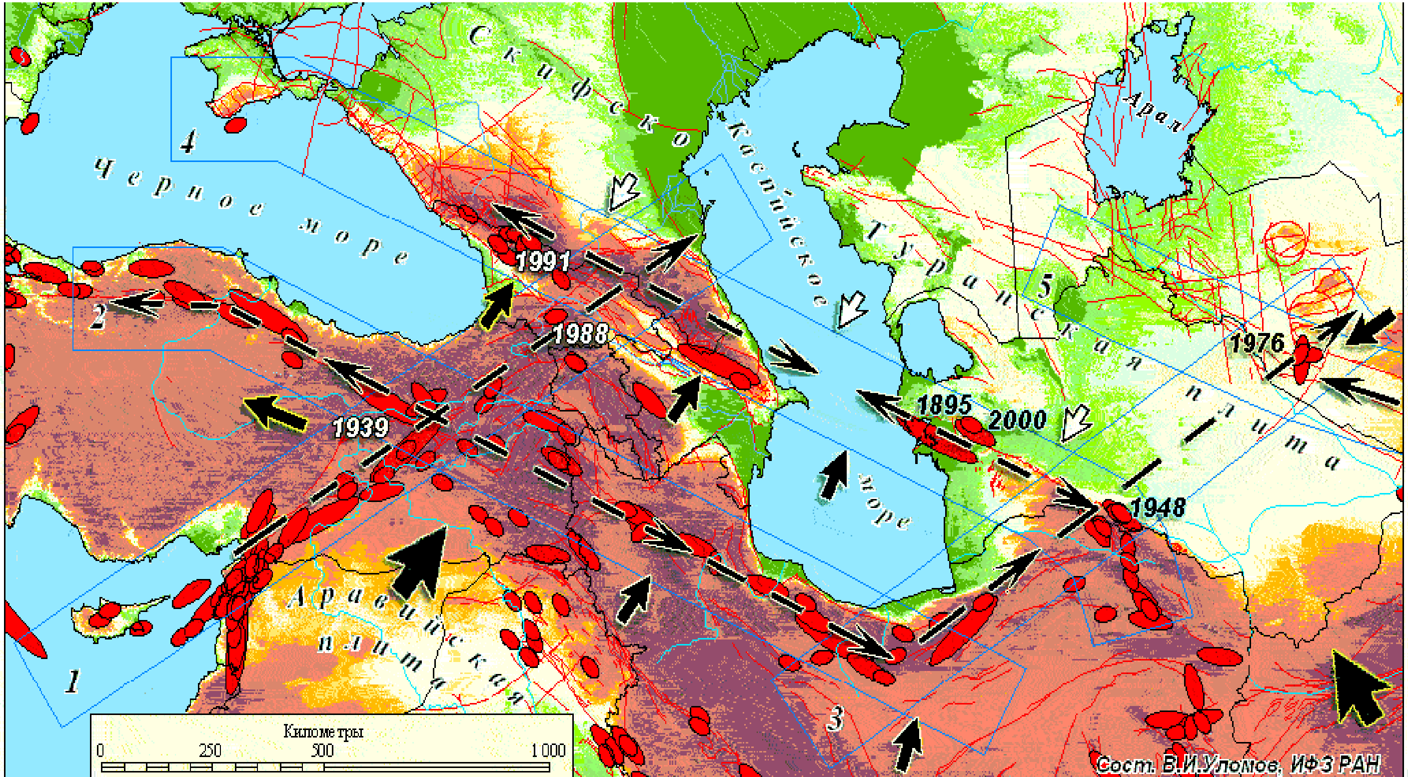
Outlook

- Seismicity of the region and historical tsunamis
- Methods
- Deterministic approach
- Probabilistic approach
- Effect of mean sea level on the propagation of tsunami waves

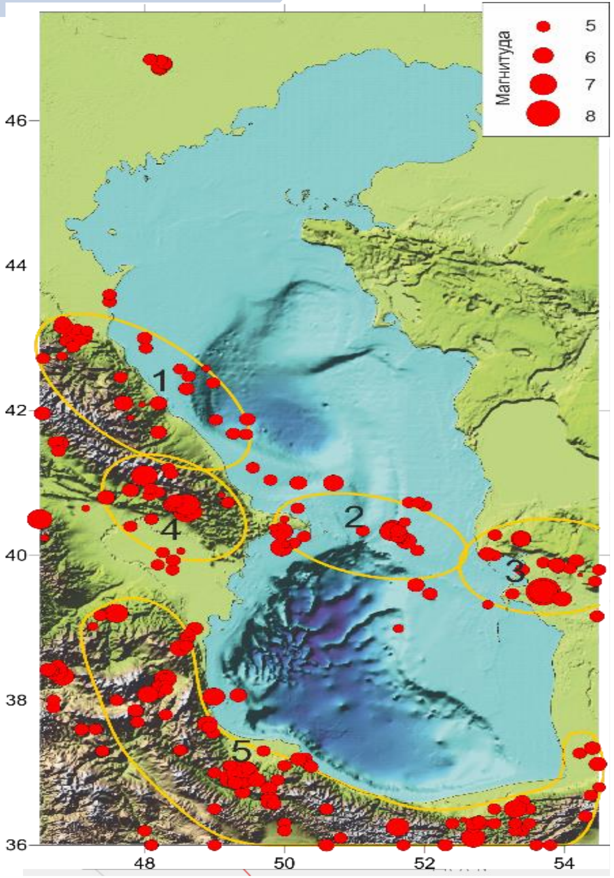
Seismicity of the Region



2 main geotectonic procceses:

I. The pseudosubduction of the southern Caspian under the Scythian-Turanian plate
II. Inconsistent orientation of the Caspian lowland in relation to the Alpine-Himalayan orogeny

Catalogue USGS from 1900 y.



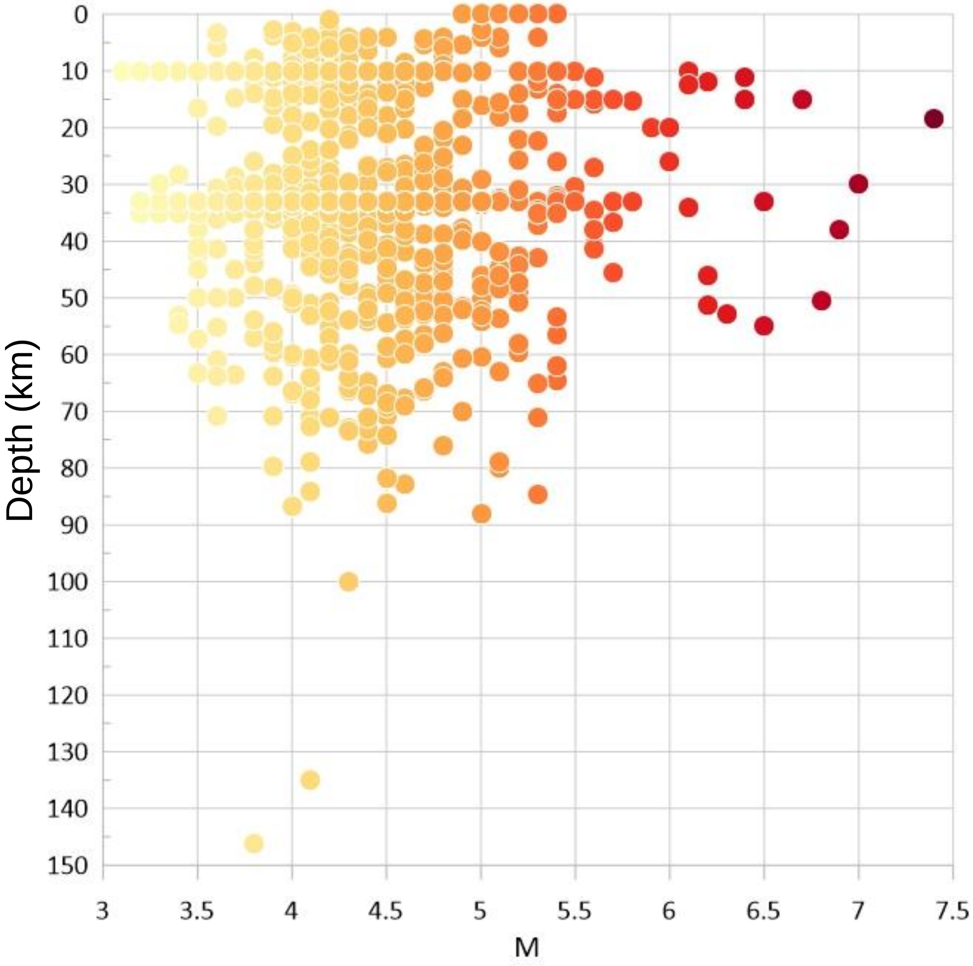
1954 earthquakes with M>=2.5

33 earthquakes with M>=6

<u>Currently, there are references to 14 cases of tsunamis / anomalous level oscillations (wave height did not exceed 1-2 m).</u>

- Rudbarskoe (Iran) 1990 with M = 7.4
- Krasnovodskoe (Turkmenistan) 1895 with M = 8 ± 0.2
- Turkmen 2000 with M = 7
- Kazandzhik 1946 with M = 7
- Bolshebalkhanskoe 2002 with M = 7.2-7.4
- 743, 918, 957 Derbent
- 1668 Terek
- 1868, 1902, 1960 Baku
- 1876 Chigil
- 1933 Guvlymayak
- 1986 Absheron threshold

Seismicity of the Region



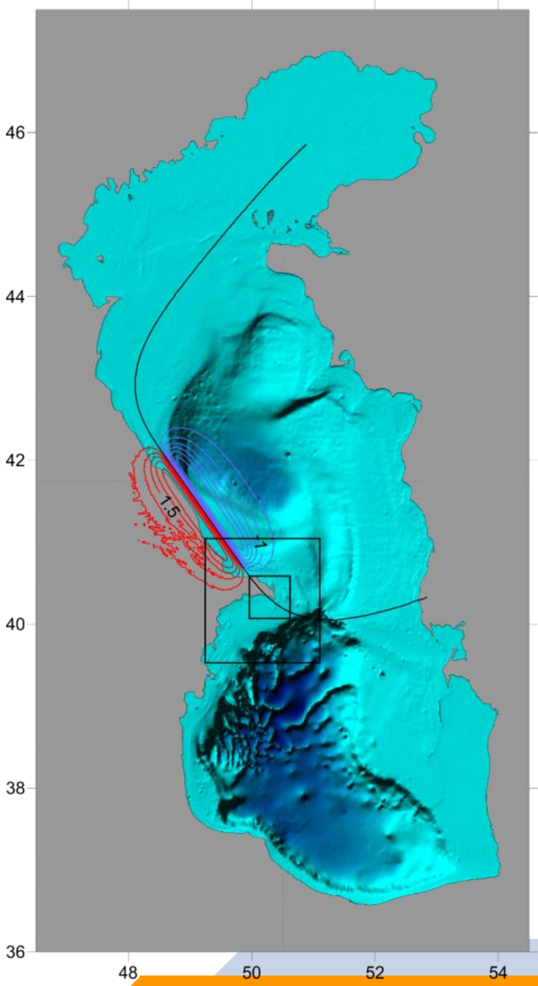
Methods

- A variation of the **TUNAMI** model [Imamura, 1996], which implements the finite-difference approximation of the shallow water equations in a spherical coordinate system

- The seabed topography was set at 30 ″ resolution according to **GEBCO** data.

- Smooth NASA SRTM3 data at 1 “(Shuttle Radar Topographic mission).

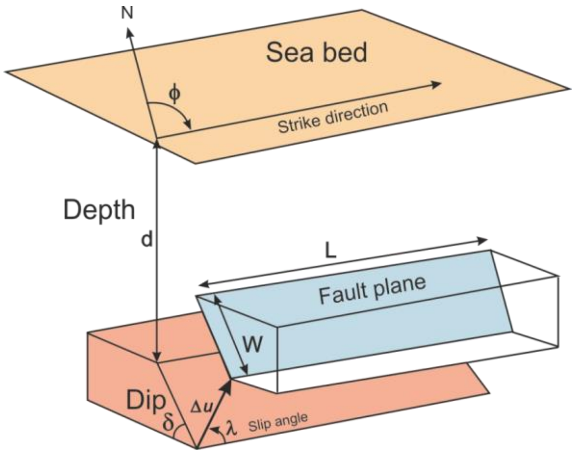
- The numerical model used nested mesh technology [Fine et. al., 2018]: the first main grid covers the entire sea with a horizontal resolution of 30 arc seconds, the second, intermediate, with a step of 6 seconds and, finally, a grid for calculating the wave run up to the coast with a resolution of 1 arc second ("), which is approximately 30 m. When generating bathymetry grids with a resolution of 1 "and 6", data from navigation charts 1: 50,000 were digitized.



(https://earthdata.nasa.gov/)

(https://www.gebco.net/)

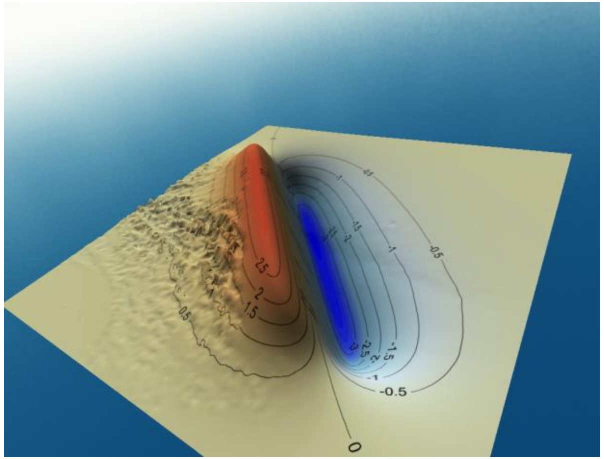
Source calculation



Regression Formulas

$$lgL = 0.59M_w - 2.44 \pm 0.16$$
$$lgW = 0.32M_w - 1.01 \pm 0.15$$
$$lg\Delta u_{av} = 0.69M_w - 4.8 \pm 0.36$$
$$lg\Delta u_{max} = 0.82M_w - 5.46 \pm 0.42$$

[*Wells & Coppersmith*, 1994]



Coseismic bottom displacements

[*Okada*, 1985]

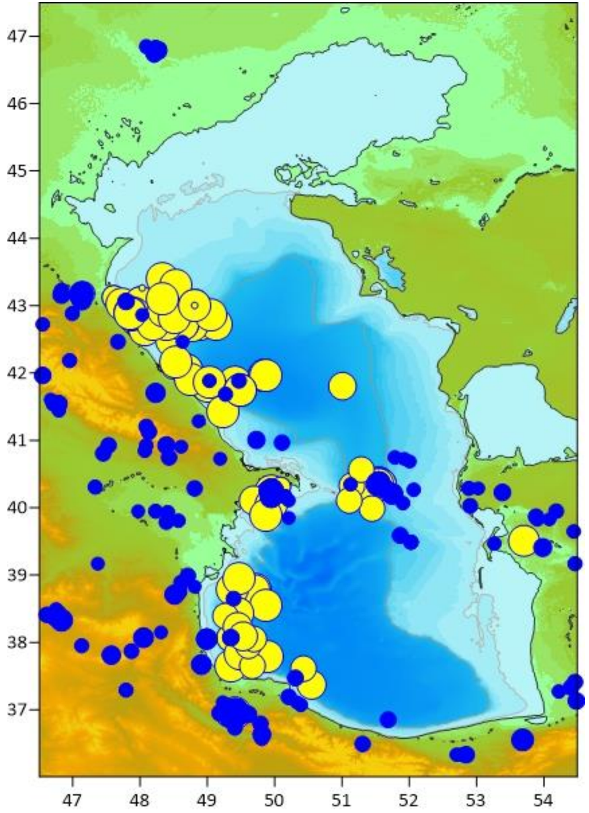
10 source parameters

Mw	° LAT	° LON	Depth (km)	Strike, φ (°)	Dip, δ (°)	Rake, λ (°)	Slip (m)	L (км)	W (км)
8	41.42	49.23	30	325	86	-90	12.6	190	35

$$M_0 = \mu LWD$$

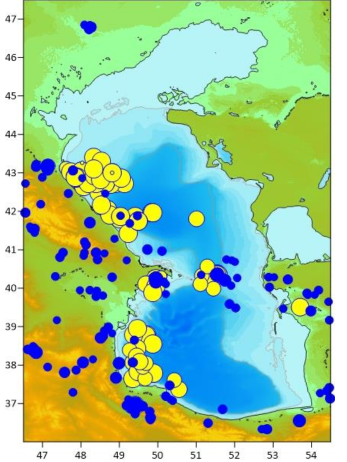
Deterministic approach

- Variation of 10 source parameters to Find the "worst-case scenario" for the selected region
- Tsunami height depends on the magnitude of the earthquake
- Steep angle (Dip), close to 90 degrees
- Shallow depth of earthquake epicenter
- The deeper the ocean, at the site of the earthquake, the higher the generated tsunami can be.
- ...



Results from real earthquakes

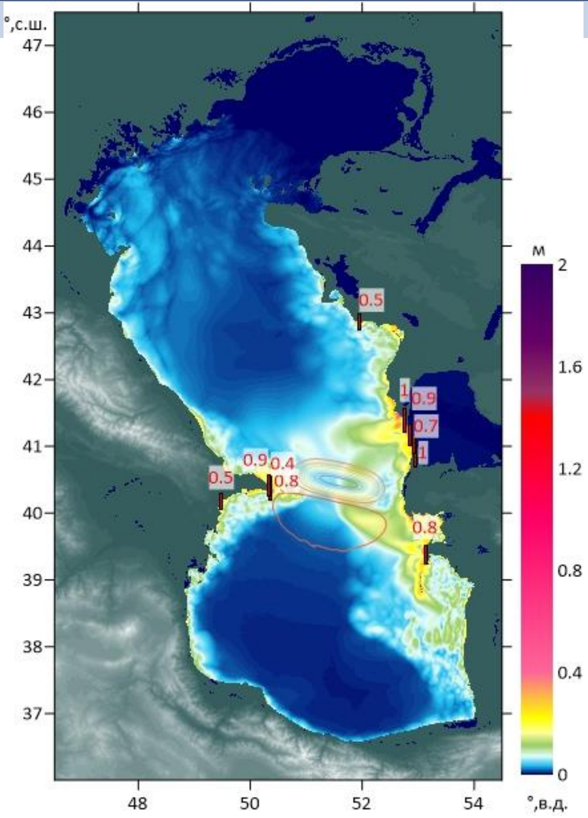
№	M	Depth (km)	Strike, °	Dip, °	Rake, °	D, m	L, km	W, km	NP	H_{max}m
11	5.6	27	159	26	40	0.14	7.3	6.1	1	0.003
12	5.6	27	32	74	110	0.14	7.3	6.1	2	0.003
14	6.2	46	1	85	90	0.42	16.5	9.4	2	0.008
01	6.8	50.4	331	80	-81	1.31	37.3	14.7	1	0.103
02	6.8	50.4	109	14	-131	1.31	37.3	14.7	2	0.103
15	6.5	33	303	67	-88	0.74	24.8	11.7	1	0.071
16	6.5	33	118	23	-95	0.74	24.8	11.7	2	0.057
17	6.5	33	299	87	-86	0.74	24.8	11.7	1	0.072
18	6.5	33	67	5	-142	0.74	24.8	11.7	2	0.035
19	6.5	54.8	332	64	-64	0.74	24.8	11.7	1	0.037
20	6.5	54.8	104	36	-132	0.74	24.8	11.7	2	0.032
21	6.2	51.4	292	36	-115	0.42	16.5	9.4	1	0.008
22	6.2	51.4	142	58	-73	0.42	16.5	9.4	2	0.010
27	7.4	18.5	19	35	179	4.06	84.3	22.8	1	0.026
28	7.4	18.5	110	90	55	4.06	84.3	22.8	2	0.868
29	7	30	322	38	132	1.91	49.0	17.0	1	0.132
30	7	30	92	63	62	1.91	49.0	17.0	2	0.130

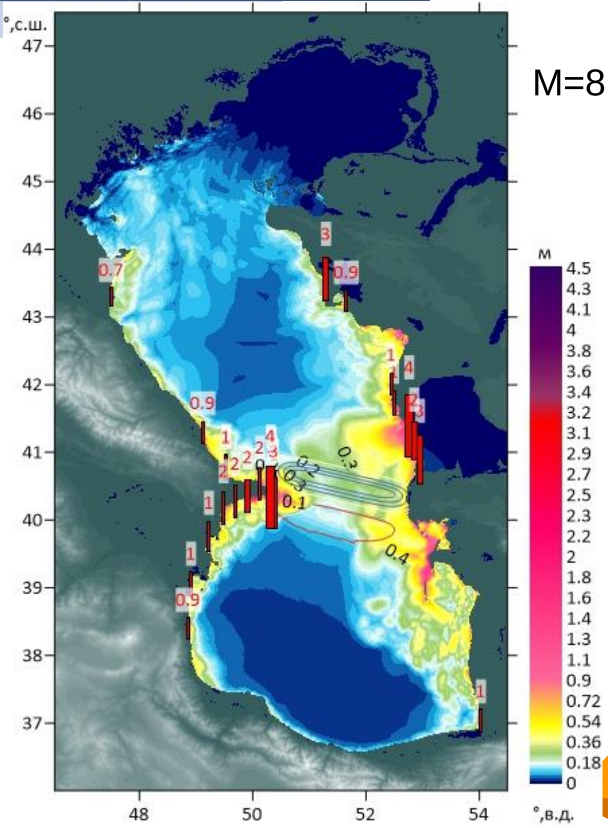


Maximum real earthquake has M 7.4 according to catalogue USGS from 1900 y.

Results - example

M=7.5



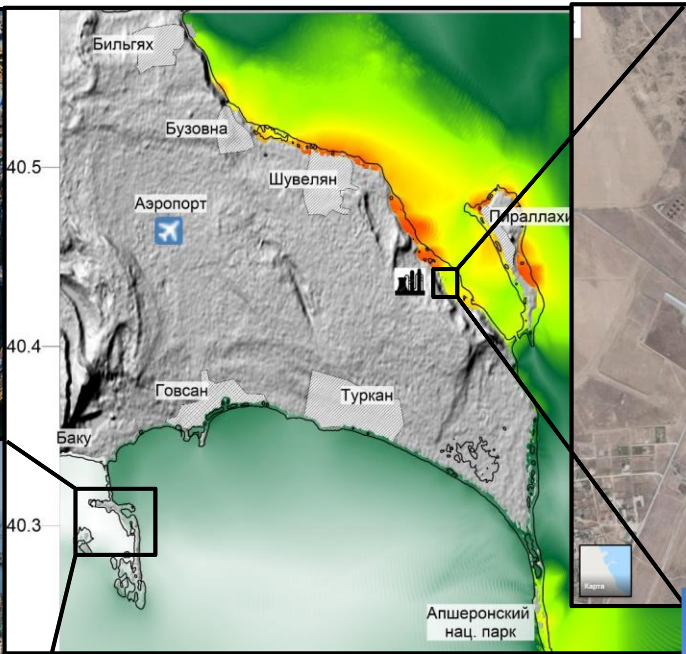


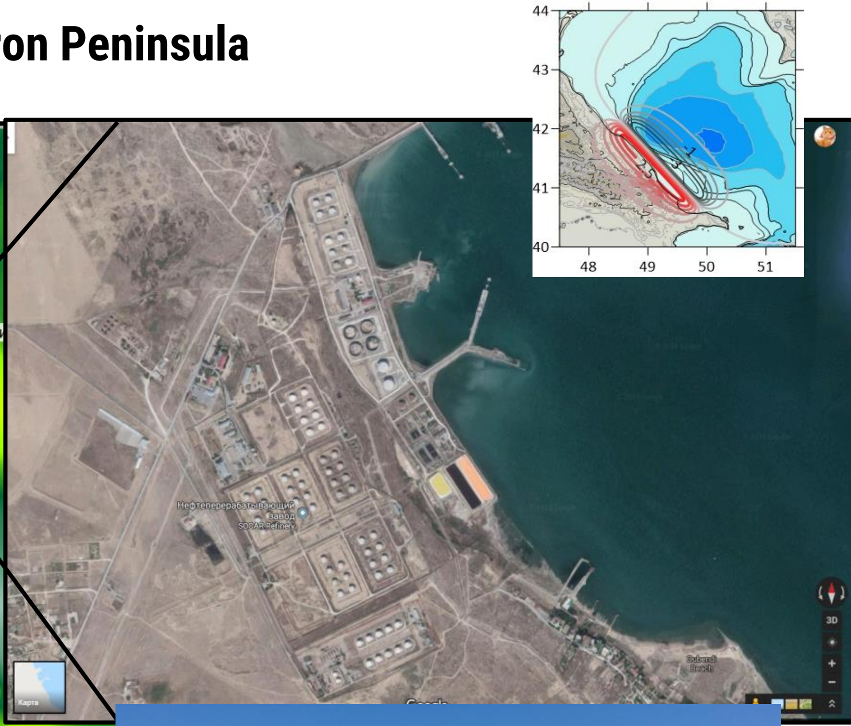
M=8

H max calculated from the 2 hypothetic seismic sources with M=7.5 and 8

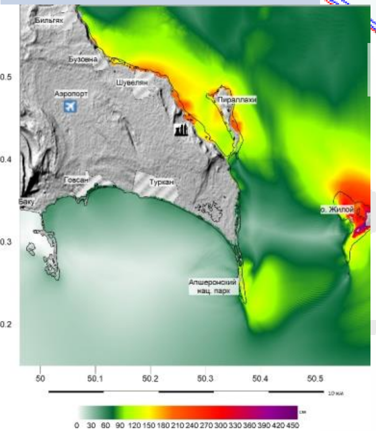
In these origin lie the real earthquake mechanism (its locations and angles, but artificially we raised magnitude)

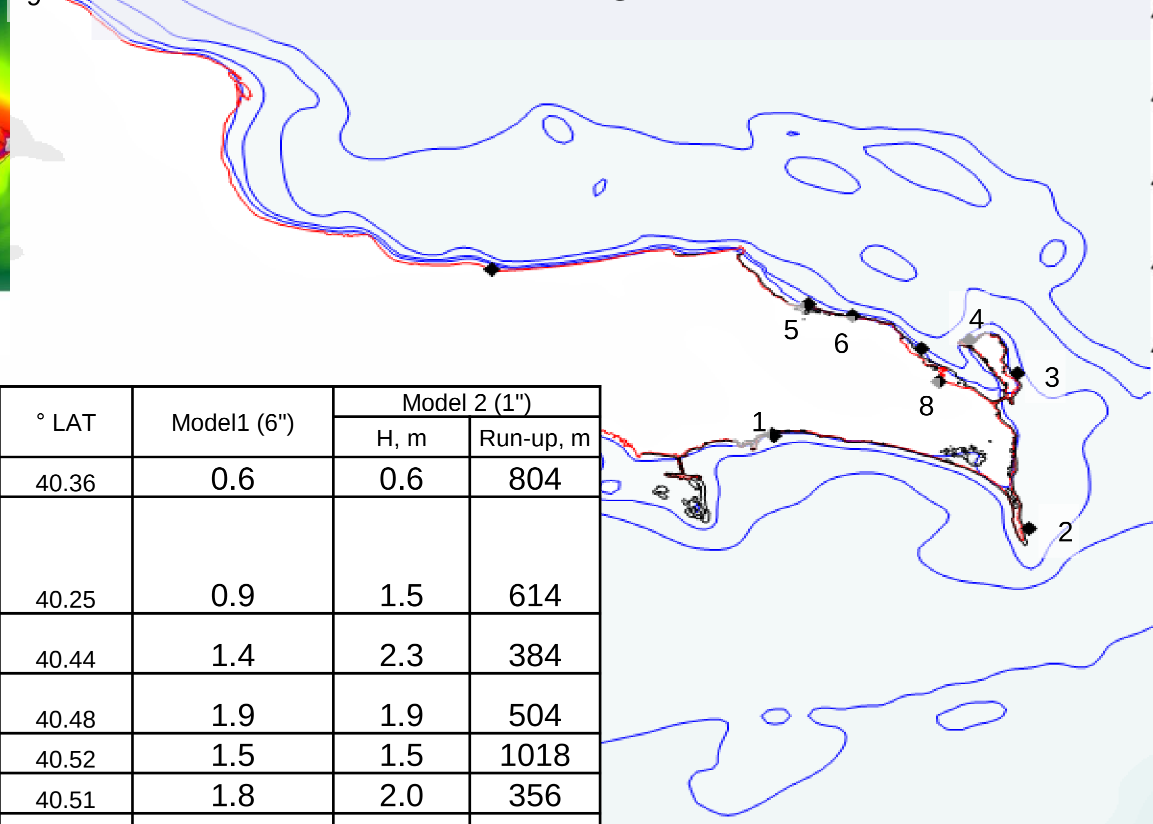
Results –run-up on the Absheron Peninsula

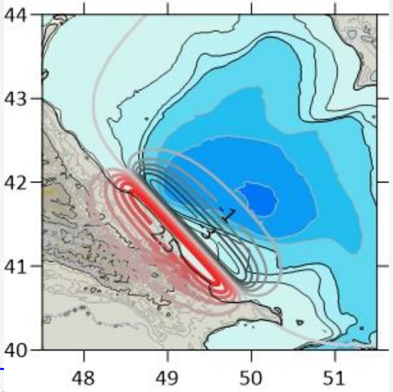




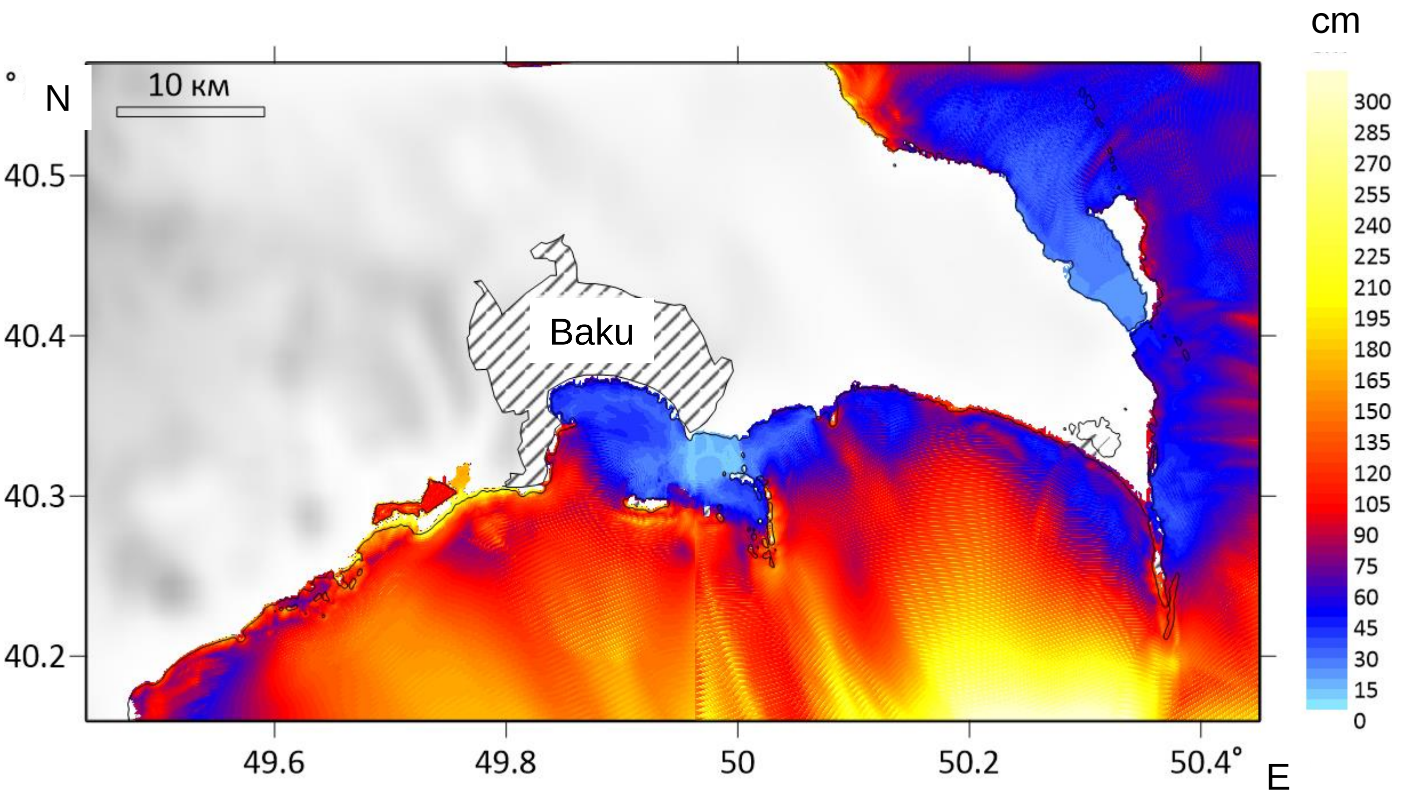
Tsunami heights for the Absheron Peninsula







№	Location	° LON	° LAT	Model1 (6")	Model 2 (1")	
					H, m	Run-up, m
1	Govsan	50.10	40.36	0.6	0.6	804
2	Cape (Absheron National Park)	50.38	40.25	0.9	1.5	614
3	Pirallahi (east)	50.36	40.44	1.4	2.3	384
4	Pirallahi (north)	50.31	40.48	1.9	1.9	504
5	Buzovna	50.14	40.52	1.5	1.5	1018
6	Shuvelyan	50.19	40.51	1.8	2.0	356
7	Isl. Jiloj	50.57	40.35	3.8	3.1	3033
8	Oil refinery	50.26	40.47	2.0	2.4	1474
9	Novhany	49.80	40.57	1.8	2.1	186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40.4
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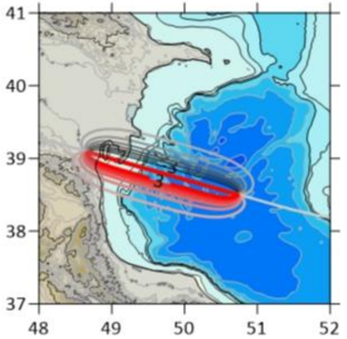
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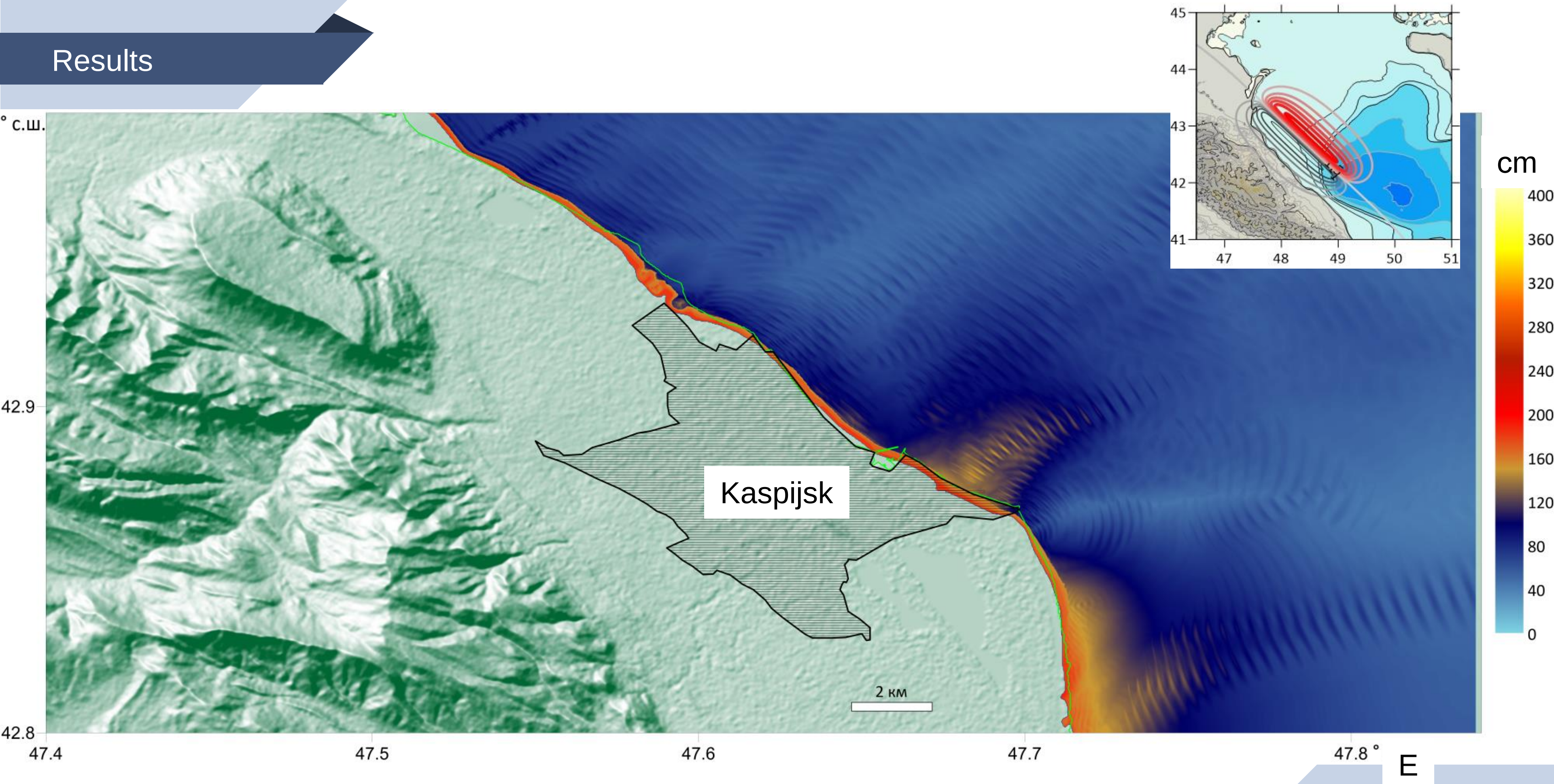
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Probabilistic model of the tsunami hazard of the Caspian Sea

Probabilistic approach

Probabilistic model of seismicity of the region

Creation of a synthetic earthquake catalog

Modeling virtual events

Statistical analysis

Tsunami hazard maps for different return period

Probabilistic approach

First application of this approach in tsunami hazard assessment

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, B01305, doi:10.1029/2010JB008169, 2012

Probabilistic tsunami hazard in the Mediterranean Sea

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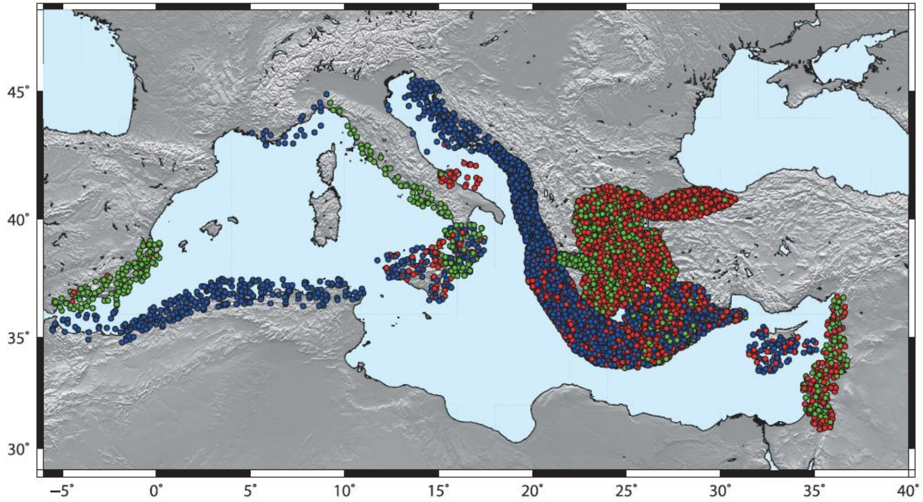
Received 17 December 2010; revised 26 October 2011; accepted 6 November 2011; published 10 January 2012.



Probabilistic approach –results of our Laboratory for the Arctic

Published Article

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ЦУНАМИОПАСНОСТЬ АРКТИЧЕСКОГО ПОБЕРЕЖЬЯ РОССИИ. ЧАСТЬ 1. КАТАЛОГ ВЕРОЯТНЫХ ЦУНАМИГЕННЫХ ЗЕМЛЕТРЯСЕНИЙ

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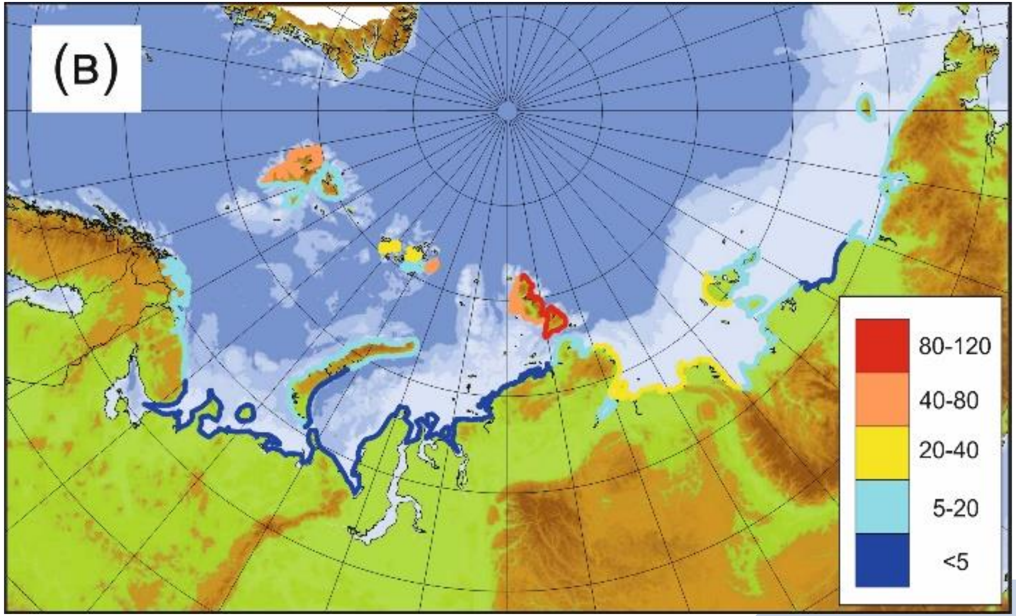
H_{max} tsunami possible 1 / 5000 y



Probabilistic approach – method in detail

AGU PUBLICATIONS

Reviews of Geophysics

REVIEW ARTICLE

10.1002/2017RG000579

Probabilistic Tsunami Hazard Analysis: Multiple Sources and Global Applications

Anita Grezio[1], Andrey Babeyko[2], Maria Ana Baptista[3], Jörn Behrens[4], Antonio Costa[1], Gareth Davies[5], Eric L. Geist[6], Sylfest Glimsdal[7], Frank I. González[8], Jonathan Griffin[5], Carl B. Harbitz[6], Randall J. LeVeque[8], Stefano Lorito[9], Finn Løvholt[7], Rachid Omira[3], Christof Mueller[10], Raphaël Paris[11], Tom Parsons[6], Jascha Polet[12], William Power[10], Jacopo Selva[1], Mathilde B. Sørensen[13], and Hong Kie Thio[14]

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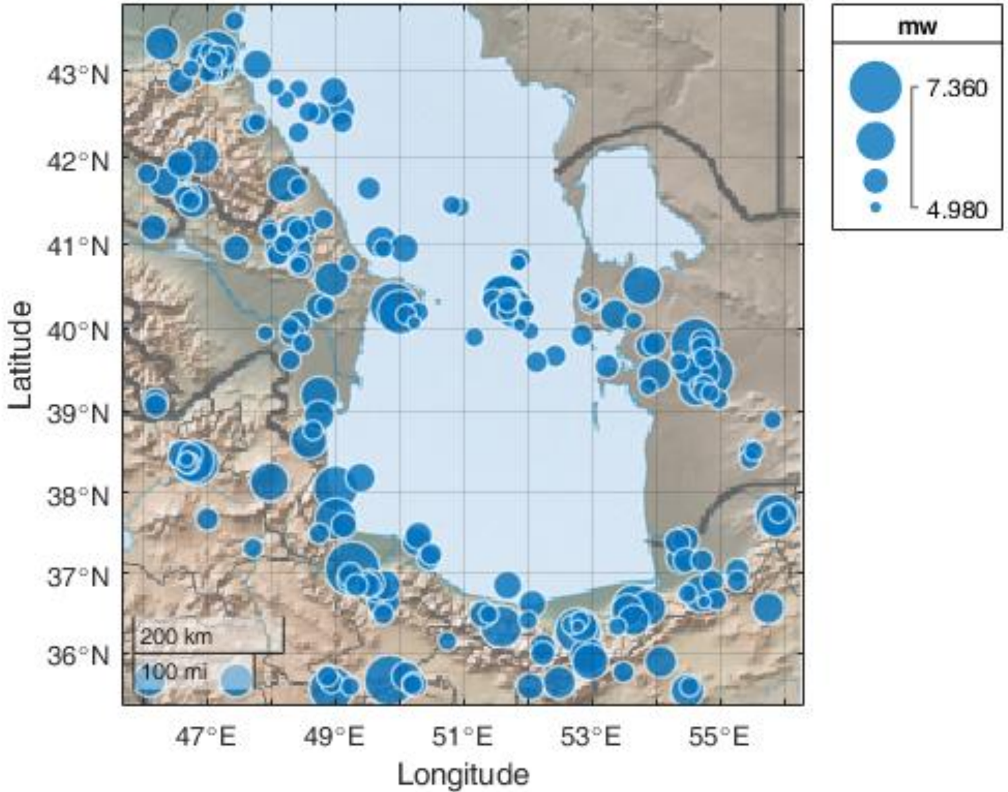
Key Points:

- PTHA quantifies the probability that different hazard intensity levels will be exceeded in a given time window at a specific place
- PTHA is the first step toward tsunami risk assessment and risk reduction planning
- A comprehensive review of PTHA is discussed for seismic and nonseismic tsunami sources with uncertainty quantification methods

Supporting Information:

- Supporting Information S1
- Data Set S1

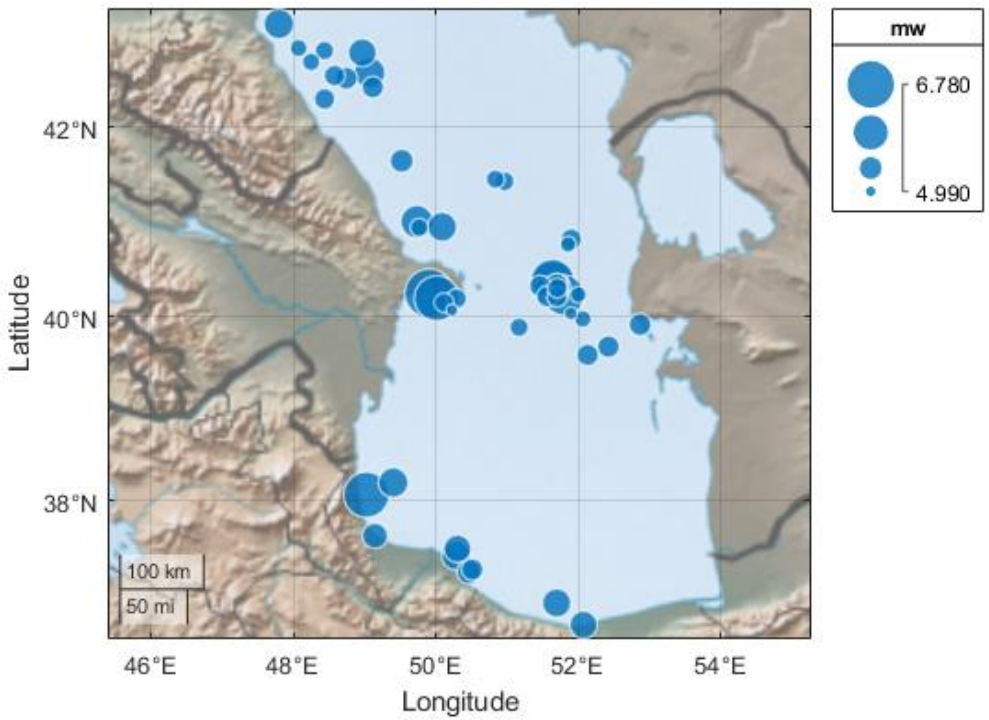
Probabilistic approach



All events of the Region

- GEM catalogue (1904-2016)
- Middle and South Caspian
- max(Mw) =7.4

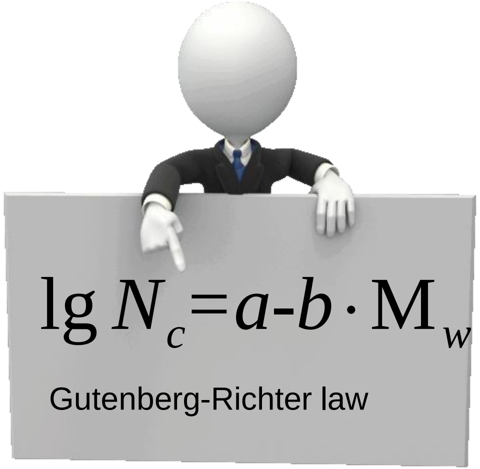
Probabilistic approach



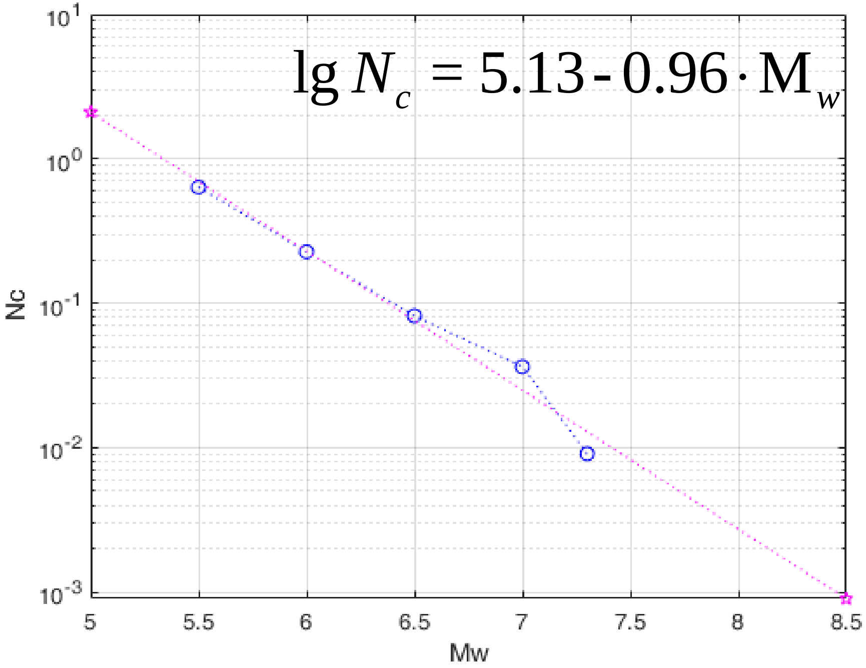
Events only at the sea

- GEM catalogue(1904-2016)
- Middle and South Caspian
- max(Mw) =6.7

Probabilistic approach

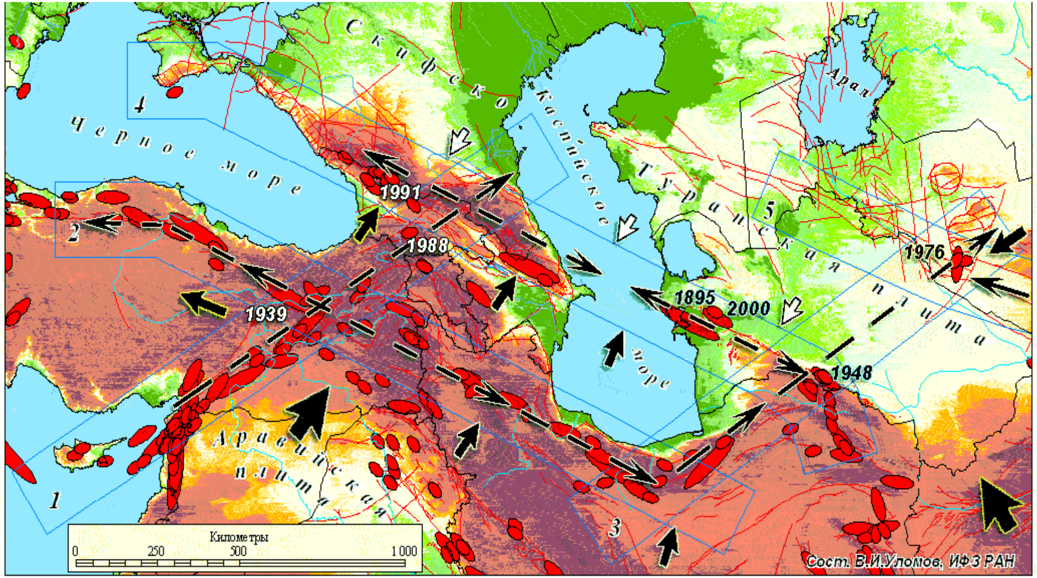


N_c – frequency of occurrence of earthquakes with a magnitude greater than or equal to Mw (the number of such earthquakes in the region per year)



Probabilistic approach

We added strong events from articles



Ulomov, 2008

- 856 y. M_w =8.1
- 958 y. M_w =8.0
- 1668 y. M_w =7.8
- 1895 y. M_w =7.9

Probabilistic approach

Kagan, 2002a,b

$M_{\mathrm{wt}} = 5.35$

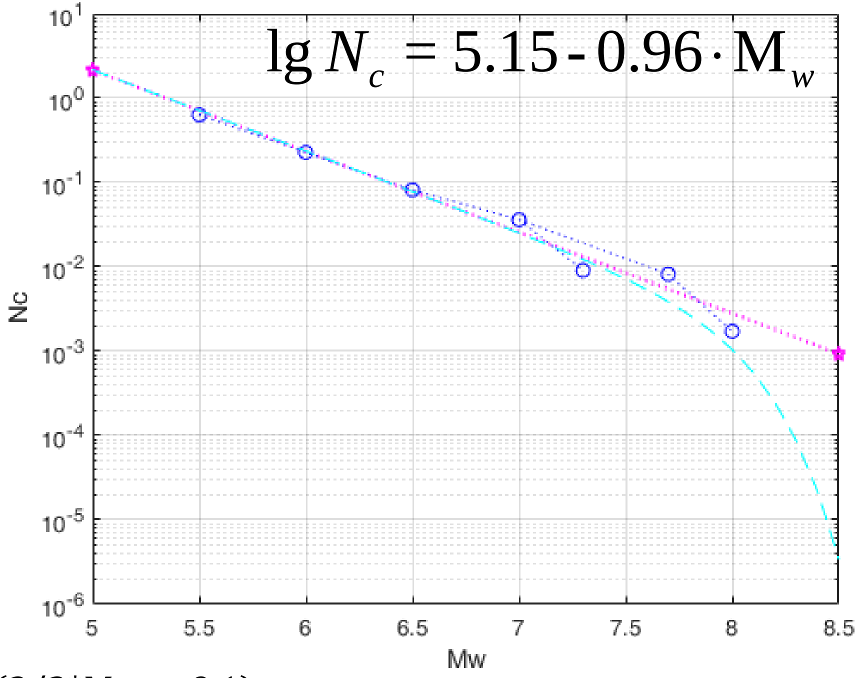
$M_{\mathrm{wc}} = 8$

$$P(M_0 \geq M) = \left(\frac{M_t}{M}\right)^{\beta} \exp\left(\frac{M_t - M}{M_c}\right)$$

M_t – the lower threshold of the seismic moment of the source, starting from which the event catalog is full

Mc - "angular" seismic moment of the source, starting from which a sharp downward deviation of the observed repeatability graph from the linear HR-graph begins

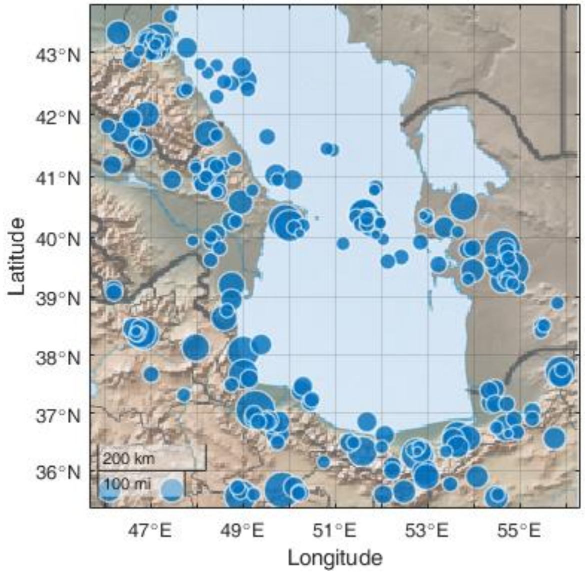
$\beta = 2/3 \times b$, where b is the slope of the standard repeatability curve



$\mathrm{M} = 10.\verb|^|(3/2 * \mathrm{M}_{\mathrm{w0}} + 9.1)$

Probabilistic approach

We got 76 mechanisms



Stk = 300 ± 22.5

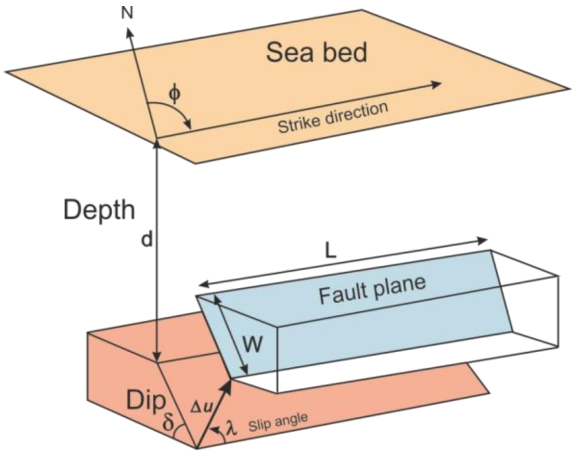
Dip = 70 ± 15

Rake = -90 ± 20

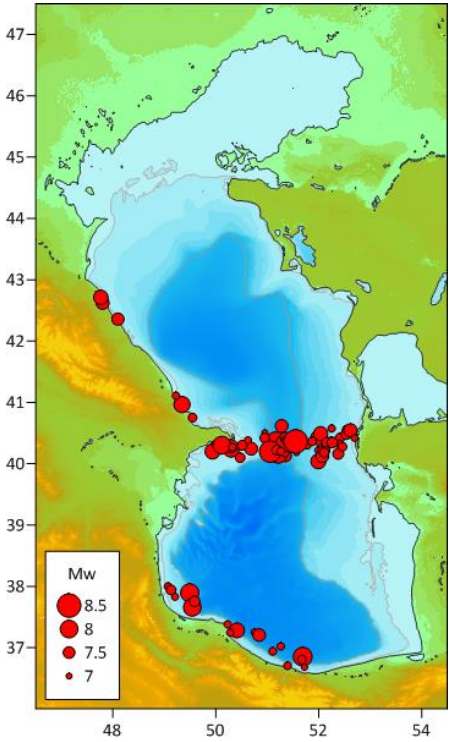
Stk = 300 ± 22.5

Dip = 70 ± 15

Rake = 90 ± 20



Probabilistic approach



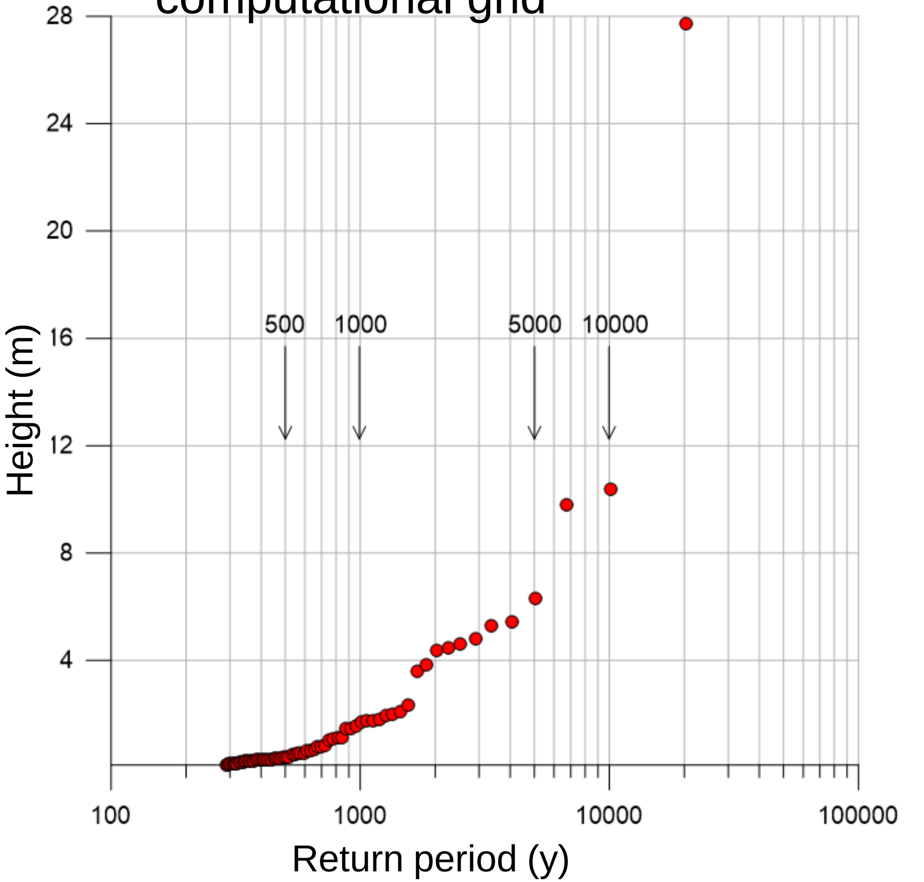
Finally we generated

20 000 years

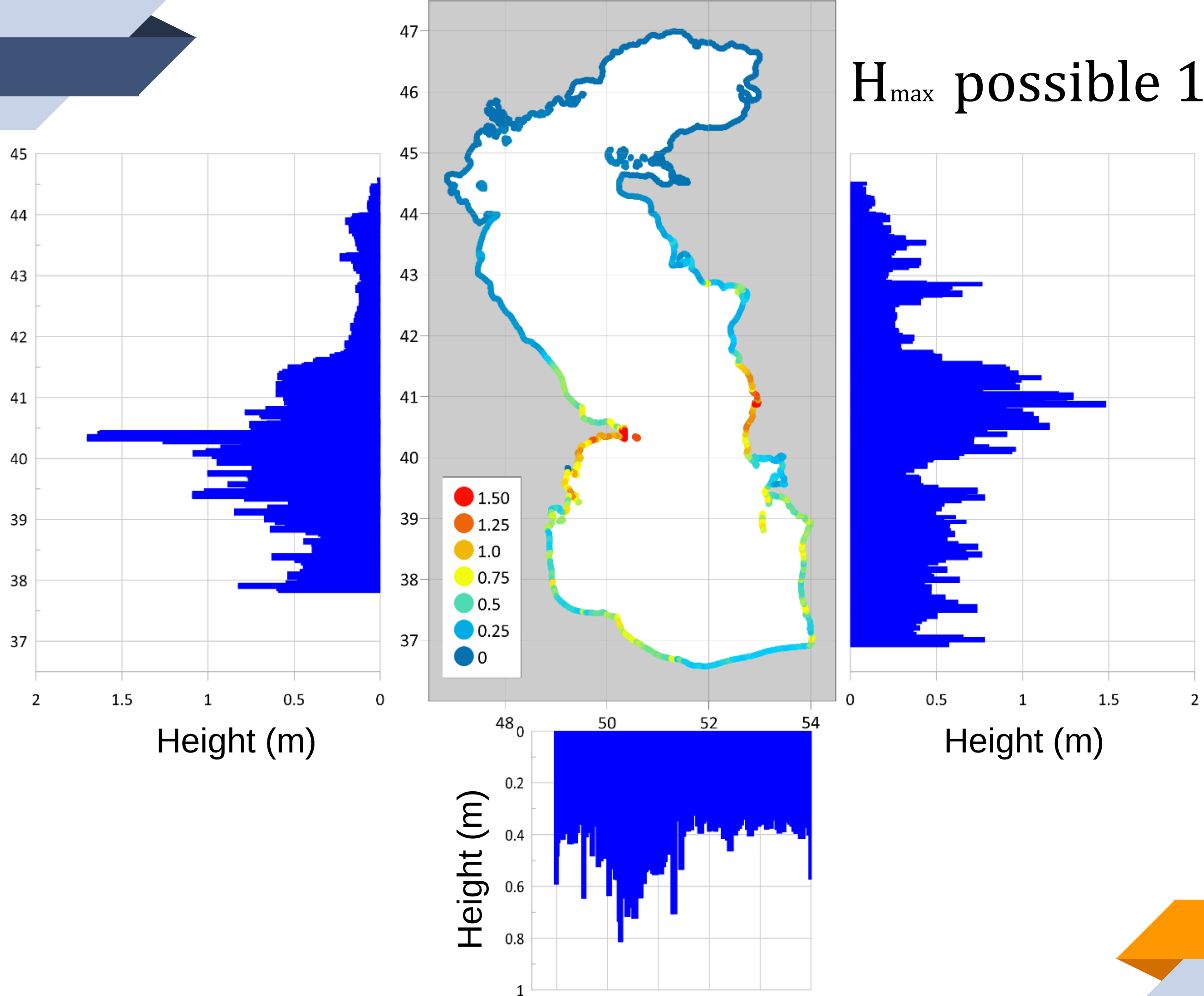
339 events with $M_w \geq 7$

78 events in the sea

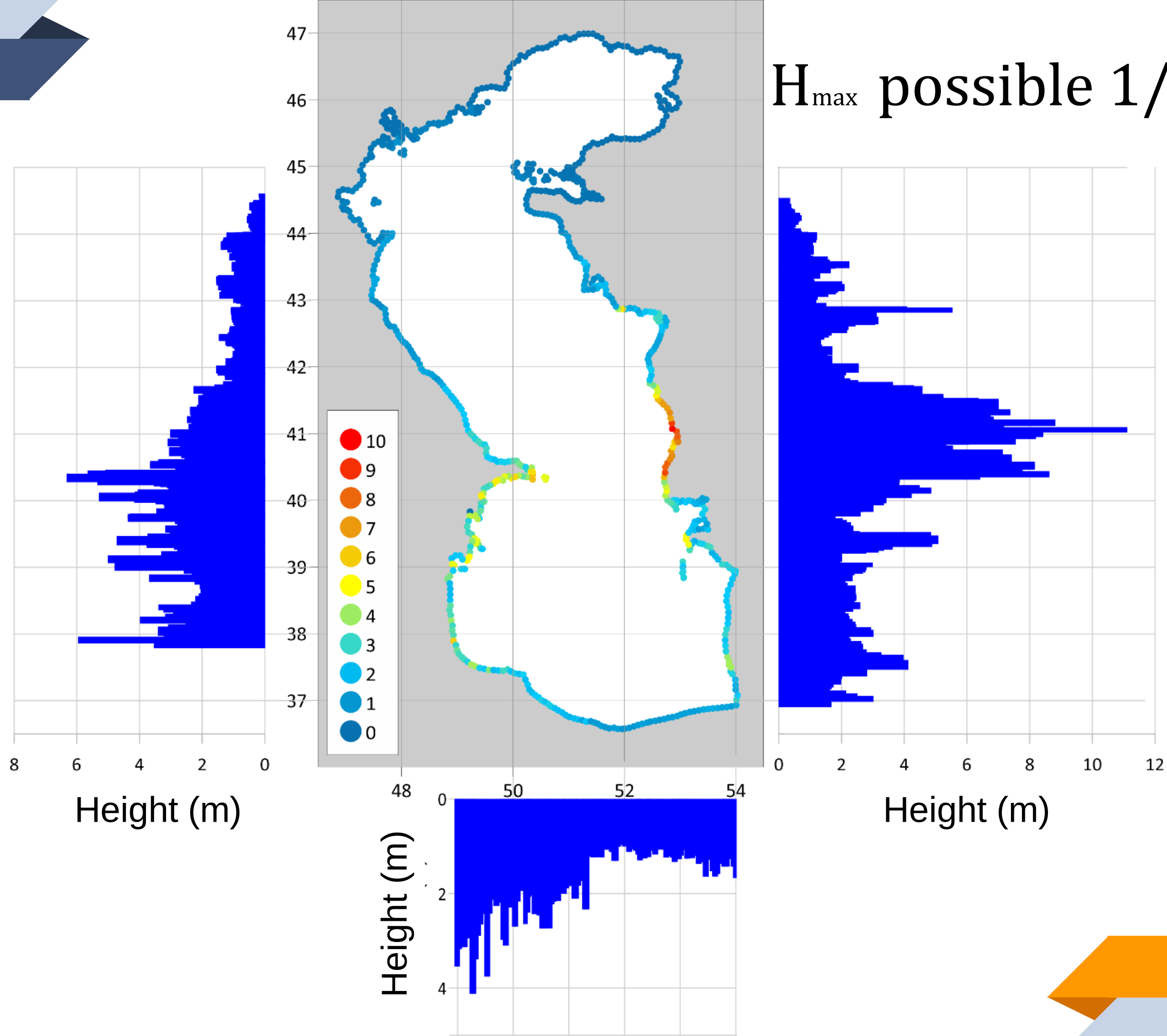
We obtained return period plots of the tsunami wave height in a separate node of the computational grid



H_{max} possible 1/1000 years

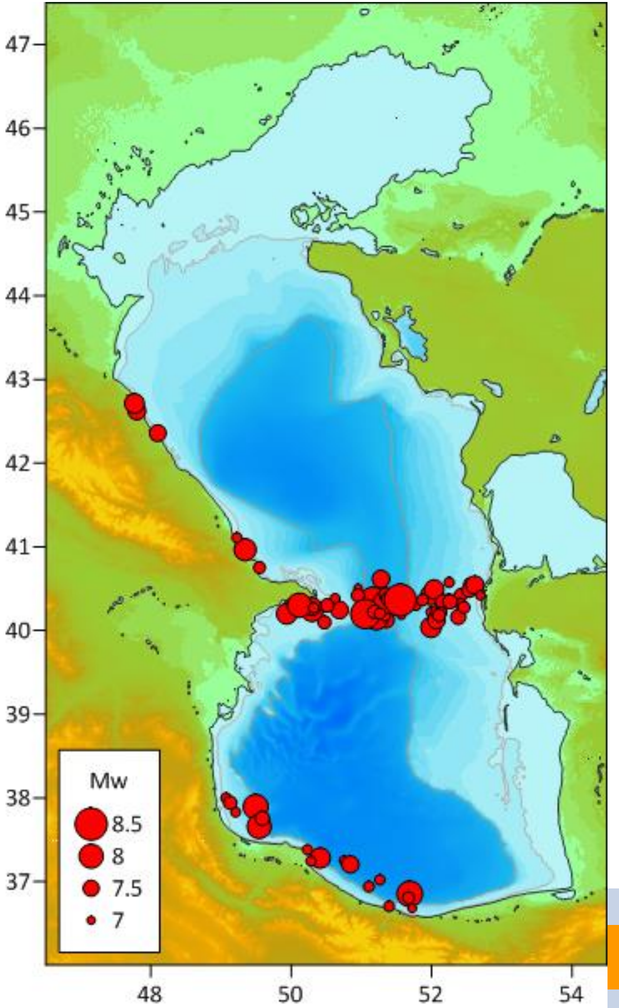


H_{max} possible 1/5000 years

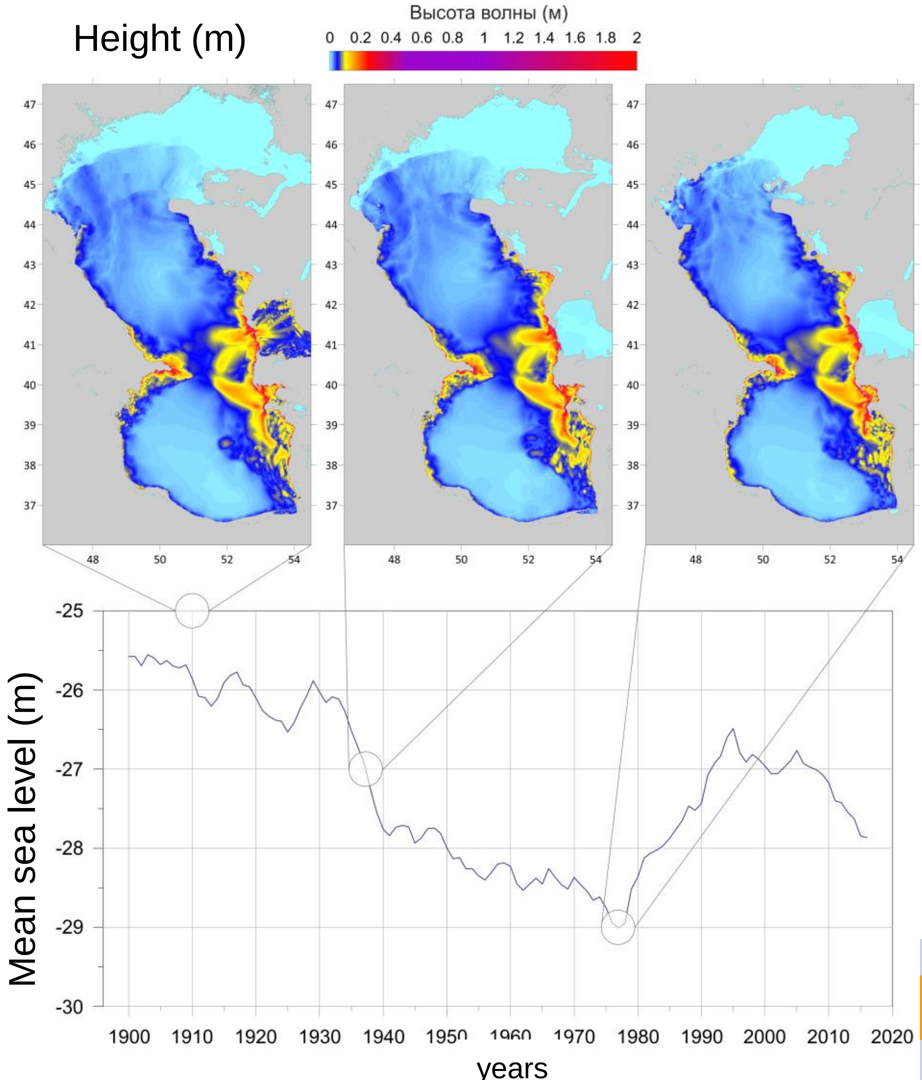


H_{max} possible 1/n years

	250	500	1000	5000
West coast	0.03	0.49	1.70	6.32
East coast	0.03	0.55	1.49	11.11
South coast	0.01	0.17	0.81	4.11
North coast	0.00	0.03	0.09	0.91
Ogurchinskij	0.02	0.27	0.84	3.07
Jiloj island	0.02	0.37	1.29	4.75
Pirallahi island	0.03	0.49	1.64	5.65
Kurdili island	0.01	0.14	0.60	2.79
Tulenij island	0.00	0.03	0.12	0.79
Tulenij islands	0.00	0.02	0.08	0.55



Influence of the mean level of the Caspian Sea



Kara-Bogaz-Gol gulf

-25 m, 0.9–1 m

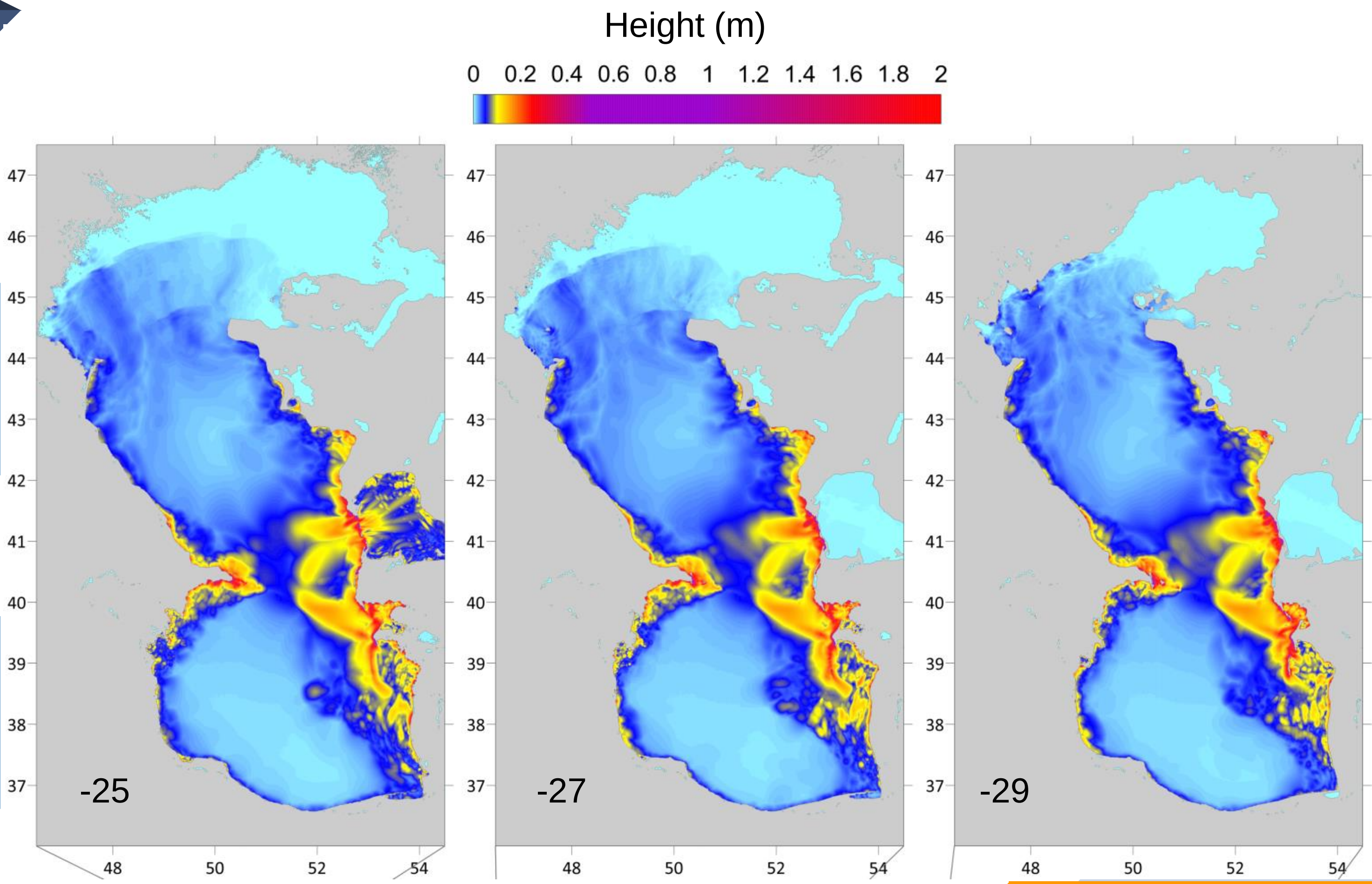
-27 m, 1.6–1.9 m

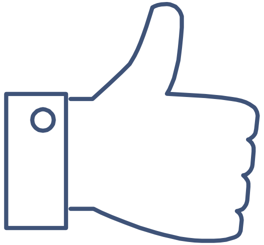
Absheron

-25 m, 1.08 m

-27 m, 0.84 m

-29 m, 0.90 m





Thank You

Questions?

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