LARGEST HISTORICAL TSUNAMIS IN THE WORLD OCEAN AND THEIR IMPLICATION FOR COASTAL HAZARD ASSESSMENT

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I would like to acknowledge the input of the following persons in the results included in my today presentation:

Prof.L.Chubarov (ICT SD RAS, Novosibirsk)
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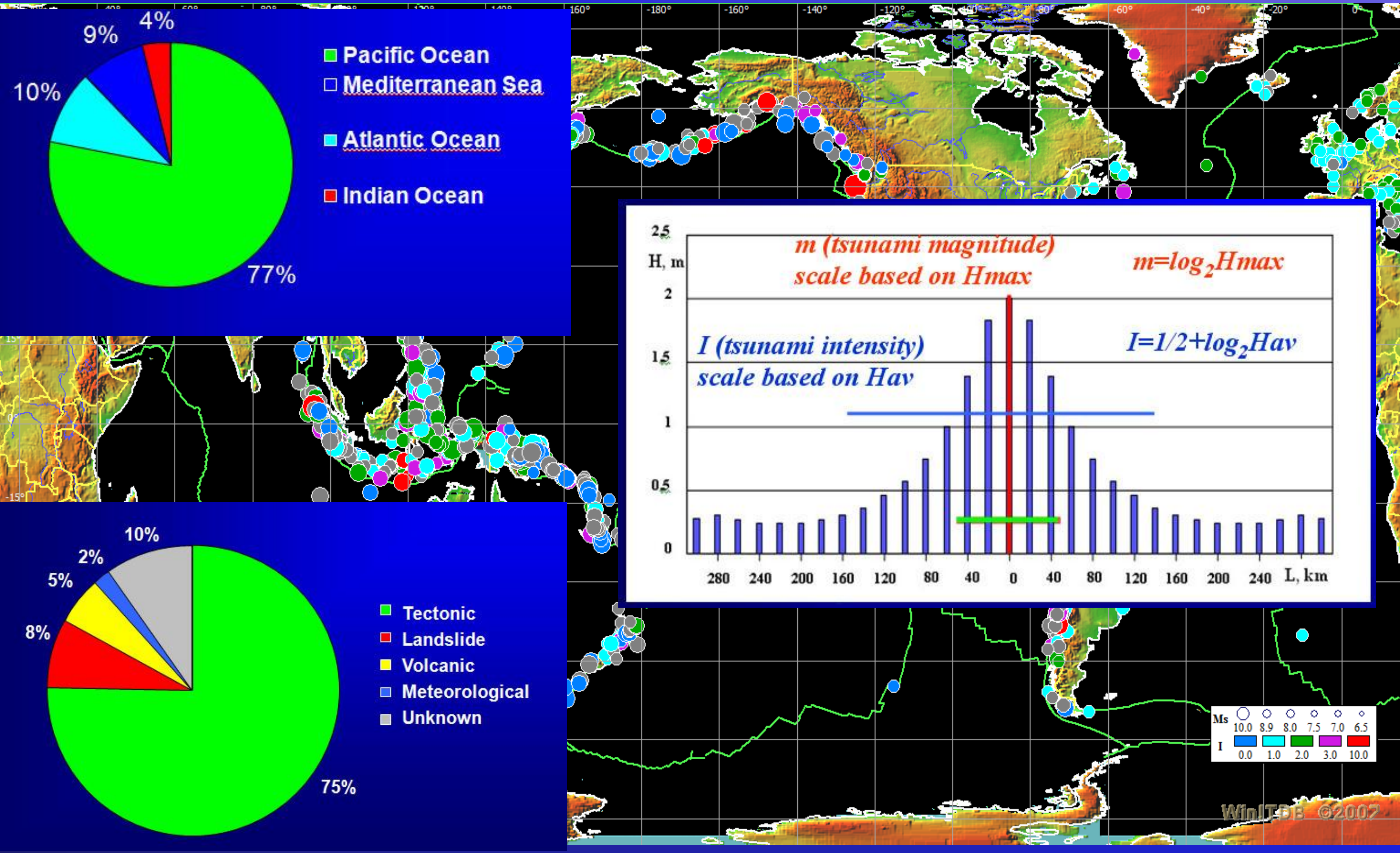
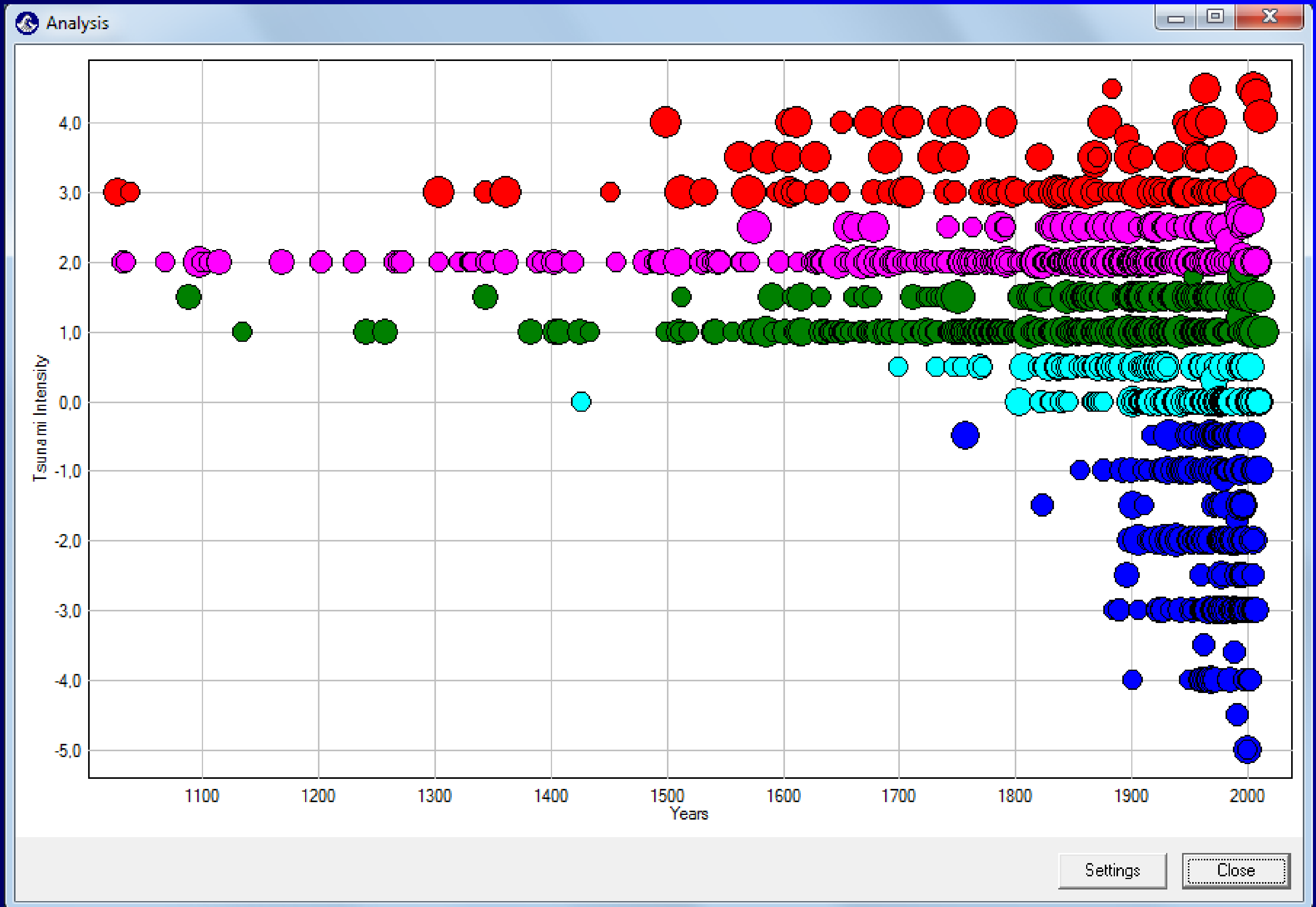
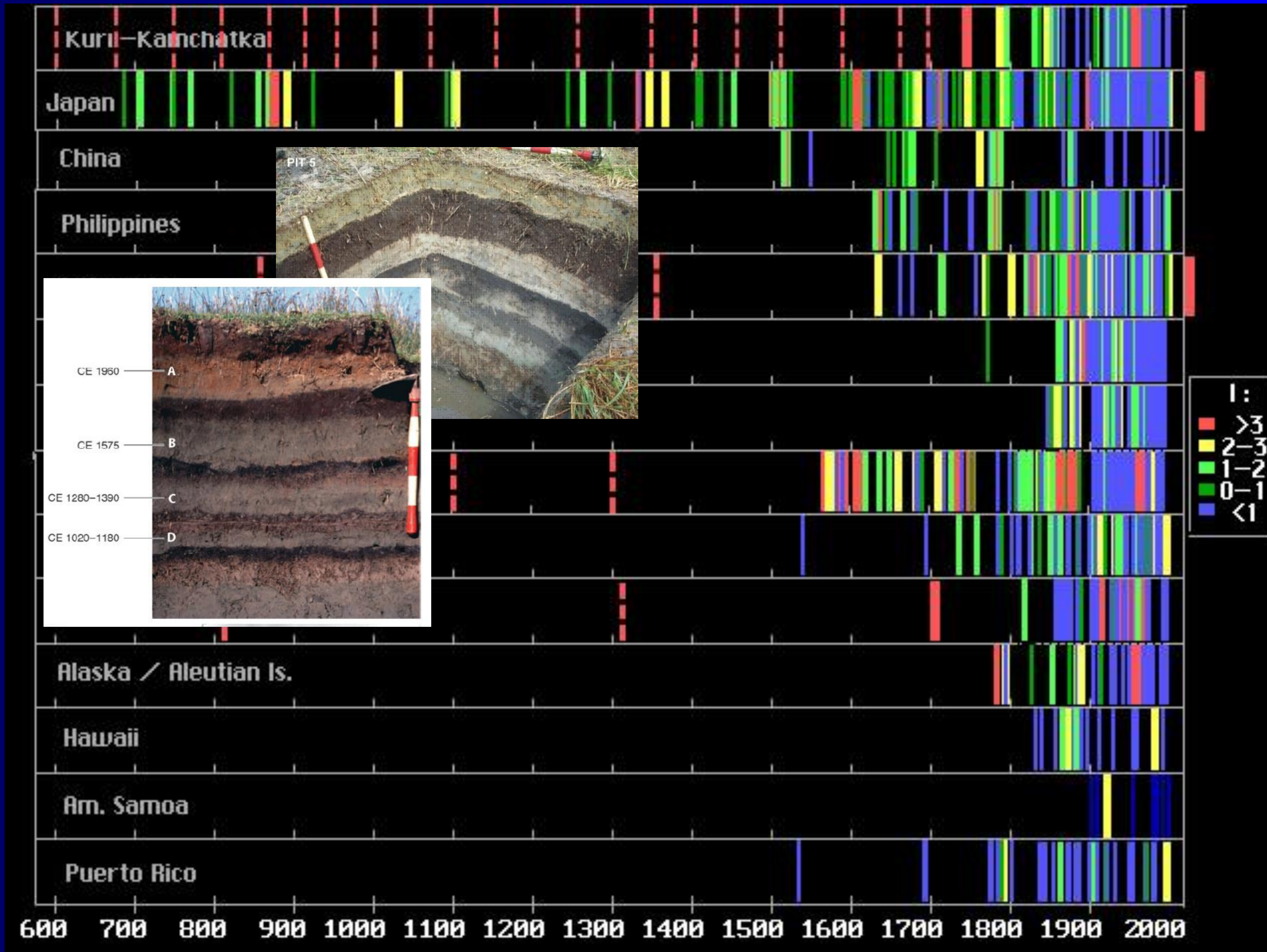


Map of historical tsunamigenic events in the World Ocean. Sources of 2250 events occurred from 2000 BC to 2012 are shown. Color represent the tsunami intensity on Soloviev-Imamura scale.



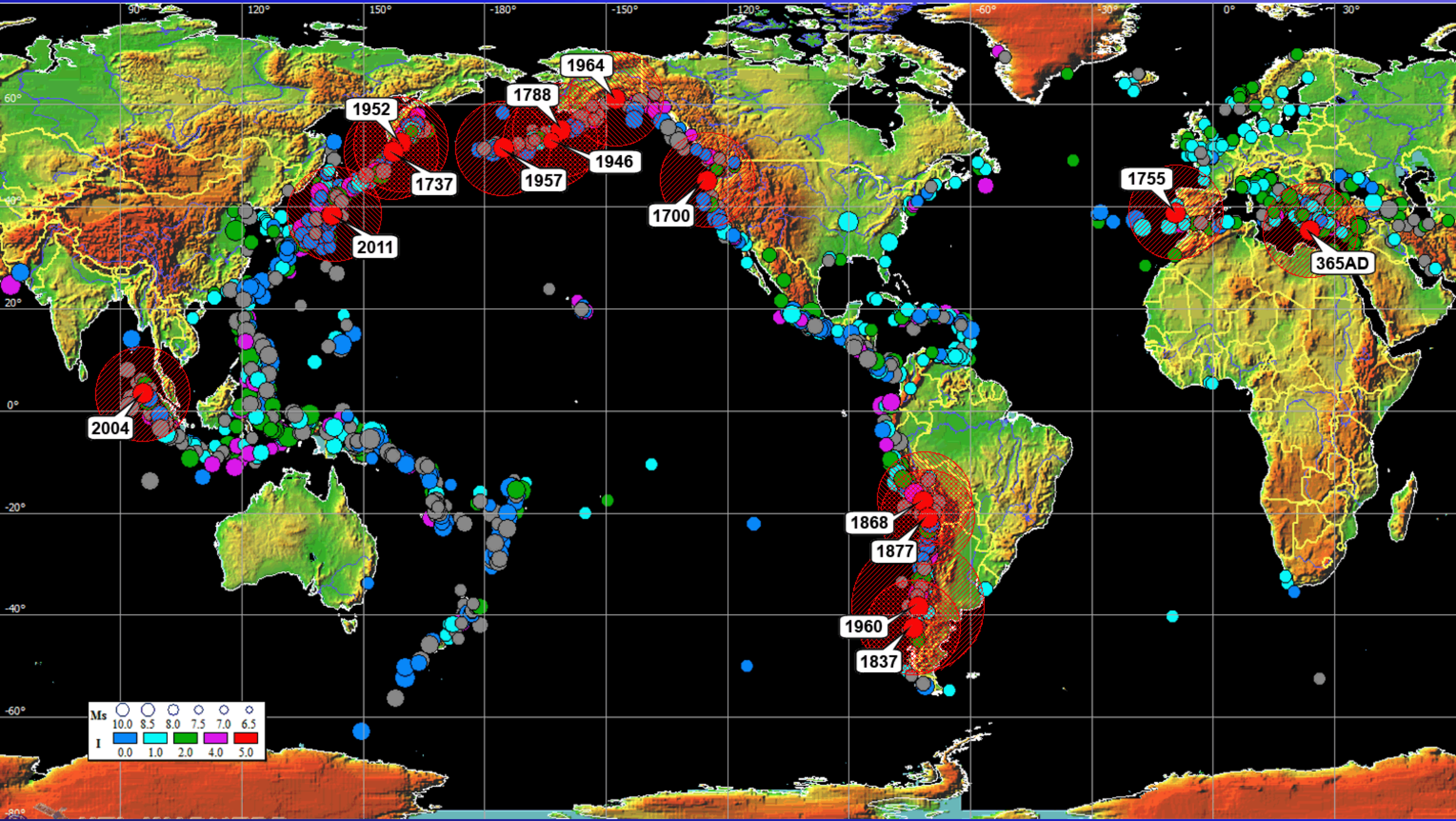
Distribution of global tsunamigenic events over time for the last 1000 years



A comparative length and completeness of regional tsunami catalogs in the Pacific. Each vertical line corresponds to a single tsunamigenic event with color representing the tsunami intensity on Soloviev-Imamura scale. Average length is 424 years.

Three groups of largest tsunamis of the World Ocean (compared by different parameters)

14 trans-oceanic tsunamis, (H > 5m at D > 5000km) N - number of run-ups	Top-15 tsunamis with highest run-up, sorted by H_{max}	Top-15 tsunamis with largest fatalities, sorted by N_{FAT}
365AD Crete N= 5	525m 1958 Lituya Bay	226,898 2004 Sumatra
1700 Cascadia N= 5	250 m 1963 Vajont Dam	36,417 1883 Krakatau
1737 Kamchatka N= 5	150m 1936 Lituya Bay	30,000 1755 Lisbon
1755 Lisbon N=49	120m 1854 Lituya Bay	30,000 1707 Nankaido
1788 Aleutian N= 3	88m 1788 Aleutians	27,122 1896 Sanriku
1837 Chile N= 23	85m 1771 Ishigaki Is.	26,000 1498 Enshunada
1868 Chile N= 115	80m 1674 Indonesia	18, 497 2011Tohoku
1946 Aleutians N= 549	70m 1936 Norway	15,000 1741 Osima
1952 Kamchatka N= 340	68m 1964 Alaska	13.486 1771 Ishigaky Is.
1957 Aleutians N= 326	63m 1737 Kamchatka	12,000 1952 Kamchatka
1960 Chile N= 1193	62m 1934 Norway	10,000 1765 Guanzhou
1964 Alaska N= 423	55m 2011 Tohoku	5,233 1703 Boso Pen.
2004 Sumatra N=1,026	51m 2004 Sumatra	5,000 1605 Nankaido
2011Tohoku N=5,570	42m 1946 Aleutians	4,376 1976 Philippines
	40m 2000 Greenland	3,000 1854 Nankaido

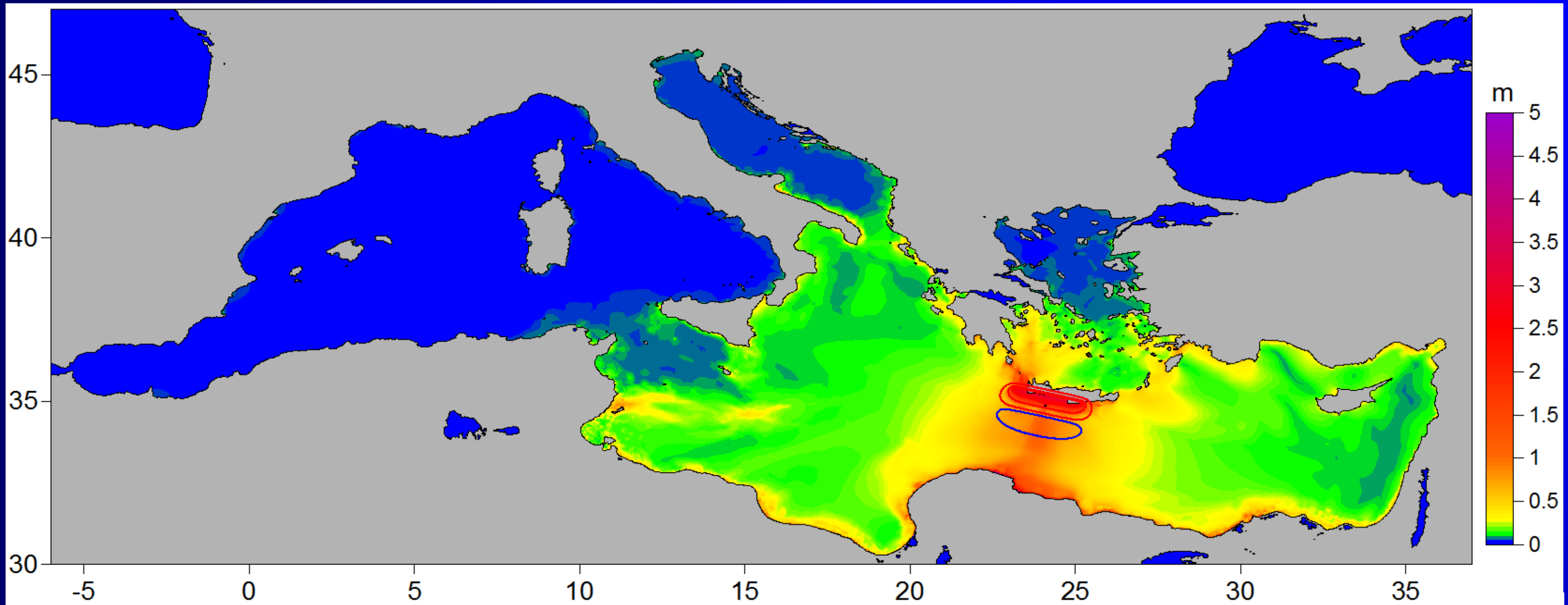


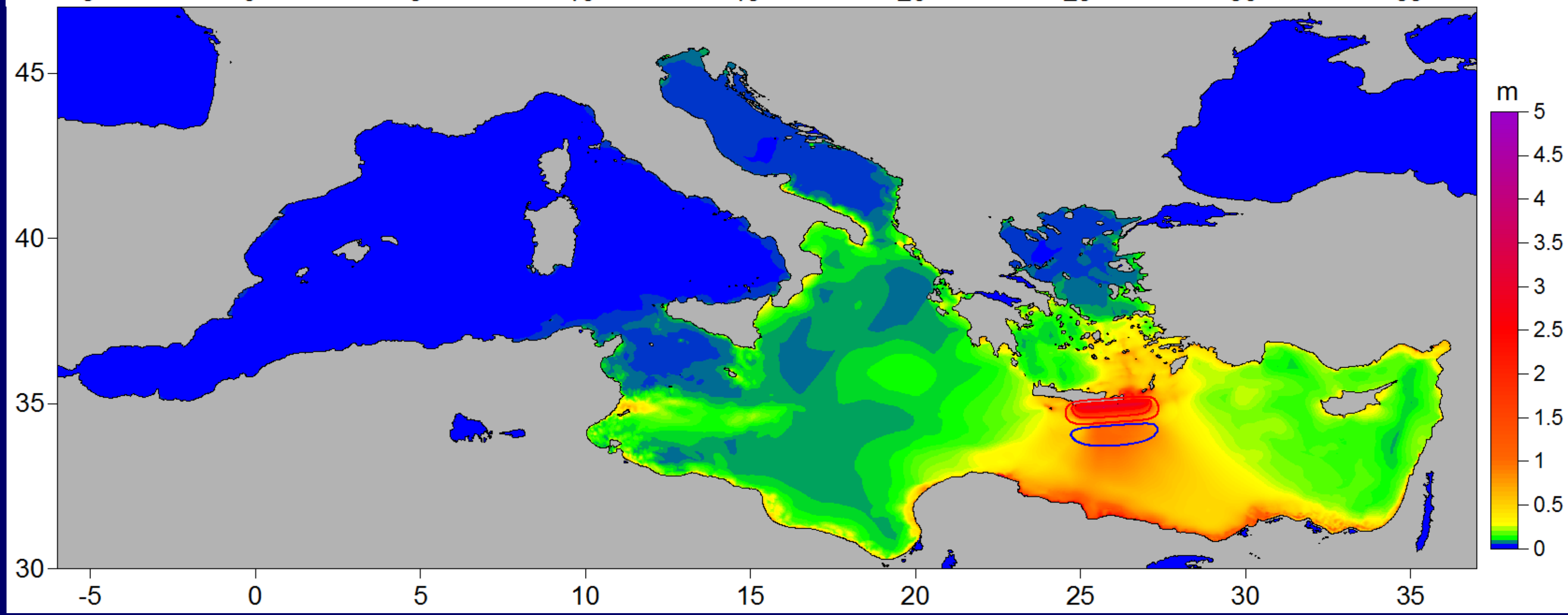
Map of historical tsunamigenic events in the World Ocean. Sources of 2250 events occurred from 2000 BC to 2012 are shown. Color represent the tsunami intensity on Soloviev-Imamura scale. Large red circles highlight the M9 class mega-events resulted in trans-oceanic tsunamis

List of historically known transoceanic tsunamis and their basic parameters

Date and location	*M*	*N*	*I*	*Hm*$_{NF}$, m	*Hm*$_{FF}$, m	F$_{NF}$	F$_{FF}$
July 21, 365, Crete	8+	3	4	Unknown	10	~5,000	~700
January 26, 1700, Cascadia	9	7	3.5	10	2–4	Unknown	0
October 17, 1737, Kamchatka	9	6	4	63	12–15	Unknown	Unknown
November 1, 1755, Lisbon	8.5	51	4	30	7	~10.000	Unknown
November 7, 1837, Chile	8.5	20	3.5	8	6	0	62
August 13, 1868, Chile	9	99	3.5	15	5.5	612	7
May 9, 1877, Chile	9	111	4	24	12	512	50
June 15, 1896, Japan	7.6	62	4	38.2	9.0	27.122	0
April 1, 1946, Aleutians	7.4	542	4	42.2	20.0	5	162
November 4,1952, Kamchatka	9.0	314	4	18	9.1	>10.000	0
March 9, 1957, Aleutians	9.1	304	3.5	22.8	16.1	0	0
May 22, 1960, Chile	9.6	537	4	15.2	10.7	~1.000	283
March 28, 1964, Alaska	9.3	292	4	68	4.9	106	18
December 26, 2004, Sumatra	9.0	1015	4.1	50.9	9.6	175.827	52.071
March 11, 2011, Tohoku	9.0	5578	4.2	55.9	3.0	18.497	2

The above table is obviously incomplete





Numerical model of the 365AD Crete earthquakes (adopted moment-magnitude Mw=8.4). Propagation model is based on the MGC package maintained in the ICT SD RAS (Novosibirsk)

List of historically known transoceanic tsunamis and their basic parameters

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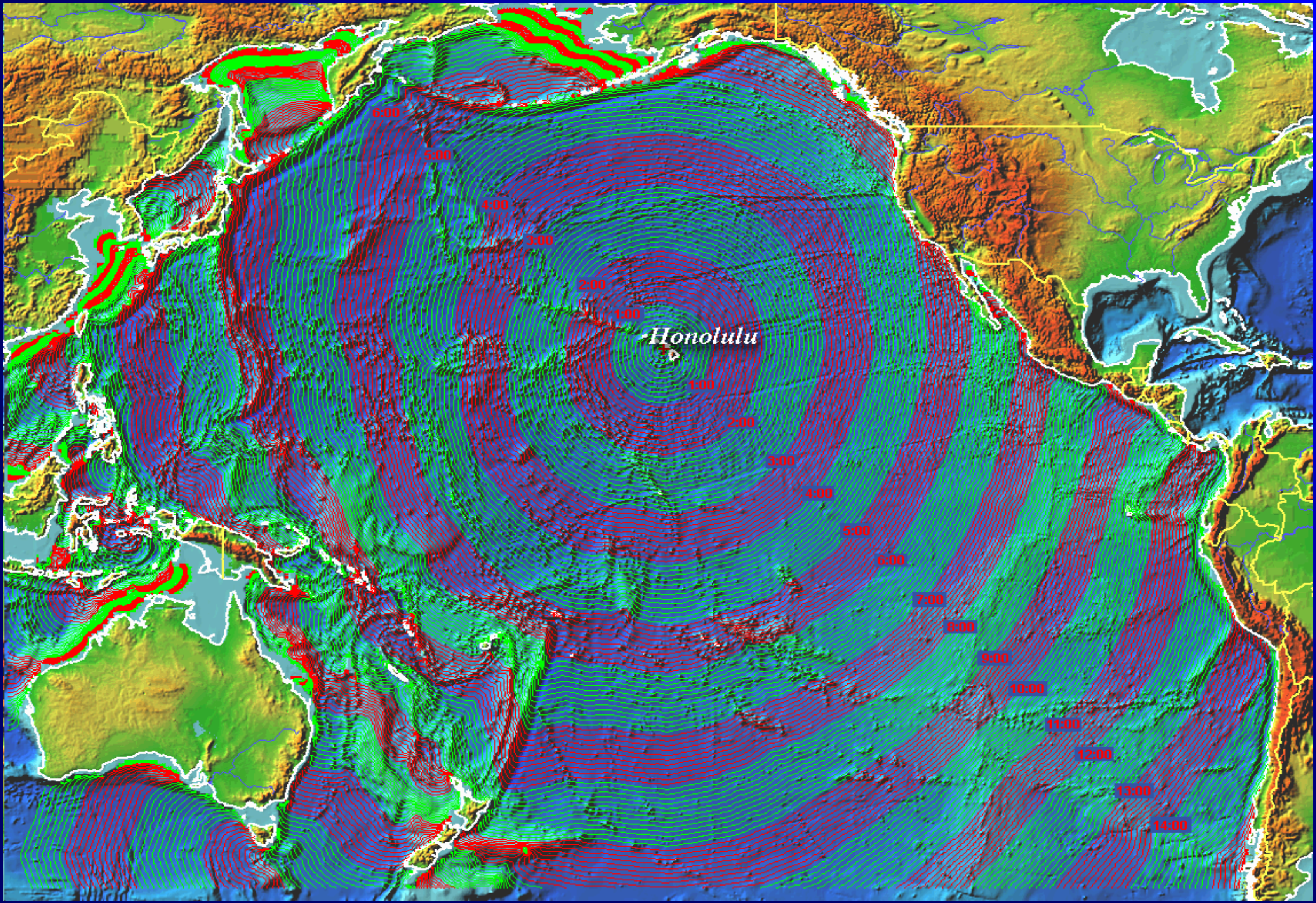
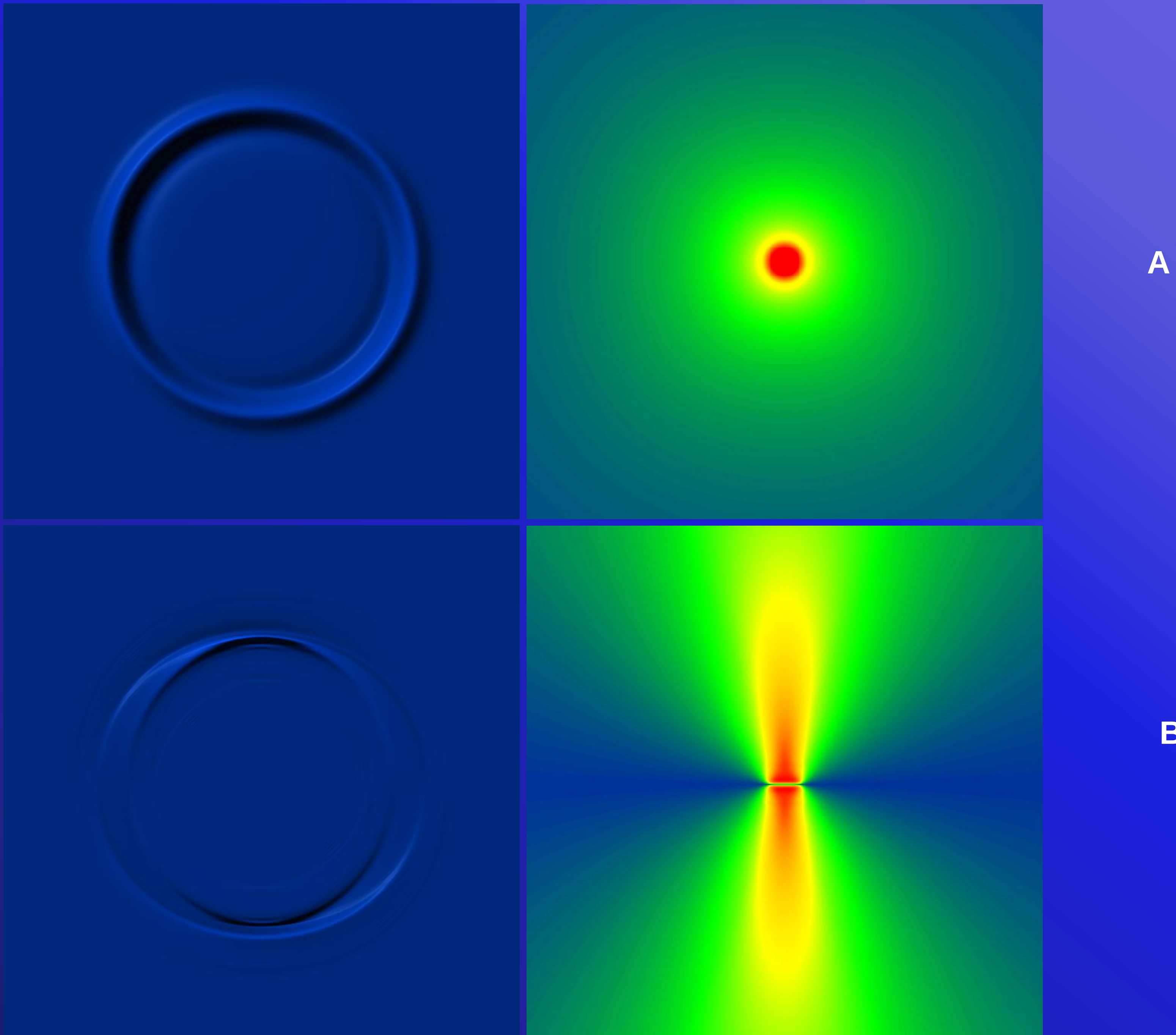
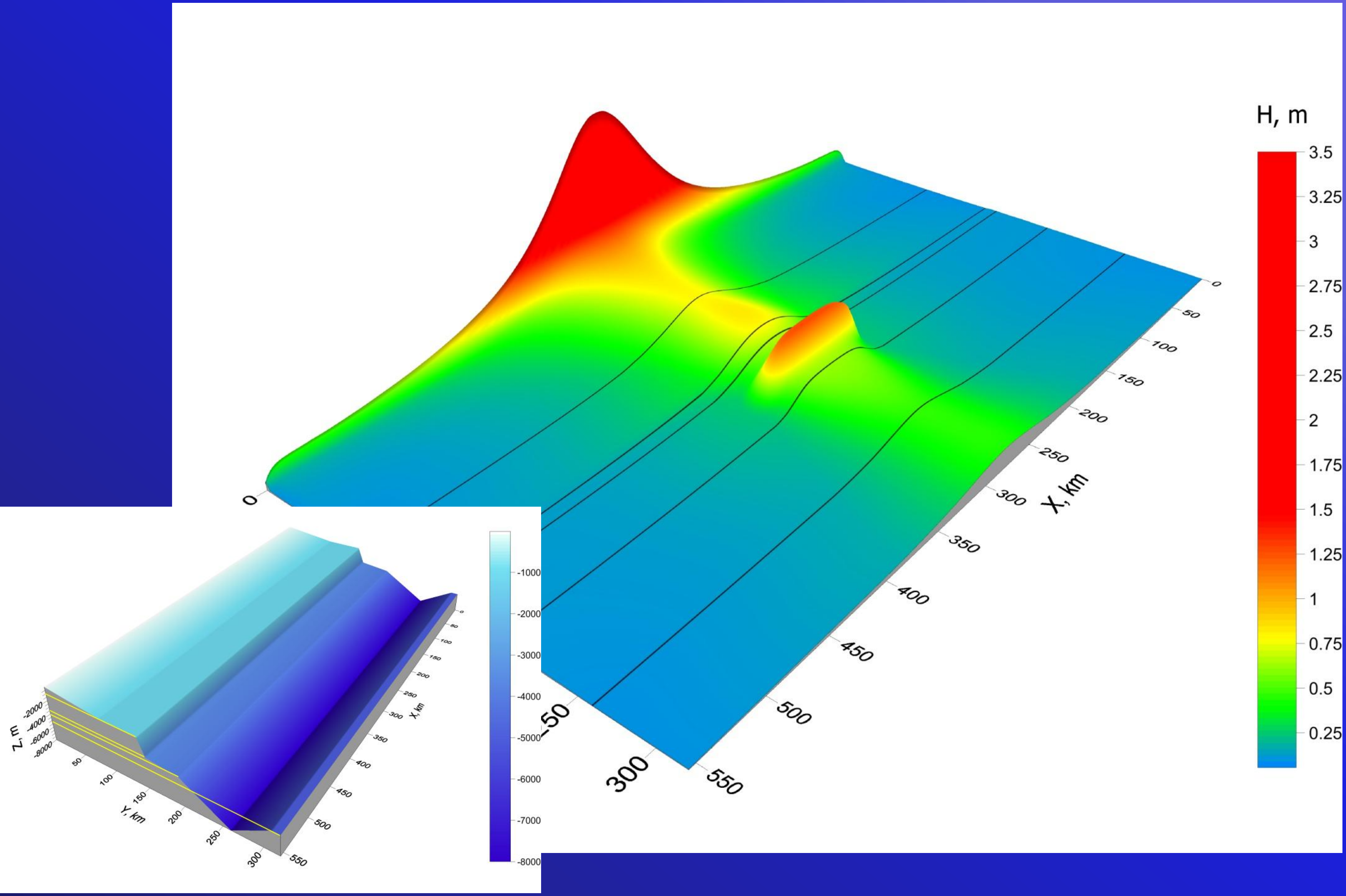


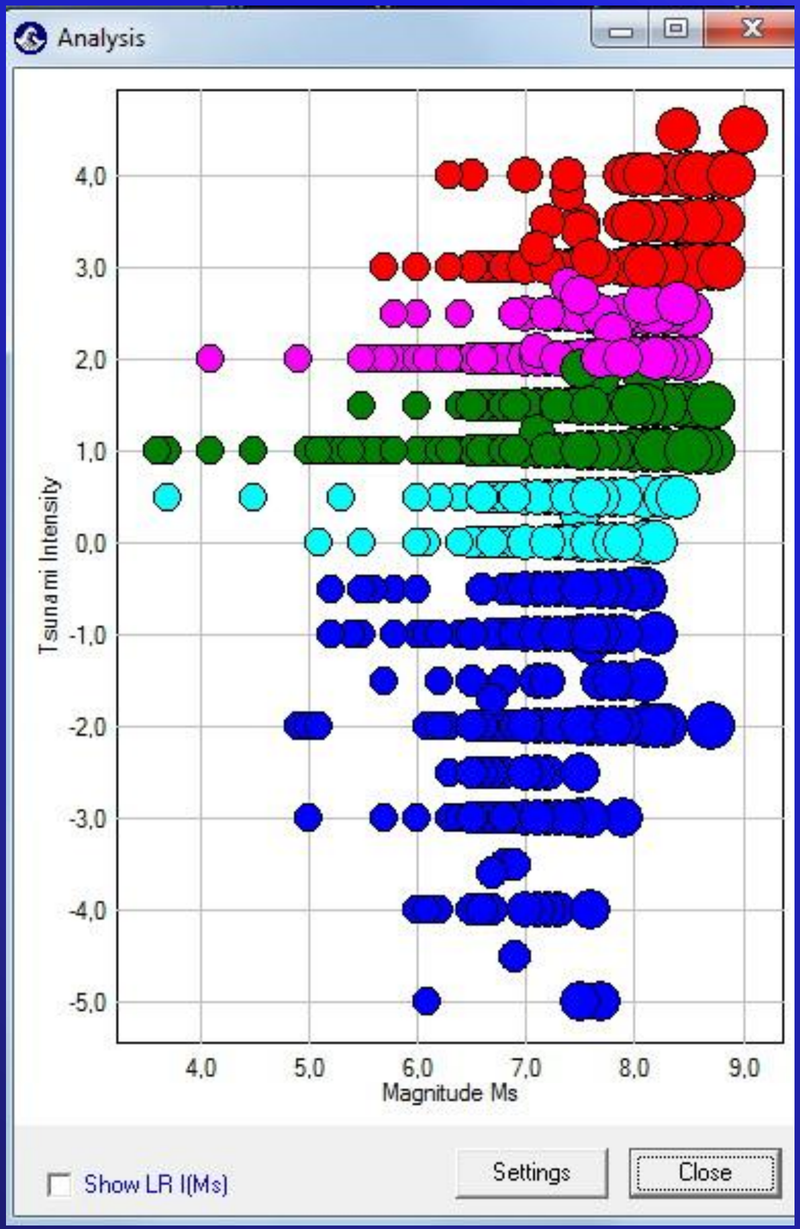
Computed tsunami travel time chart (point source near Hawaii)

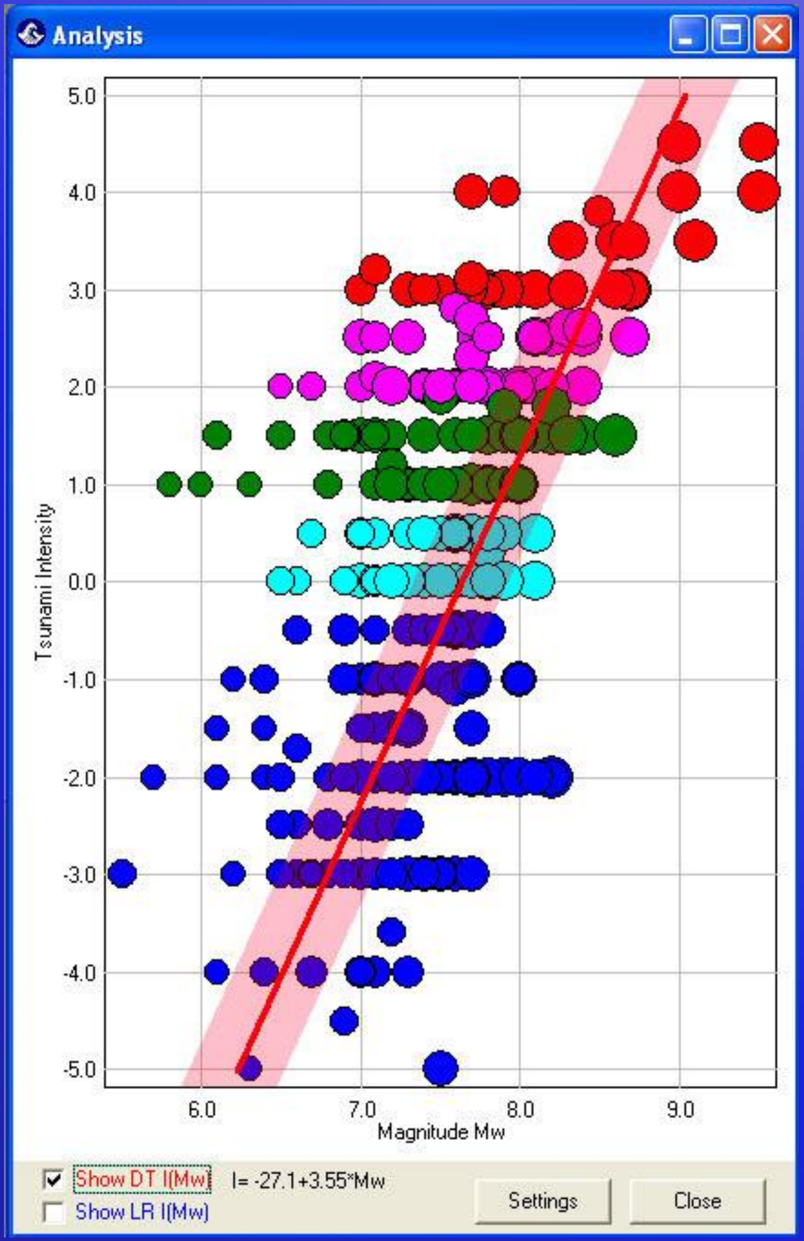


Tsunami propagation over a flat bottom from a circular (A) and model seismic (vertical dip-slip) sources (B)

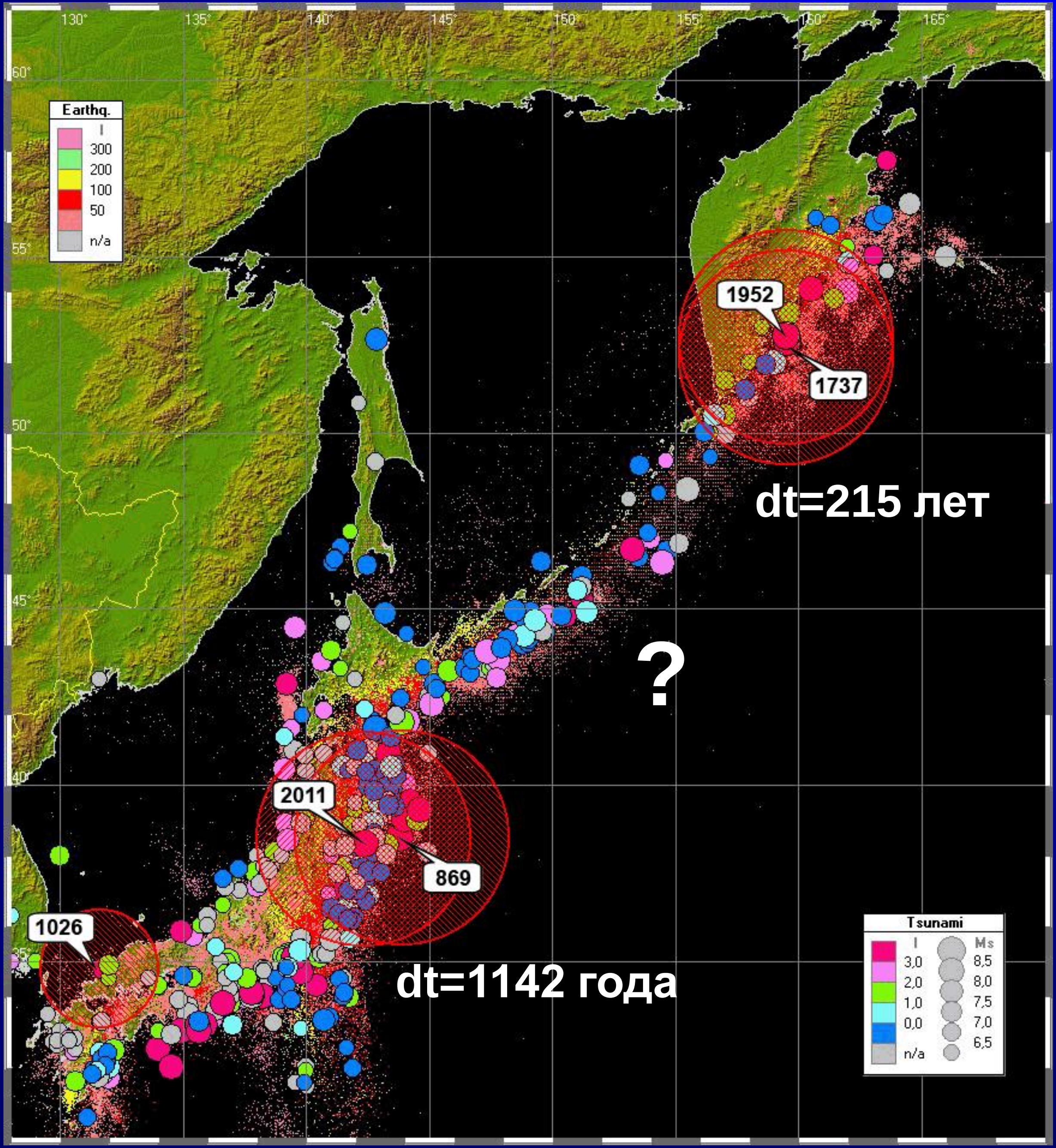


Numerical modeling of tsunami propagation on the model relief typical for subduction regions. Source – low-angle thrust with Mw=7.8 and rupture length 100km.



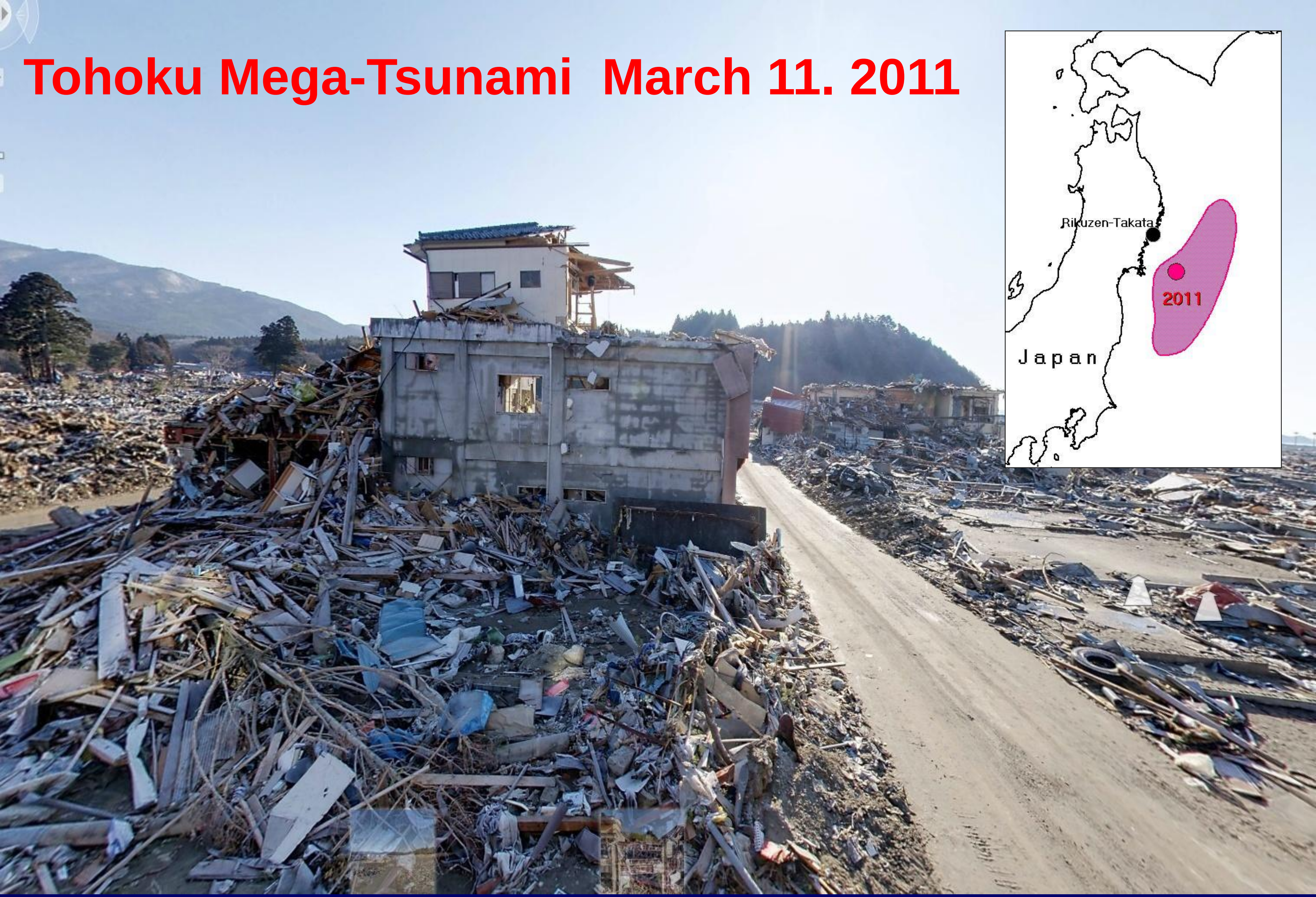


Dependence of tsunami intensity I (on Soloviev-Imamura scale) on Ms magnitude (on the left) and Mw magnitude (on the right) of submarine earthquake occurred since 1900 in the World Ocean

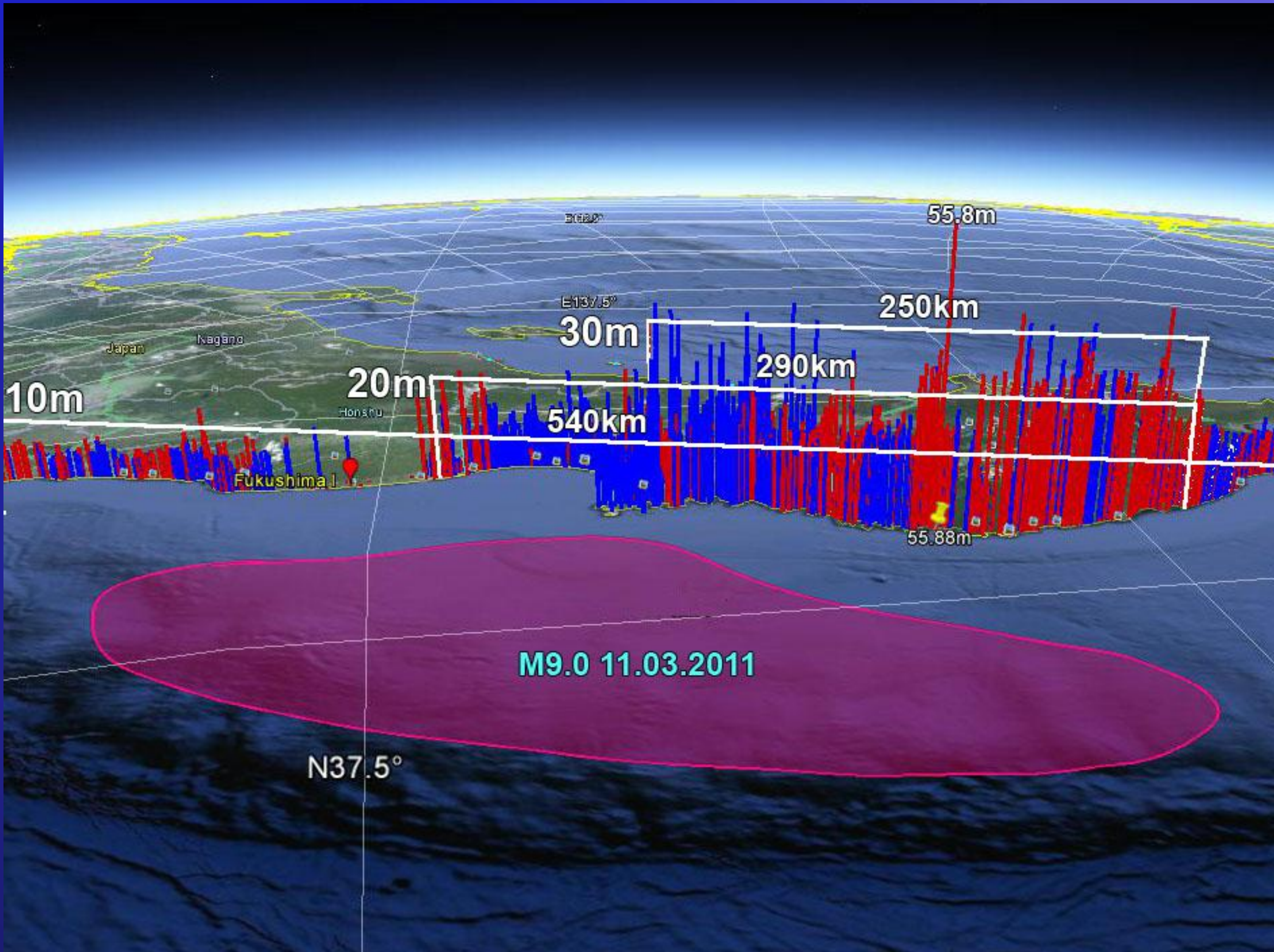


Tsunami source map in Kuril-Kamchatka and Japan regions

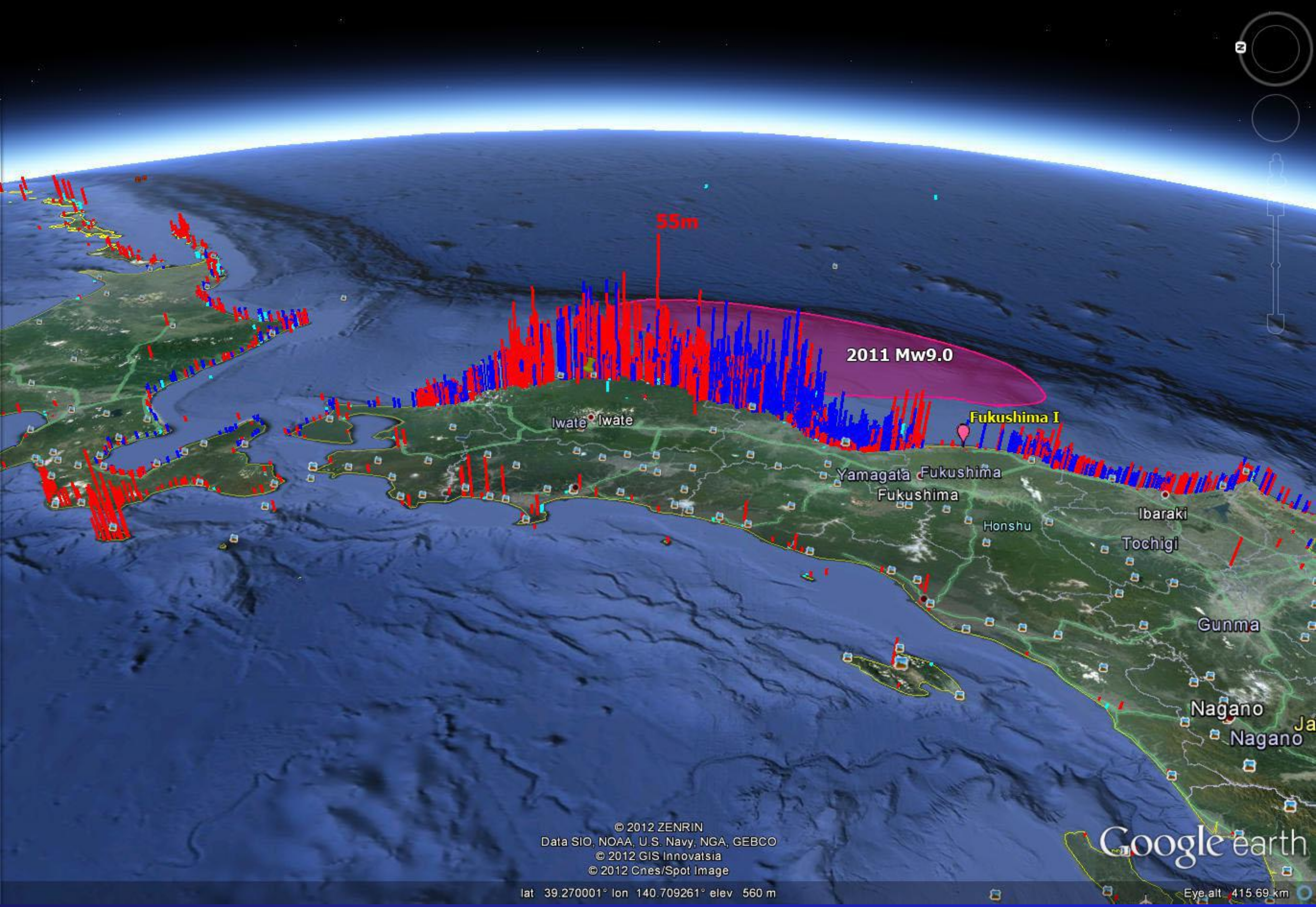
Tohoku Mega-Tsunami March 11. 2011



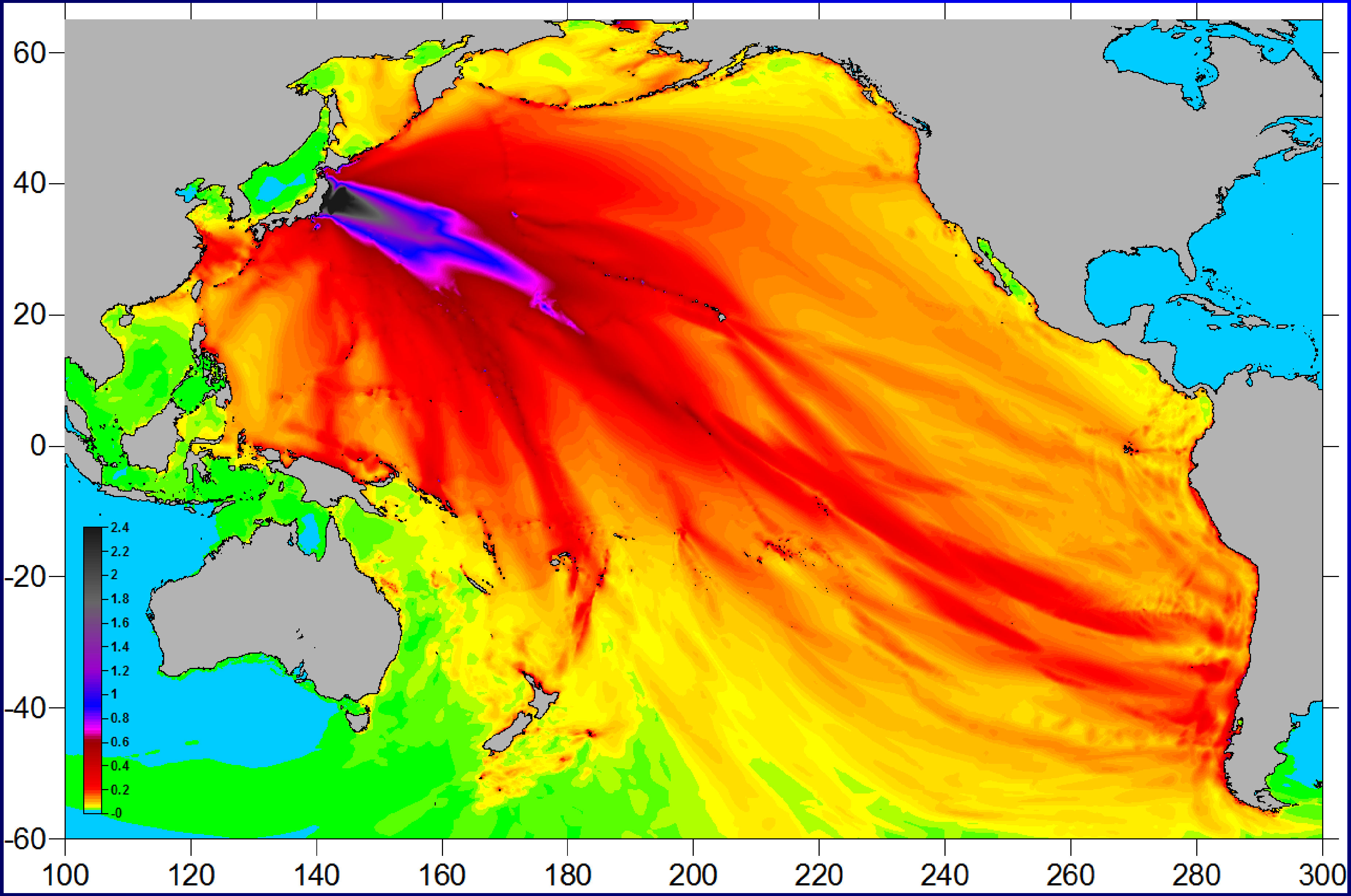
Rikuzen-Takata, Miyako Prefecture, Japan, one of most severe damaged towns along the Tohoku coast



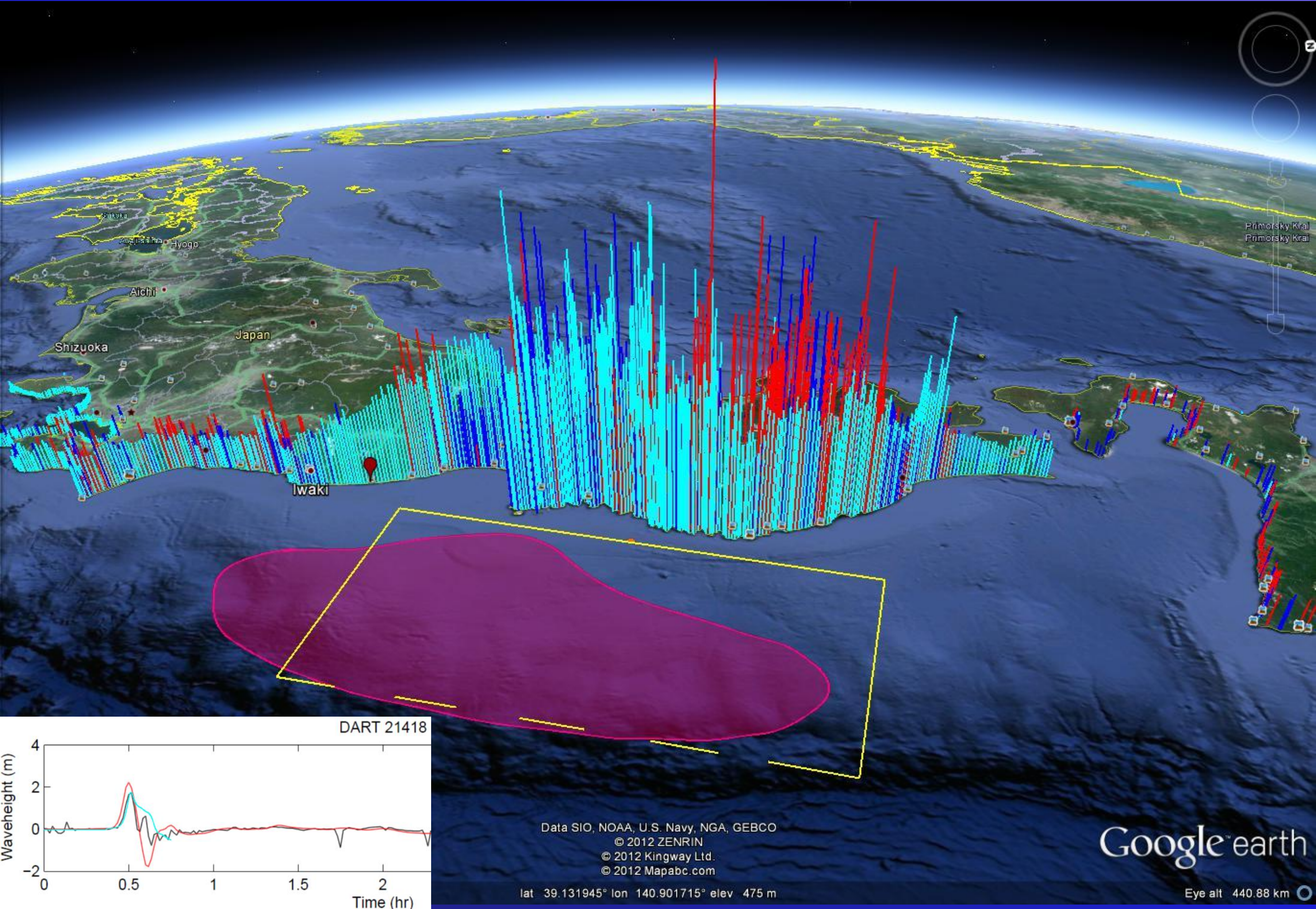
Distribution of measured inundation (blue) and run-up (red) heights after March 11, 2011Tohoku tsunami



Historical run-up distribution along the coast of Honshu before and after 2011



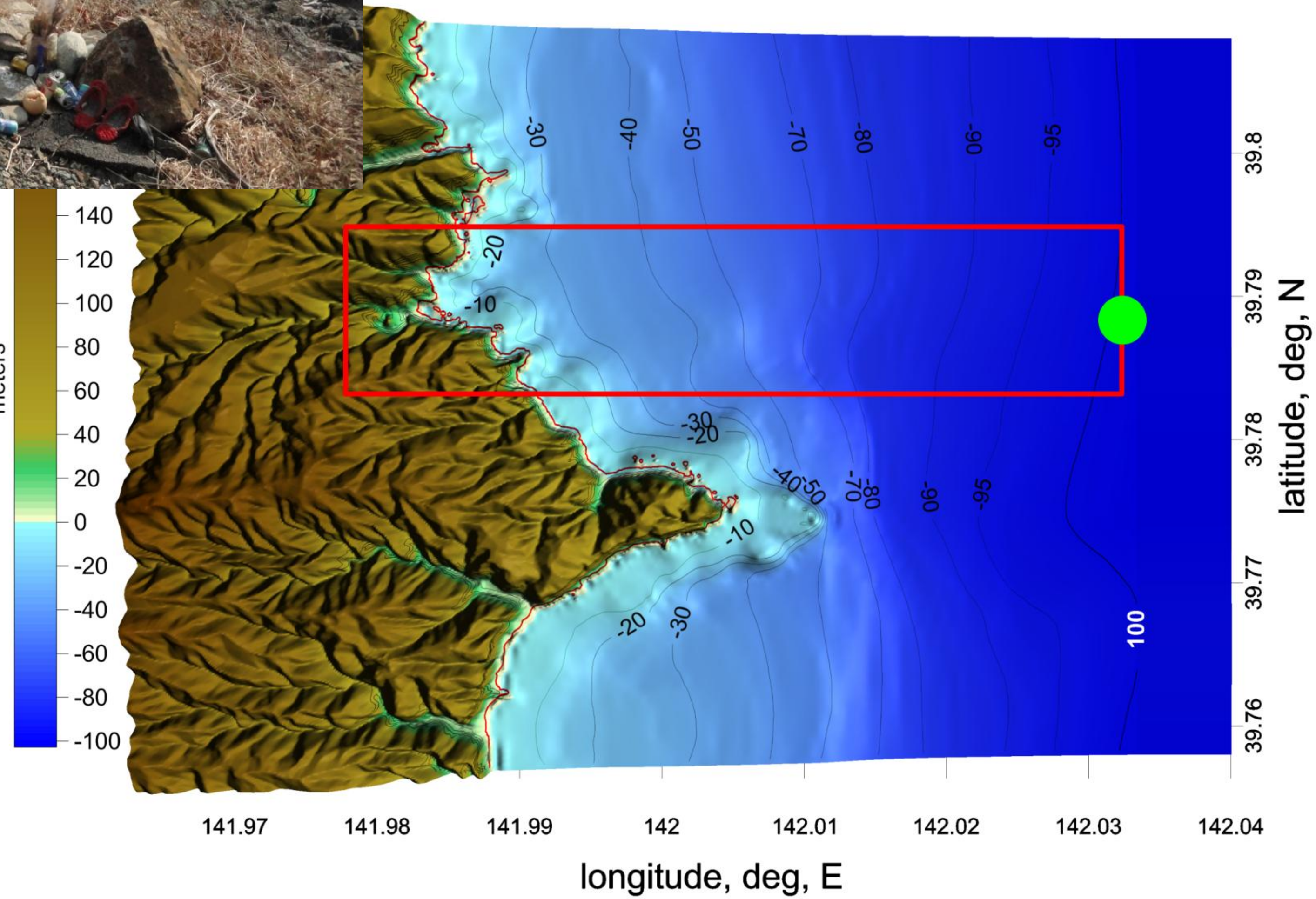
ICT-ICMMG SD RAS model of the March 11, 2011 Tohoku tsunami



Comparison of calculated (blue) and measured (red) wave heights along the Tohoku coast

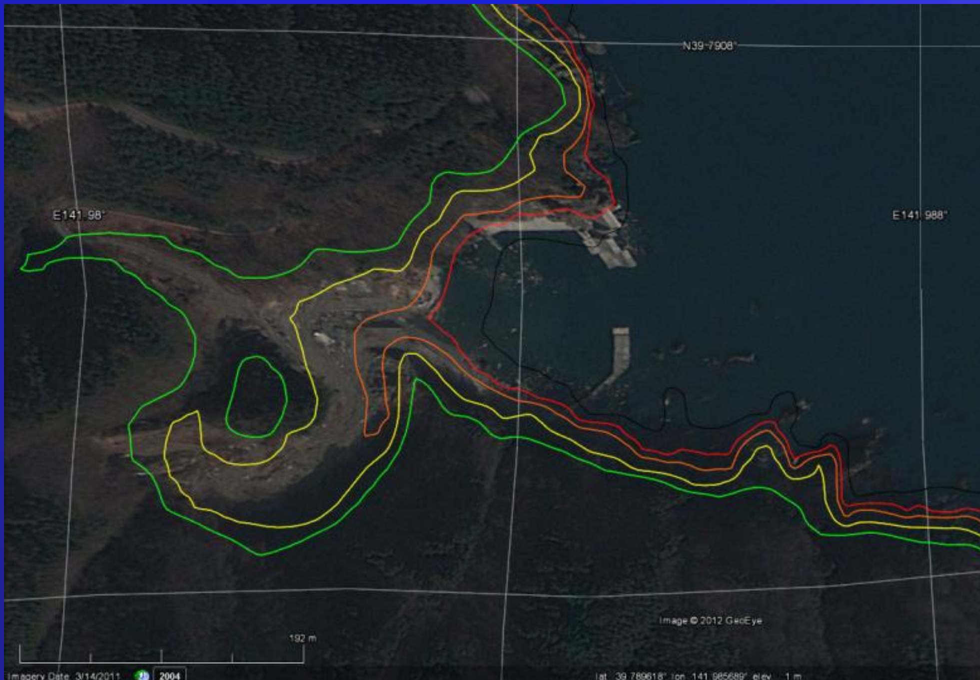
Koborinai Basy, Sanriku coast, Japan, with run-up 37 m

Модельная область для расчета заплеска в б.Коборинай

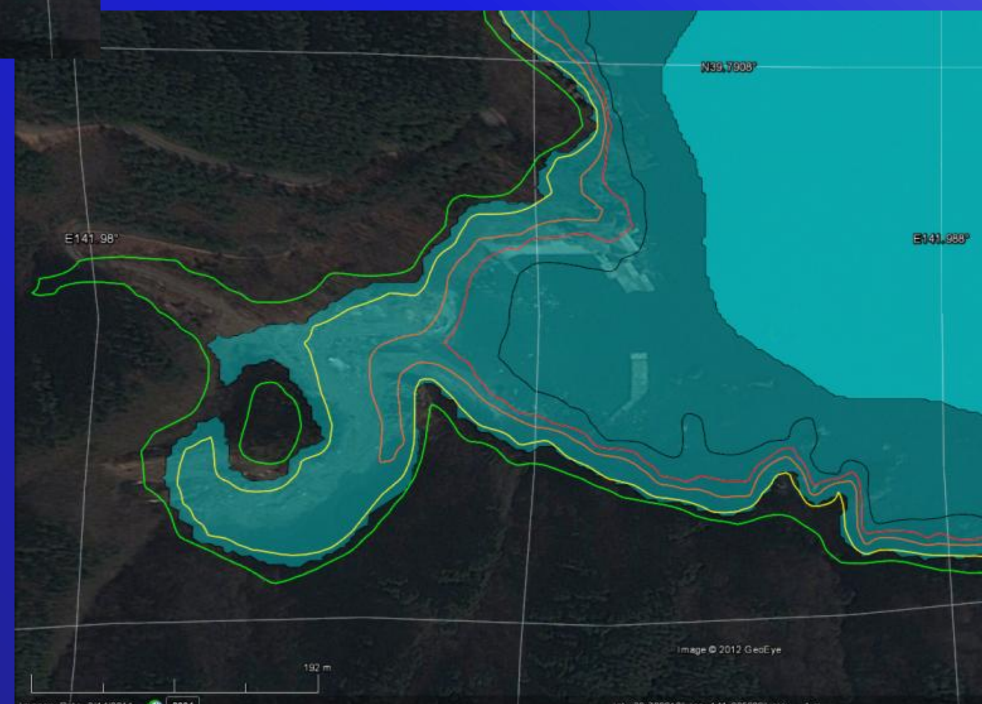


Koborinai Bay run-up modeling made in ICT SD RAS (Beisel et al., 2013)

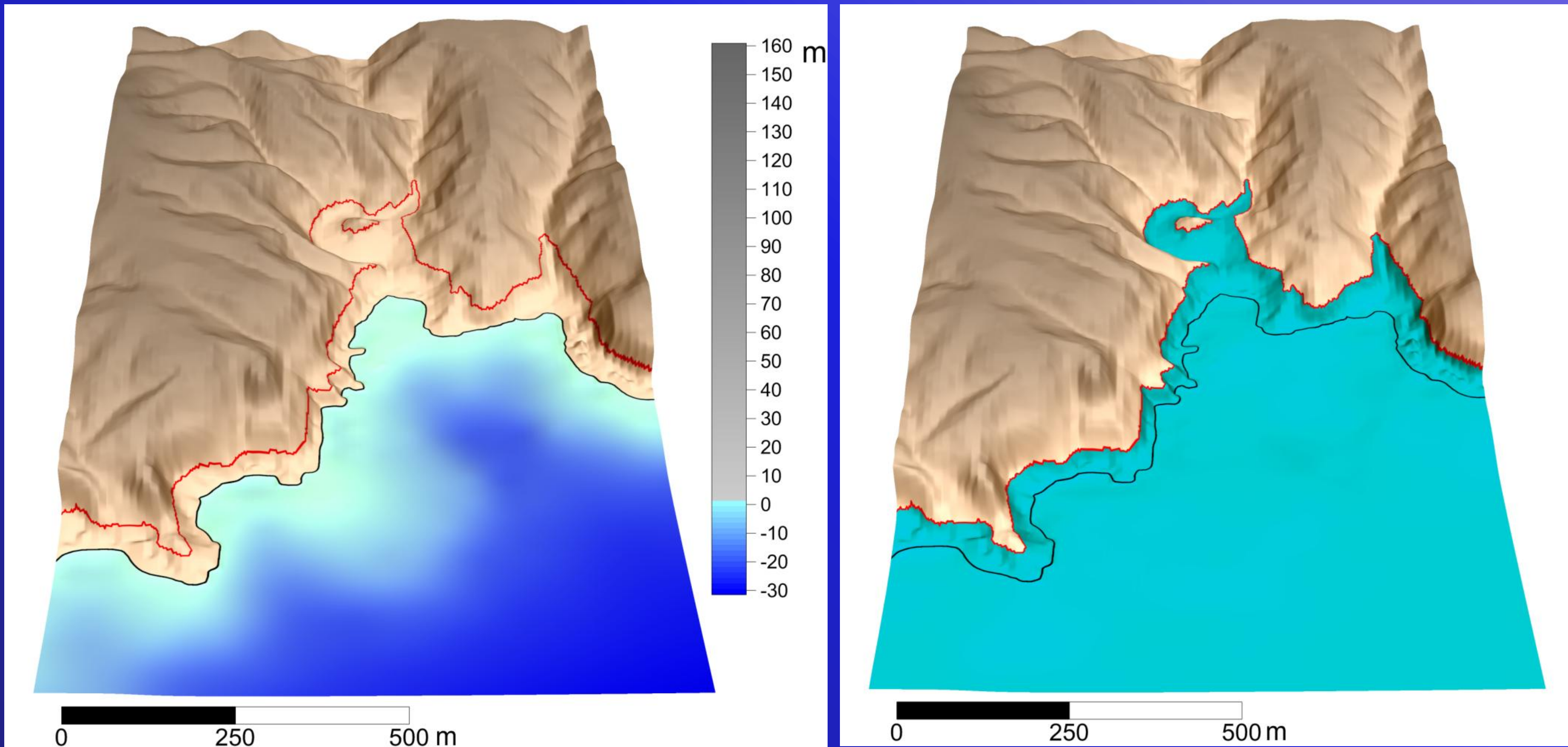
The results of simulation of the Koborinai Bay inundation by the 2011 Tohoku tsunami. Solod blue area shows the inundation limit obtained in 2D modeling of tsunami run-up. Light blue solid area in the upper right corner shows the initial level of the free surface at the level –4.7 m, resulted from co-seismic displacement caused by model earthquake source.



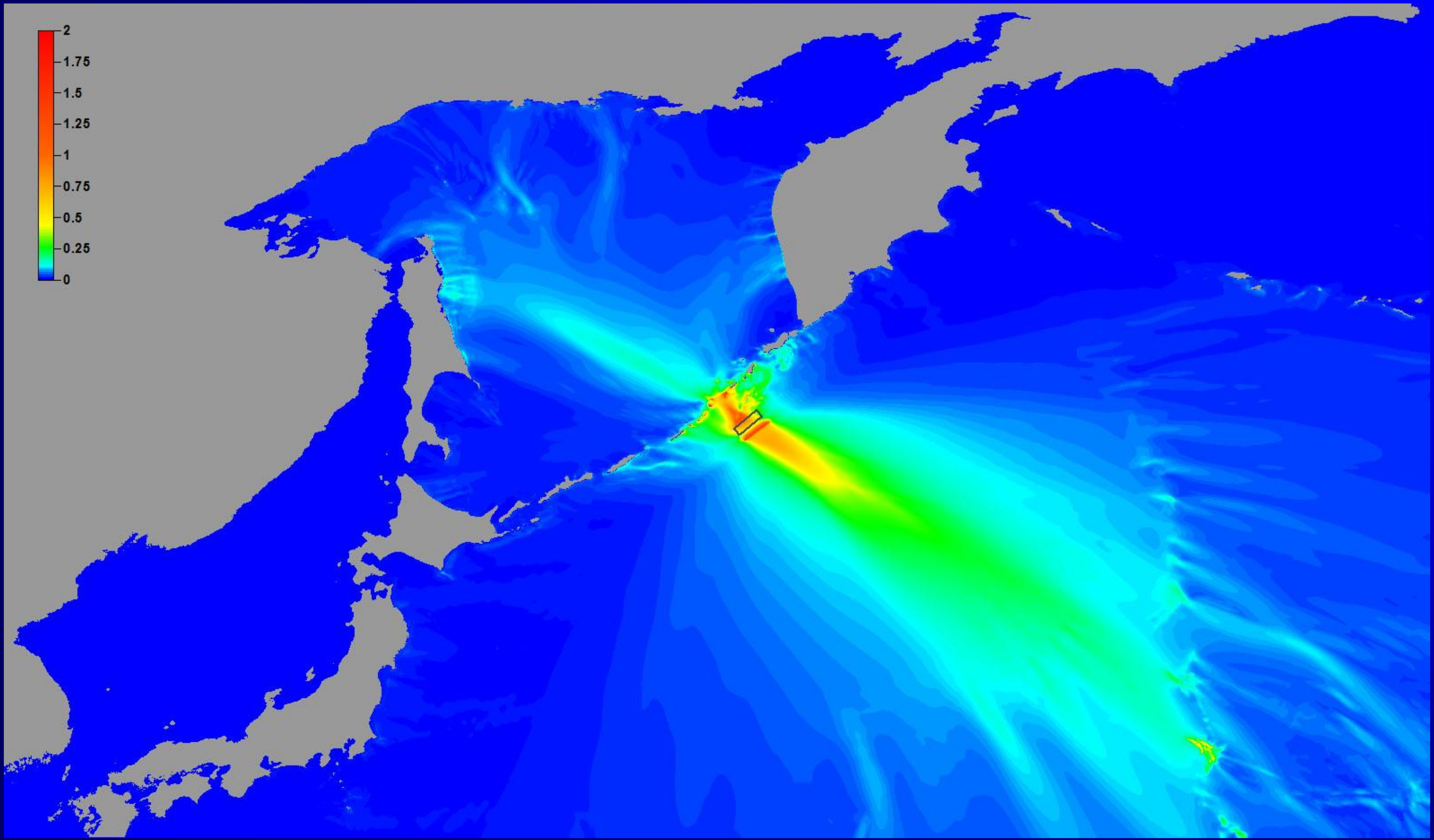
Google image of the Koborinai Bay as of March 14, 2011 (right after the 2011 Tohoku tsunami) with isolines of availasble DEM overlaid.



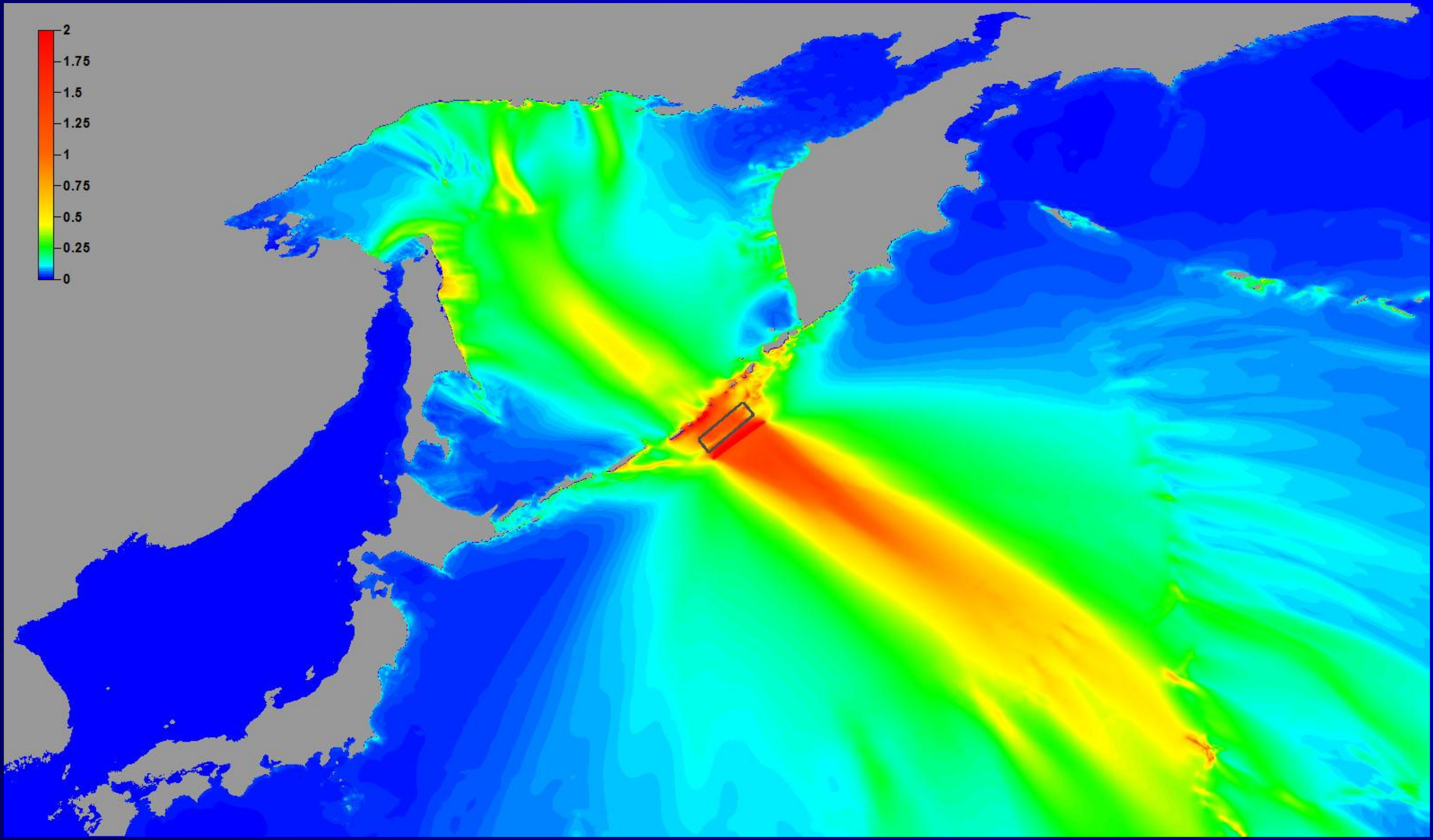
Color isolines shows isolines of applied digital terrestrial topography: black line – the initial position of the shoreline (0 m), red – 5 m, orange - 10 m, yellow – 20 m, green – 30 m.



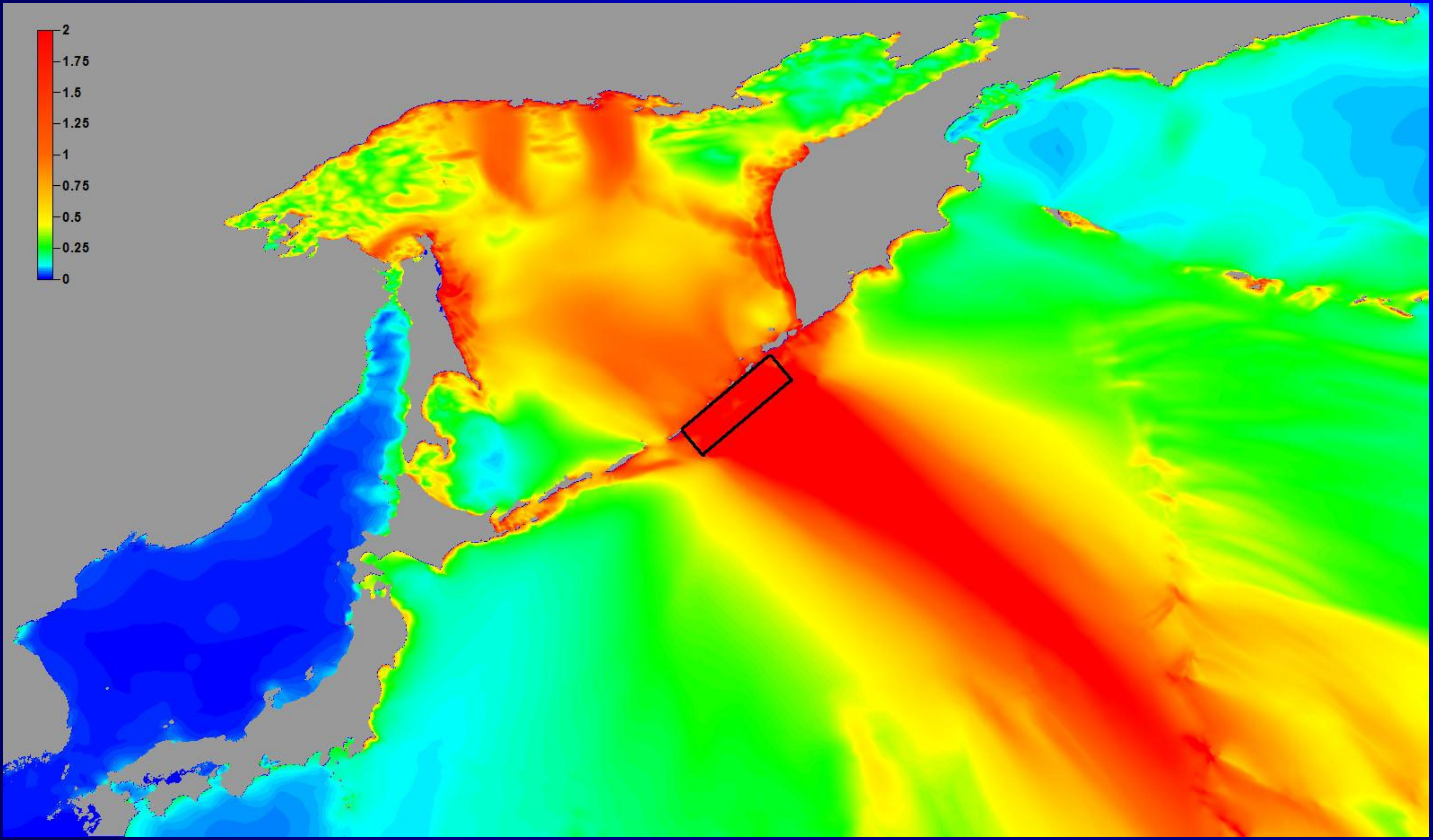
Numerical modeling of run-up in Koborinai Bay. Calculation is made in the ICT SD RAS (Rychkov, et al., 2013)



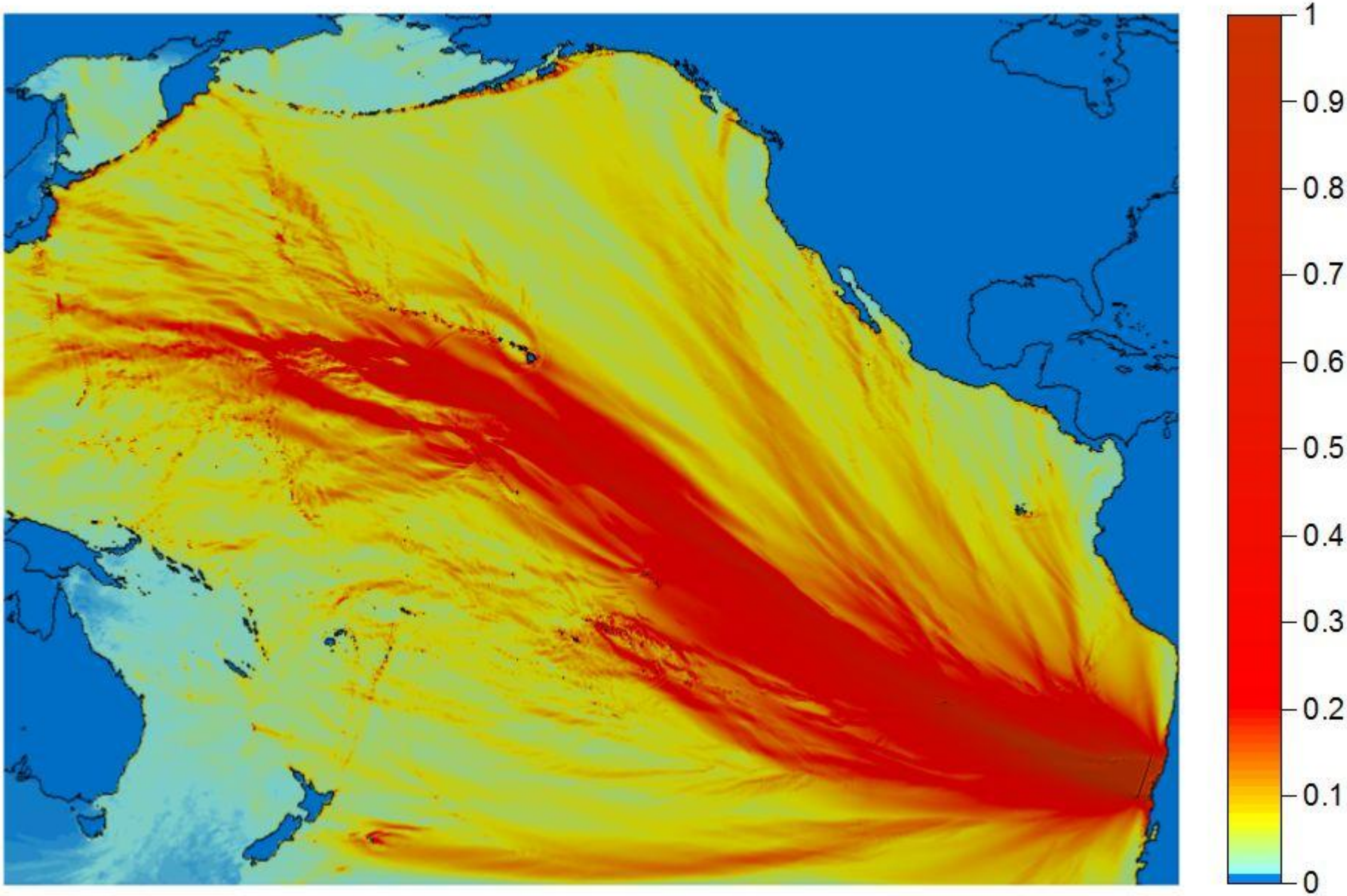
Tsunami propagation modeling in the Kuril-Kamchatka region for Mw=7.8 model source



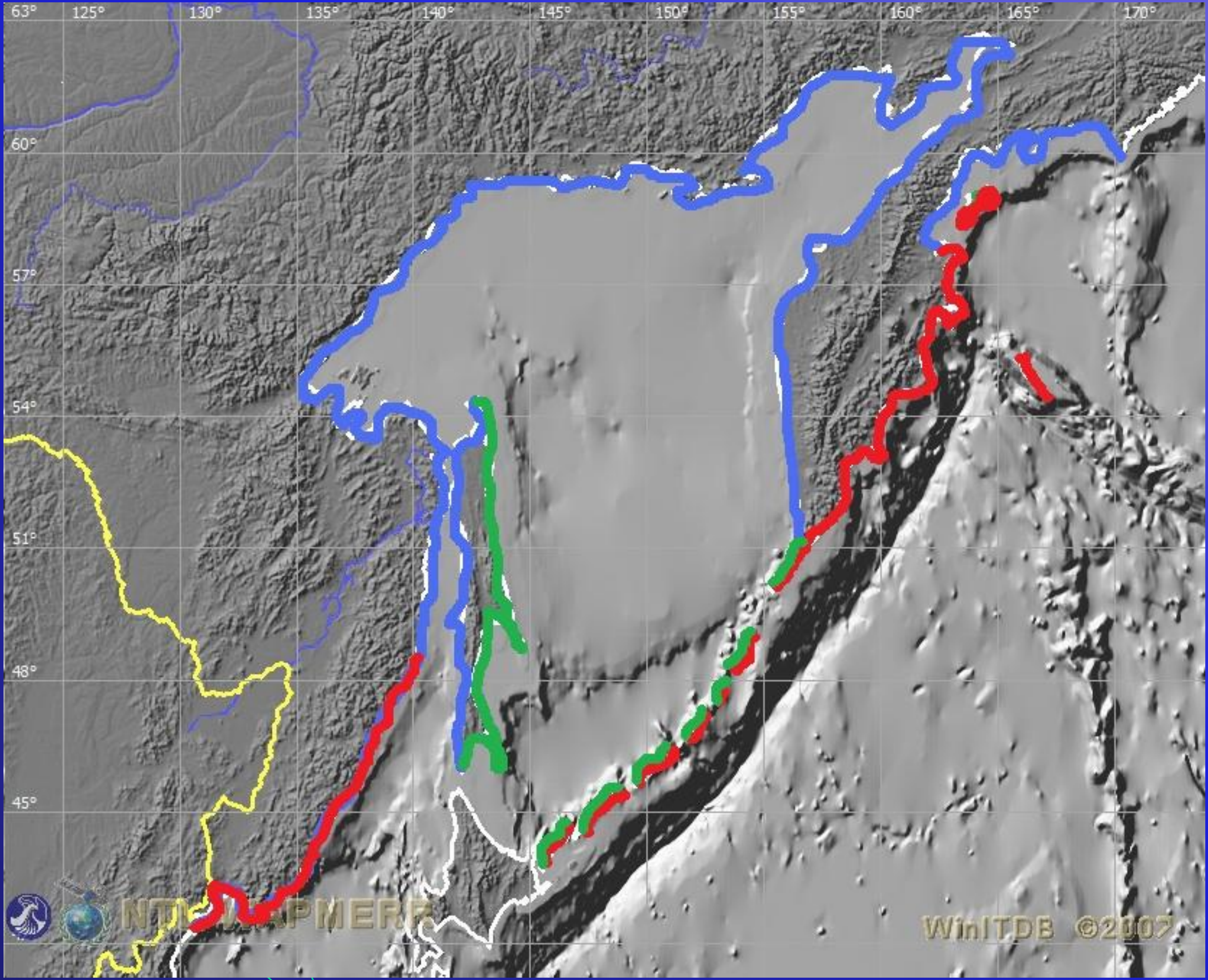
Tsunami propagation modeling in the Kuril-Kamchatka region for Mw=8.4 model source



Tsunami propagation modeling in the Kuril-Kamchatka region for Mw=9.0 model source



Numerical model of the 1960 Chilean tsunami



Parts of Far East coast with predominant input into tsunami hazard from local earthquakes (red color), from far-field sources (blue color), and mixed input (green color)

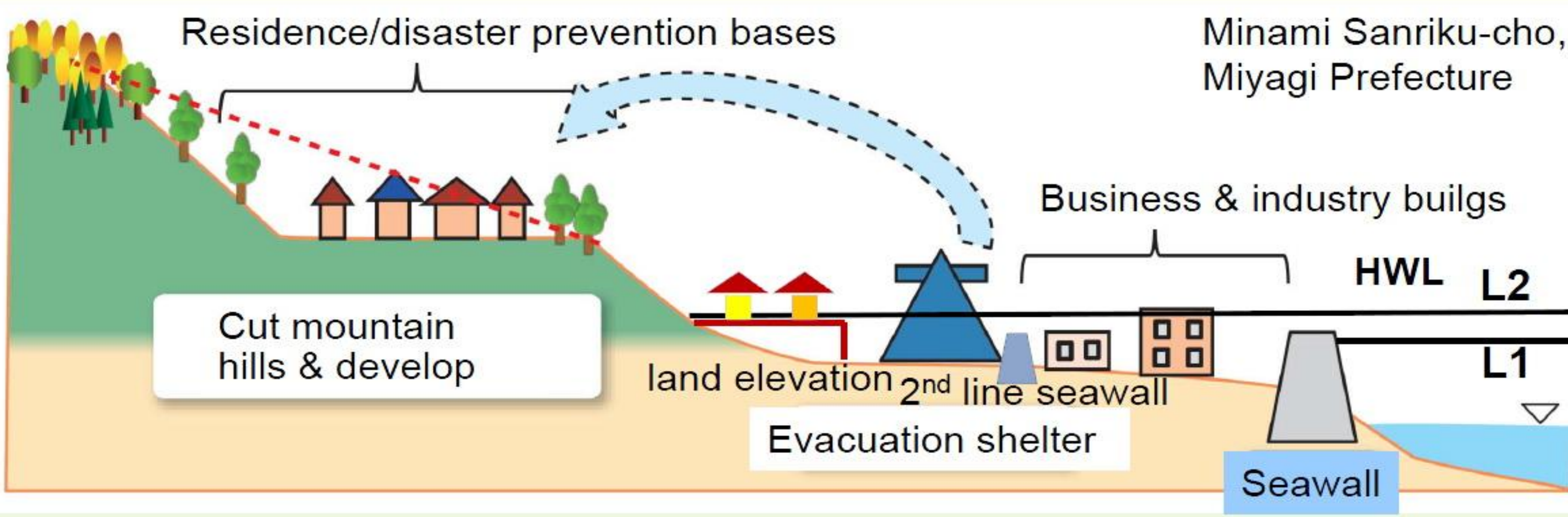
Reconstruction principles in Tohoku

(Central Disaster Management Council, 28 Sept 2011)

Two levels Approach

Level 1 Tsunami (Frequent scale: 50-150 years)
Life, properties & livelihood

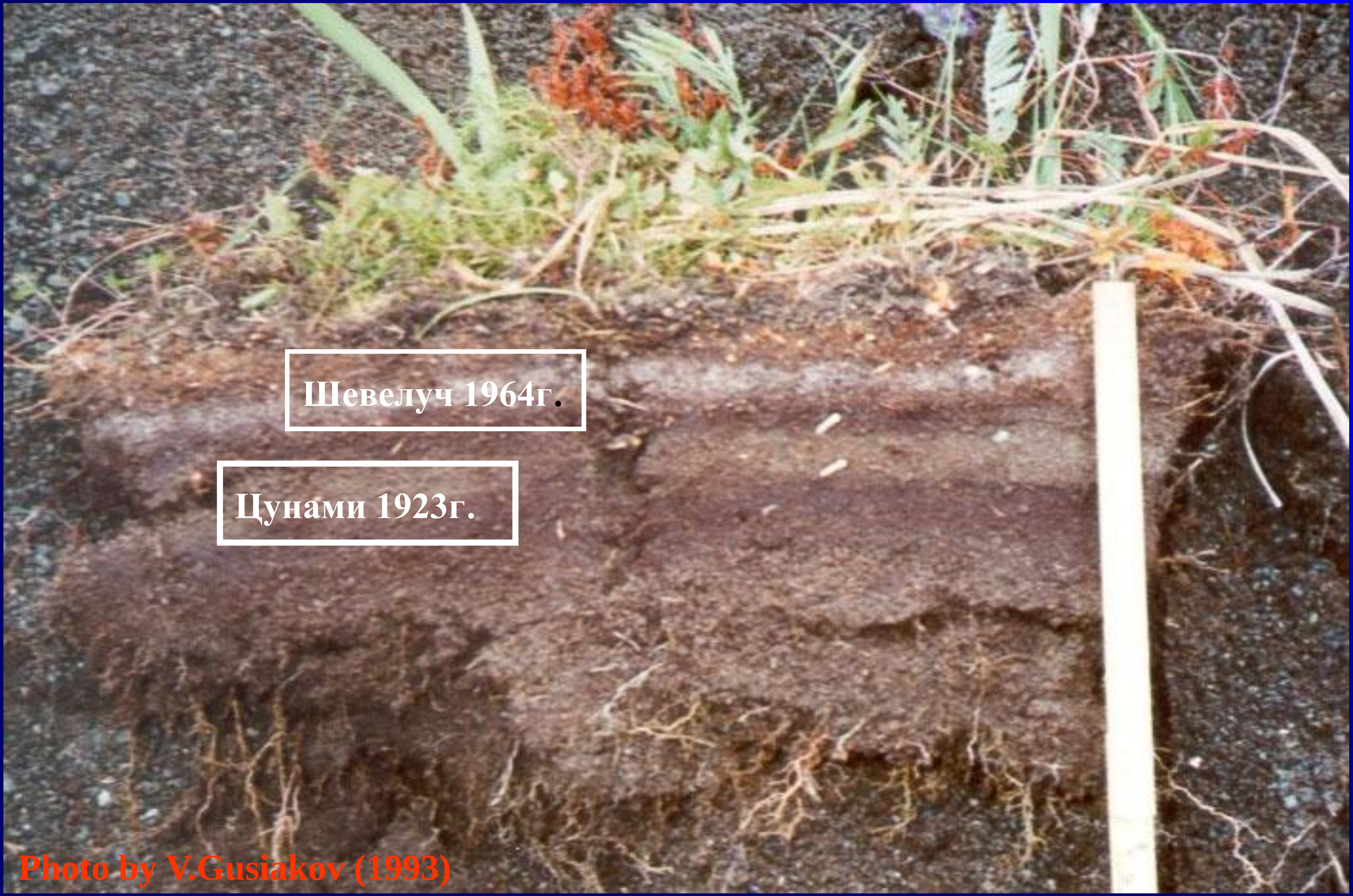
- Sea walls, dikes, highways:



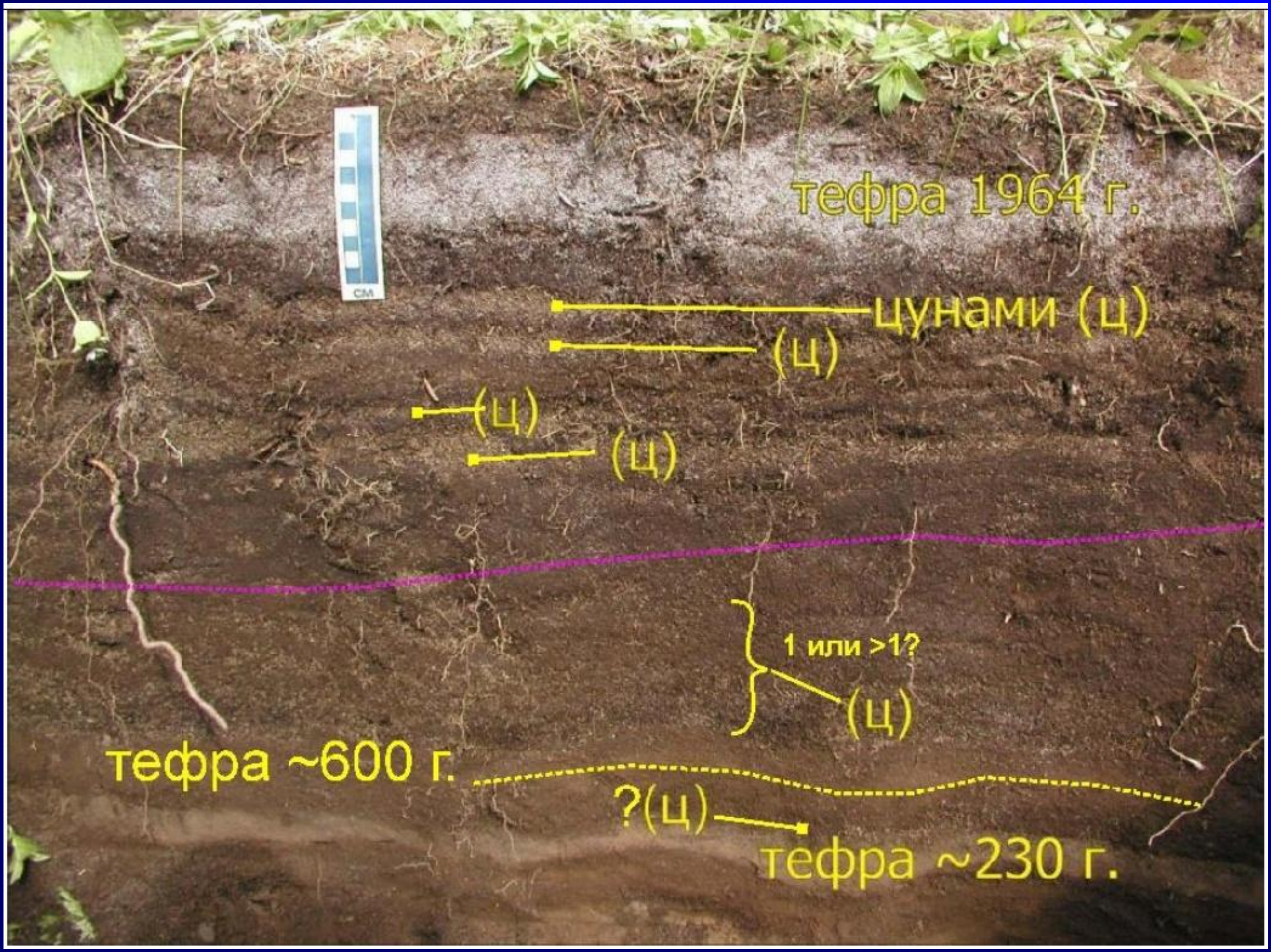
Level 2 Tsunami (Maximum scale: 1000 years) Life

- Move to higher lands
- Tall buildings to evacuate
- Landuse (park, factories, farmland; commercial/business, residential areas)

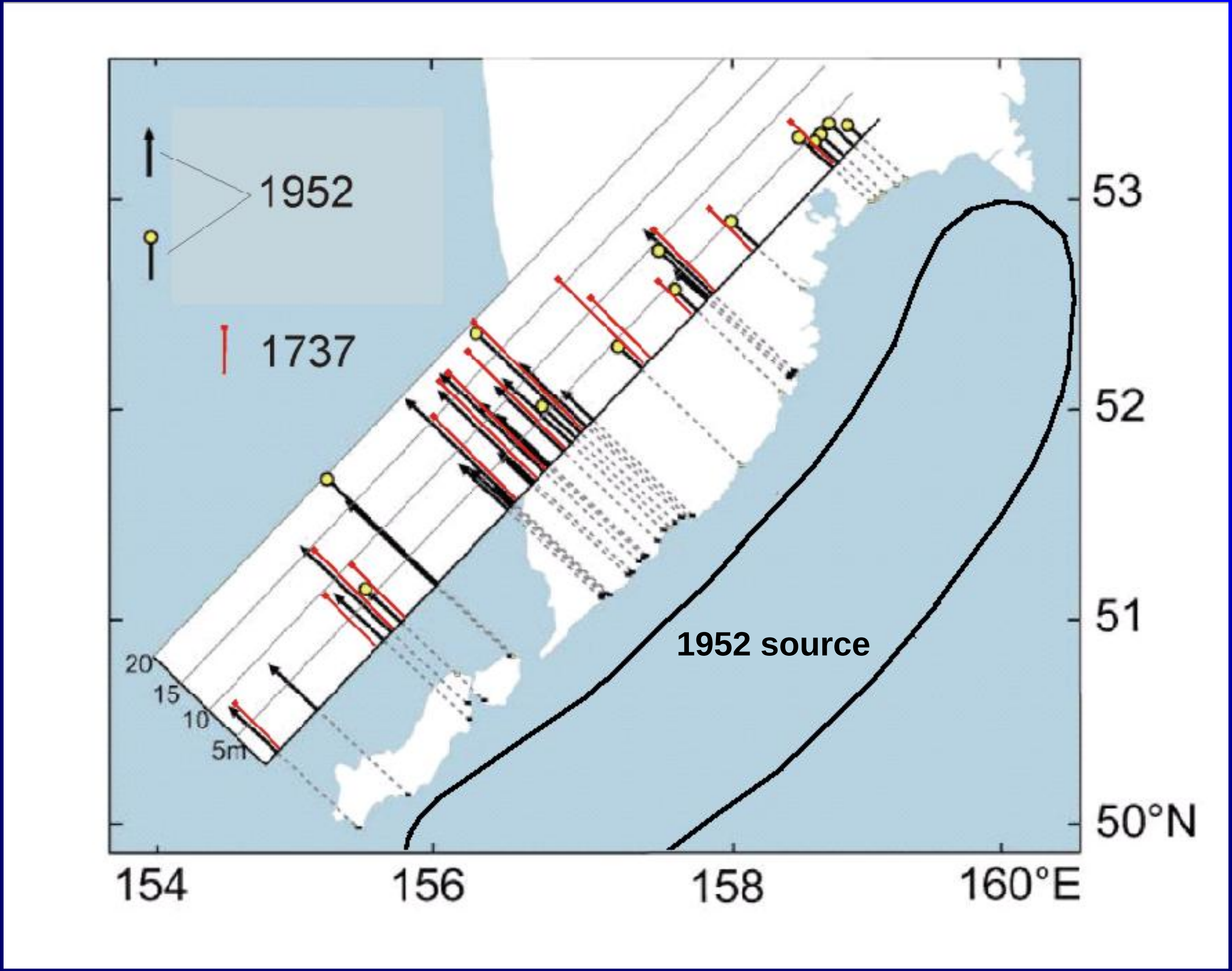
New paradigm in tsunami hazard mitigation in Japan – two-level strategy in tsunami hazard management (Takeuchi, 2013)



Ust-Kasmchatsk plain, July 1993, the first paleotsunami expedition in Kamchatka. Distance from the coast is ~1km.

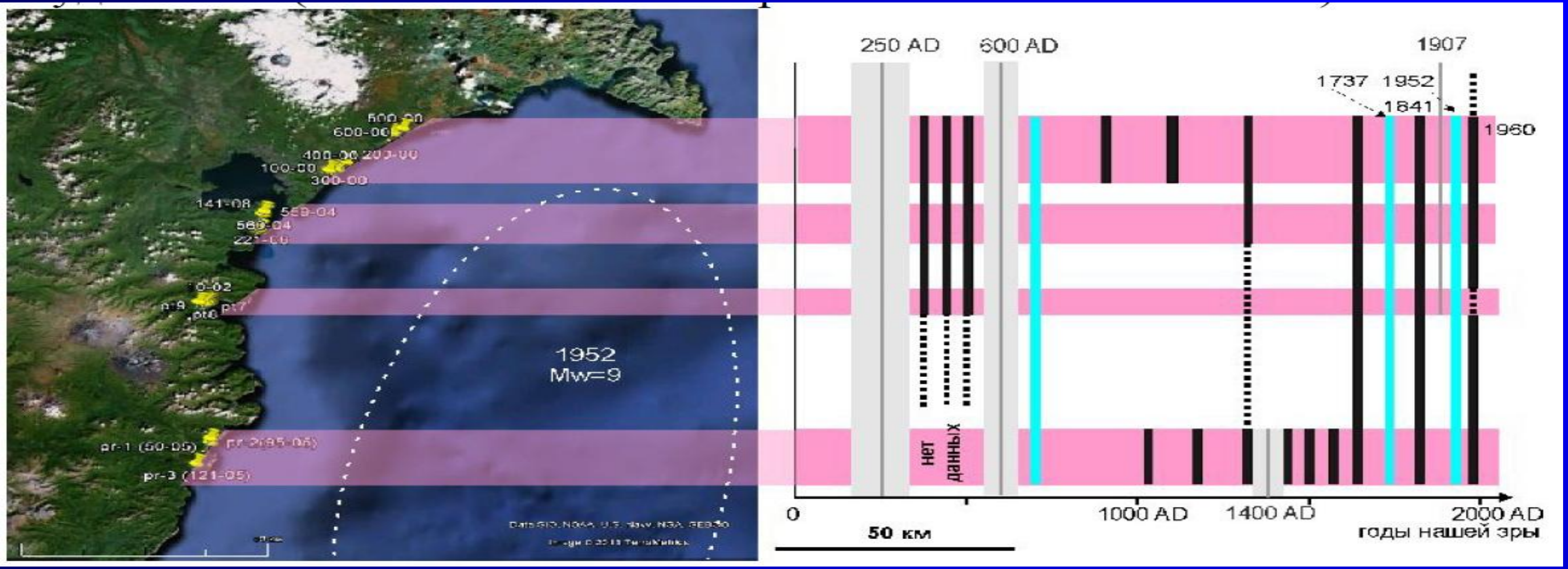


Tsunamigenic sand layers in the cross-section made at the altitude of 20.5 m on the Kamchatskiy Cape (Pinegina, 2014)

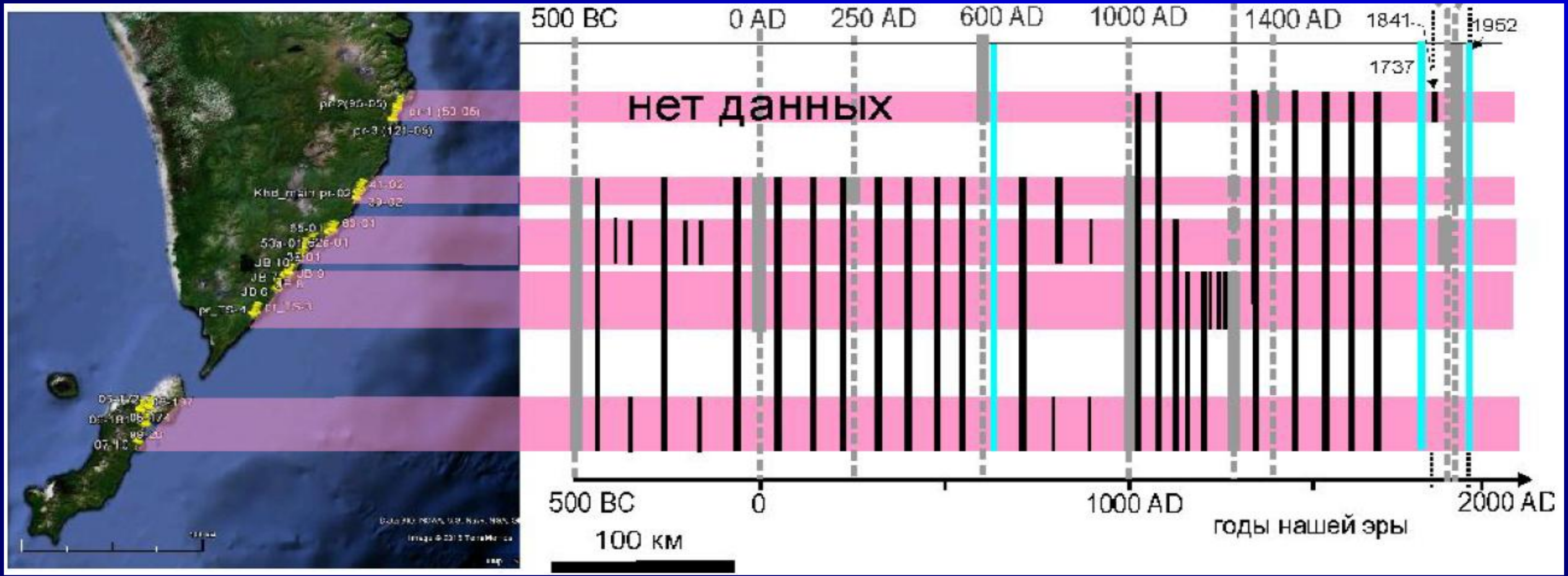


Restored (by paleo-geological tracing) run-up heights of the 1737 and 1952 tsunamis along the Paramushir – Kamchatka east coast (Pinegina, 2014)

A



B



Restored time history of paleotsunami events near Avacha Bay (A) and along the SE coast of Kamchatka (B) (Pinegina, 2014)

Massive boulder at the top of coastal cliff near Wollongong, South East coast of Australia

Selected key-points (as conclusions to my talk)

Trans-oceanic tsunamis resulted from M9 class subduction earthquakes gives major input in overall tsunami hazard (1% of events responsible for >50% of all fatalities).

With few exceptions (1896 Sanriku, 1946 Aleutians) the magnitude value Mw=9.0 looks like a threshold for generating of trans-oceanic tsunamis.

Geological methods of paleotsunami tracing is indispensable tool for long-term tsunami hazard assessment and needs to be used in all regions

Modern numerical technique allows adequate modeling of general run-up distribution in the near and far-field and allows close reproduction of extreme run-ups provided that fine bathymetry/elevation models are available.

Thanks for your attention!

a