Evaluation of Tsunami Risk

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Tsunami Risk Assessment
or Long-Term Prediction

Components of Risk are:

- Probable frequency of occurrence
- Number of people (or facilities) exposed

Risk thus deals with the cumulative impacts in an area

TTsunami Risk Assessment

Sshould include:

MMechanics” (Run-up and velocity)

HHuman (Life Safety)

E**Economics (Finances)**

E**Ecology (Land, etc)**

RISK = Run-up + Probability

LONG-TERM PREDICTION (*HOW OFTEN*?)

TSUNAMIS are RARE EVENTS

Poisson statistics is one *extreme* type of distribution

$$P_n = \frac{(\nu t)^n}{n!} \exp(-\nu t)$$

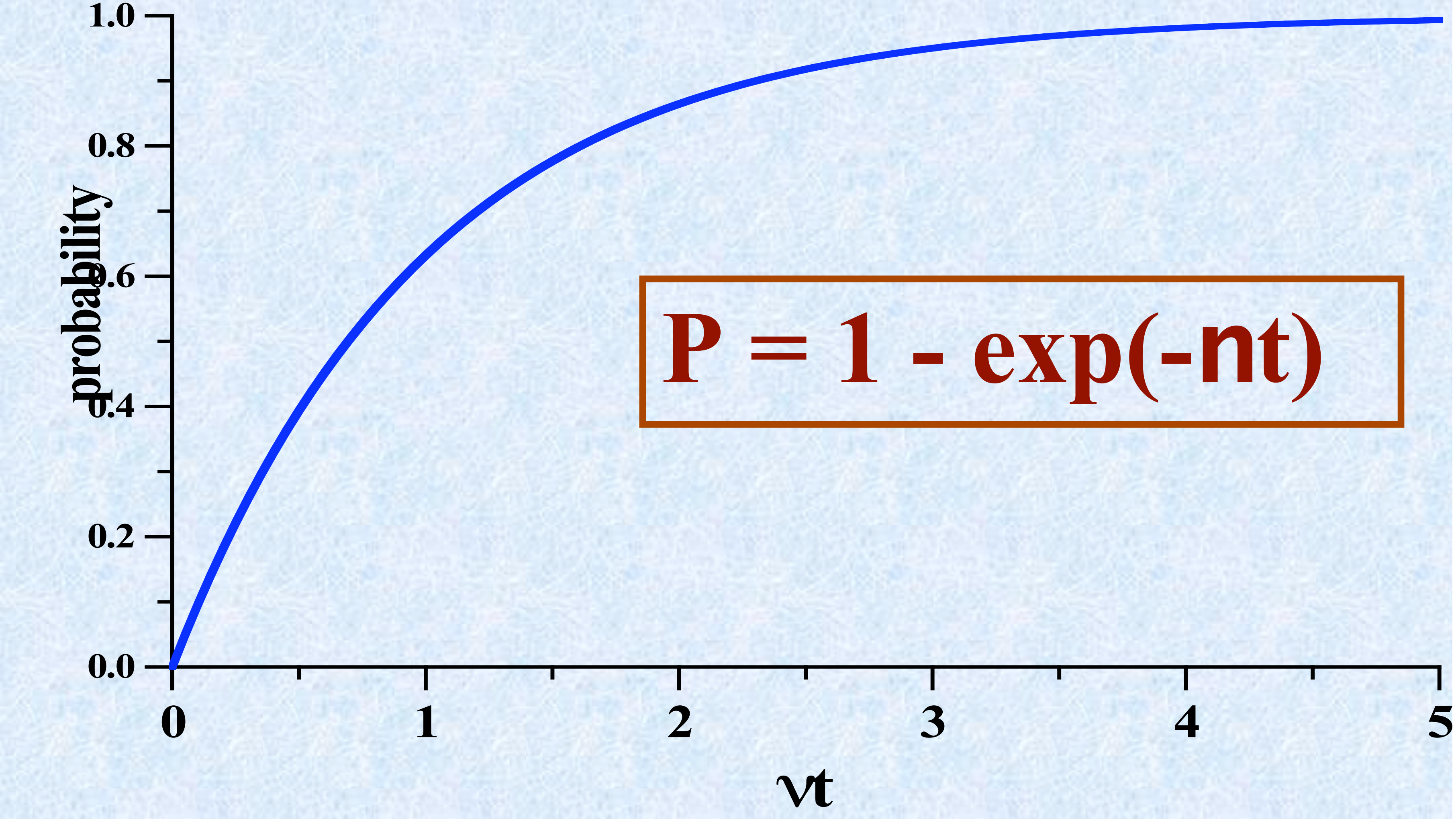
***n* *rare events will be during time* *T* *with probability* P_n**

Here* n *is the MEAN frequency of appearance of rare events

n - where we may take it?

PROGNOSTIC PROBABILITY

Probability that *at least* one event will take place in this period is



$$P = 1 - \exp(-nt)$$

Exceedance (Cumulative) Frequency

EVENT is TSUNAMI with *run-up height* exceeded R,

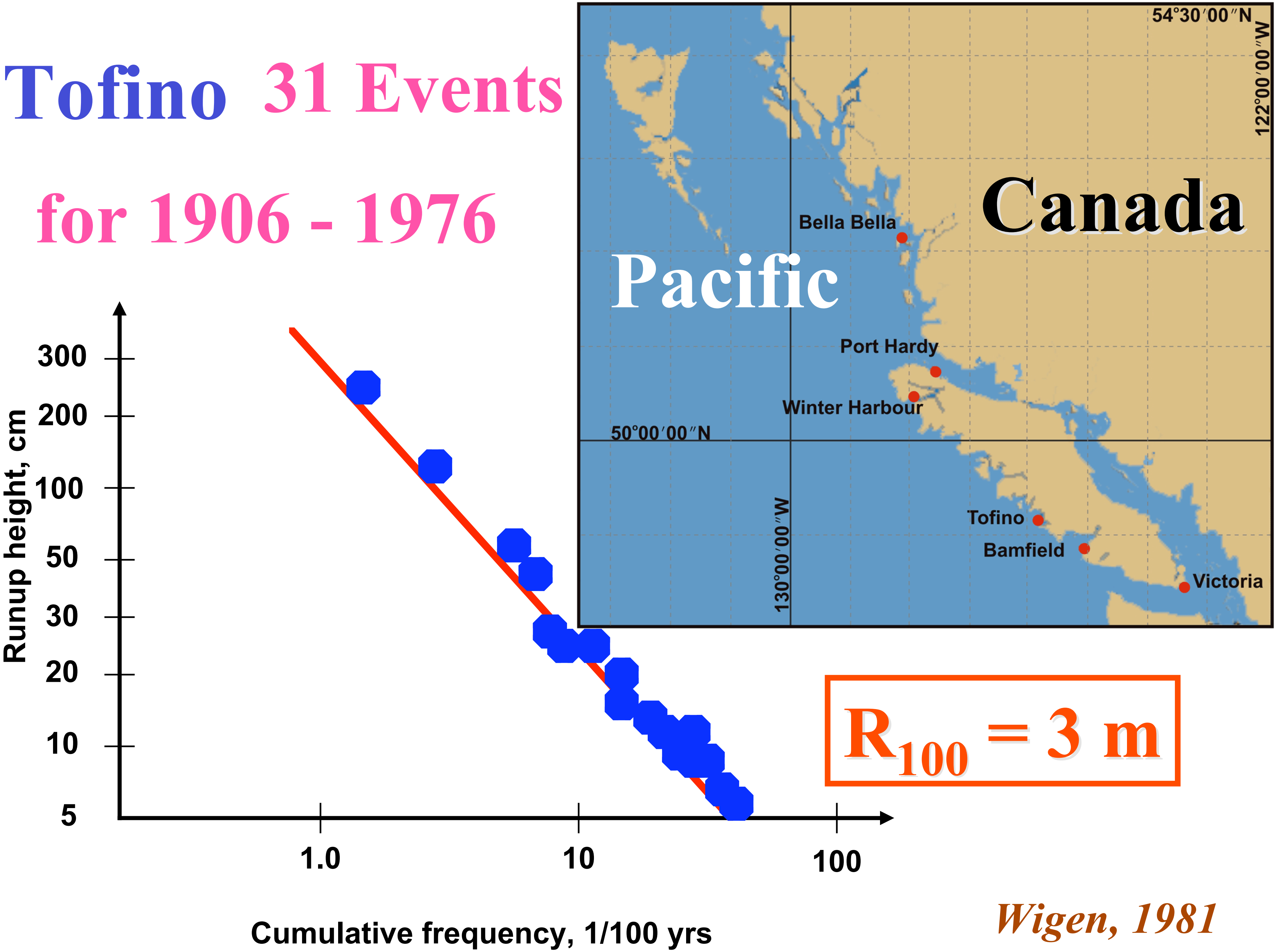
and n is cumulative frequency

From Statistics of Extremes (Gumbel)

is known

$$\boxed{n \sim \mathit{exp}(-R) \qquad \text{or} \qquad n \sim R^{-m}}$$

Tofino 31 Events for 1906 - 1976



$R_{100} = 3$ m

Wigen, 1981

Cumulative Frequency – Runup Height

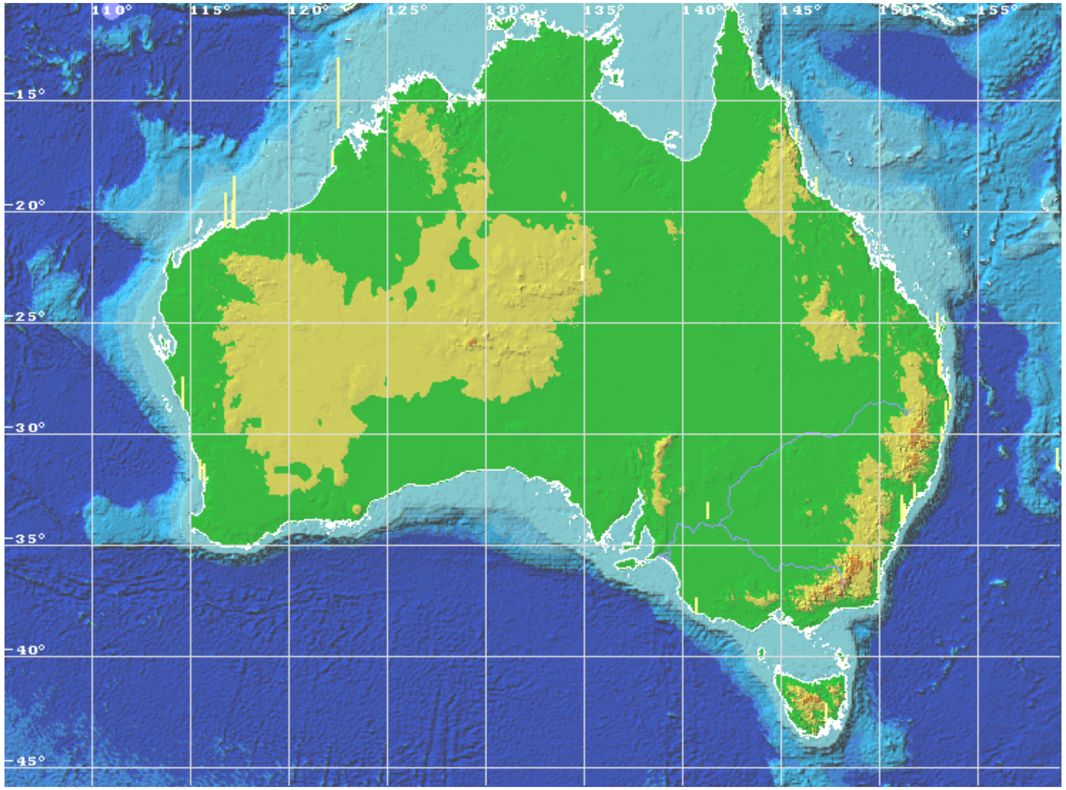
Tofino, Canada - 31 events for 1906-1976

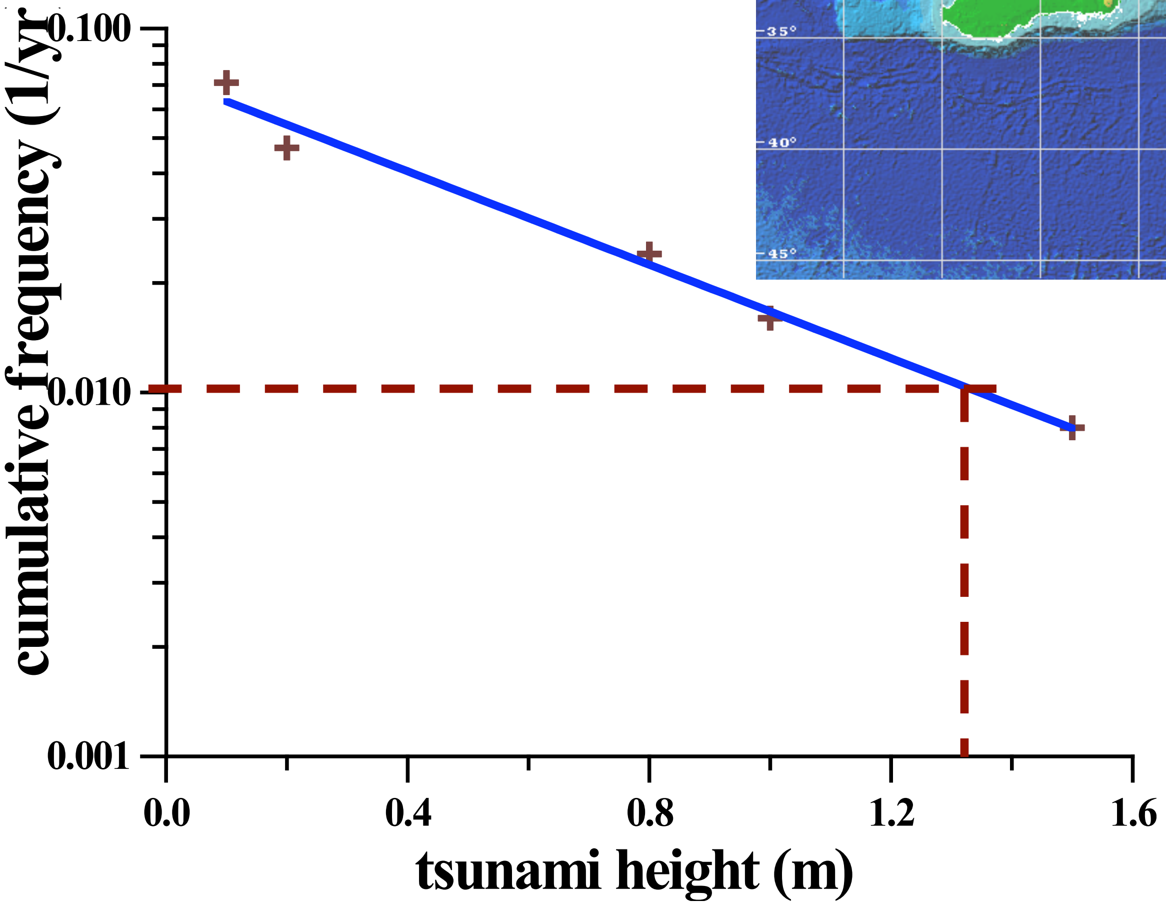
Hilo, USA - 28 events for 1832-1964

But for most areas of the World there are relative small samples of numerical tsunami data

Eastern Coast of Australia

(10 events)





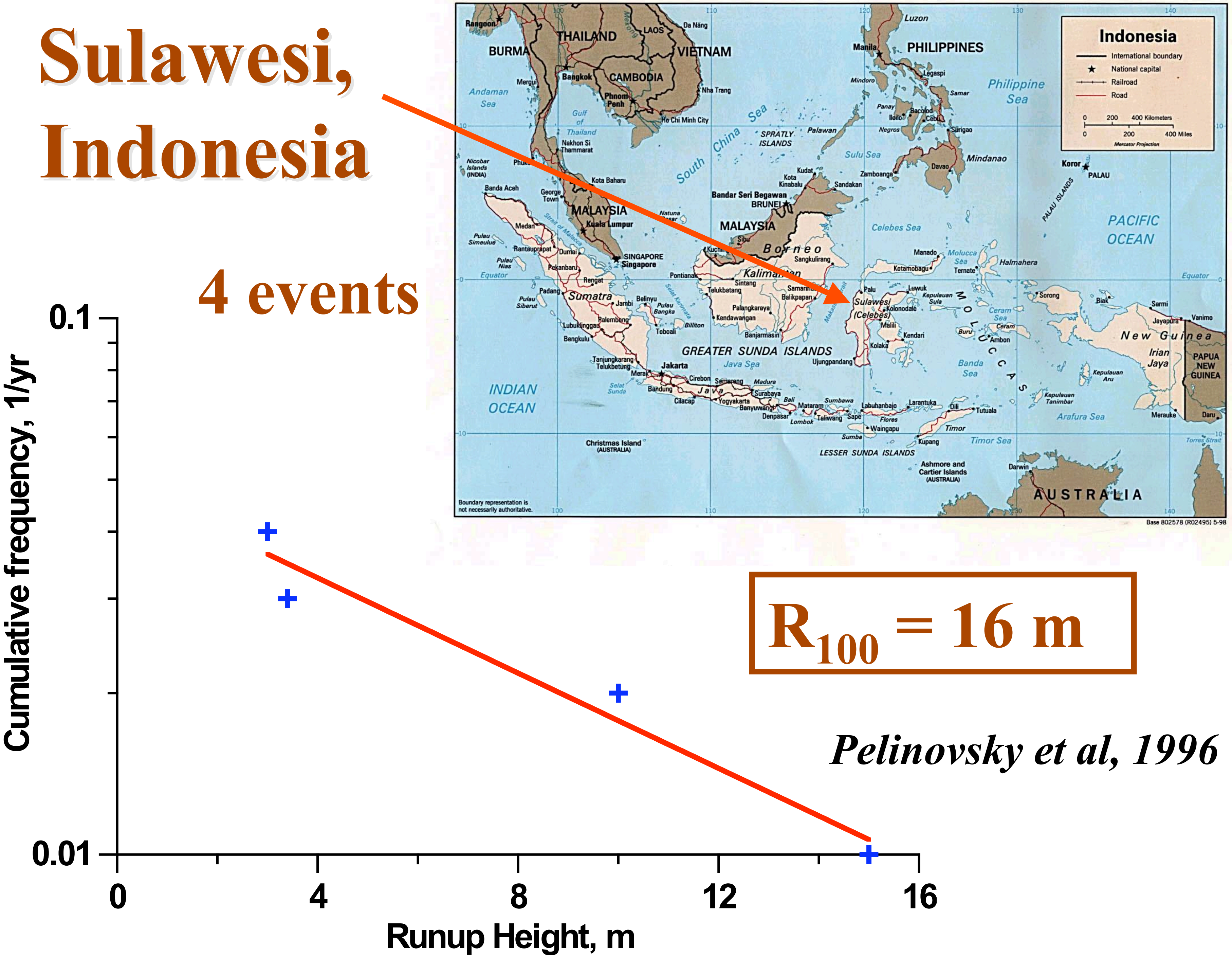
R_{100} = 1.3 m

low accuracy

Pelinovsky, 1997

Sulawesi, Indonesia

4 events



R_{100} = 16 m

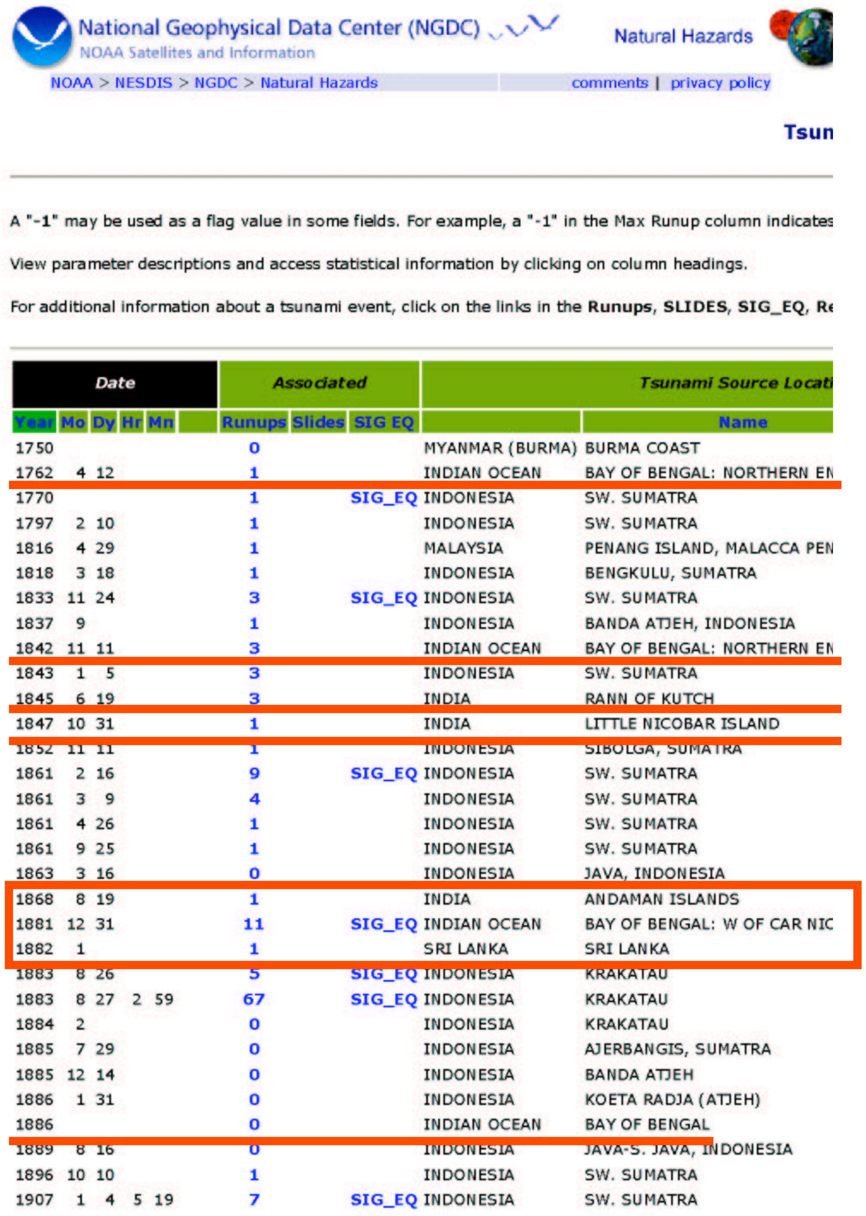
Pelinovsky et al, 1996

Israel

24 events
in Mediterranean and Dead Seas
and Kinerret Lake
for whole history

Quantitative information
is available for tsunami
30 October 1759 only:
R = 2-2.5 m

India – 13 events



National Geophysical Data Center (NGDC)
NOAA Satellites and Information
Natural Hazards

NOAA > NESDIS > NGDC > Natural Hazards
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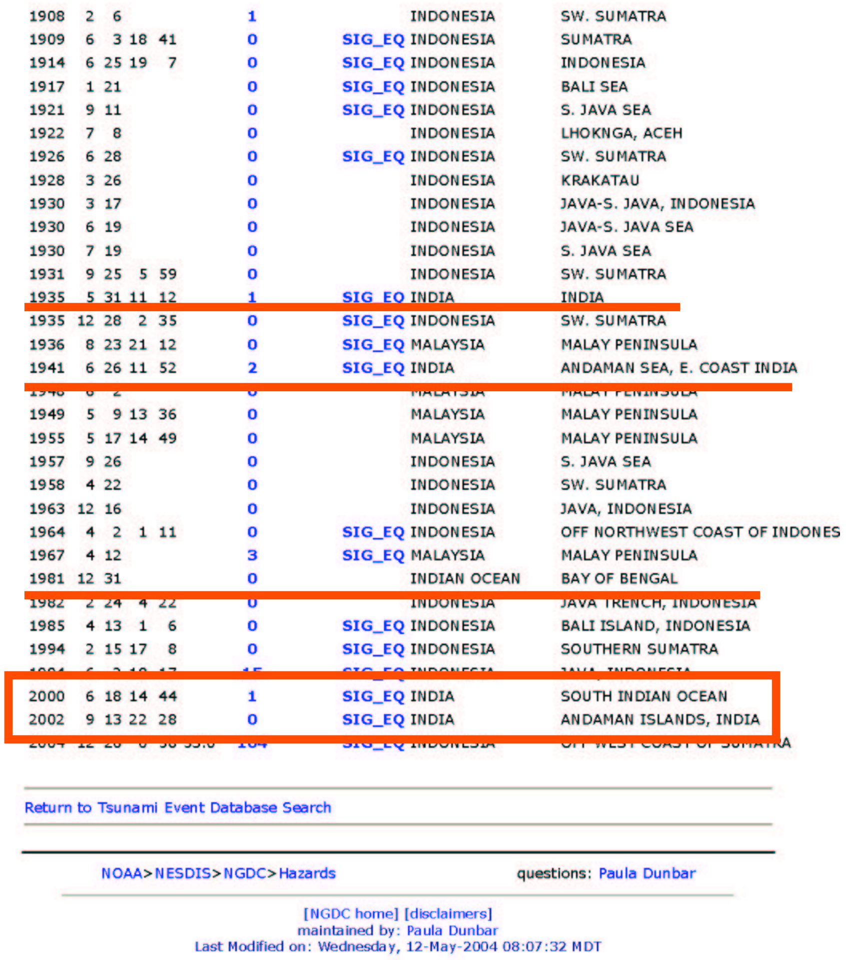
Tsun

A "-1" may be used as a flag value in some fields. For example, a "-1" in the Max Runup column indicates

View parameter descriptions and access statistical information by clicking on column headings.

For additional information about a tsunami event, click on the links in the **Runups, SLIDES, SIG_EQ, Re**

Date						Associated			Tsunami Source Locati	
Year	Mo	Dy	Hr	Mn		Runups	Slides	SIG EQ		Name
1750						0			MYANMAR (BURMA)	BURMA COAST
1762	4	12				1			INDIAN OCEAN	BAY OF BENGAL: NORTHERN EN
1770						1		SIG_EQ	INDONESIA	SW. SUMATRA
1797	2	10				1			INDONESIA	SW. SUMATRA
1816	4	29				1			MALAYSIA	PENANG ISLAND, MALACCA PEN
1818	3	18				1			INDONESIA	BENGKULU, SUMATRA
1833	11	24				3		SIG_EQ	INDONESIA	SW. SUMATRA
1837	9					1			INDONESIA	BANDA ATJEH, INDONESIA
1842	11	11				3			INDIAN OCEAN	BAY OF BENGAL: NORTHERN EN
1843	1	5				3			INDONESIA	SW. SUMATRA
1845	6	19				3			INDIA	RANN OF KUTCH
1847	10	31				1			INDIA	LITTLE NICOBAR ISLAND
1852	11	11				1			INDONESIA	SIBOLGA, SUMATRA
1861	2	16				9		SIG_EQ	INDONESIA	SW. SUMATRA
1861	3	9				4			INDONESIA	SW. SUMATRA
1861	4	26				1			INDONESIA	SW. SUMATRA
1861	9	25				1			INDONESIA	SW. SUMATRA
1863	3	16				0			INDONESIA	JAVA, INDONESIA
1868	8	19				1			INDIA	ANDAMAN ISLANDS
1881	12	31				11		SIG_EQ	INDIAN OCEAN	BAY OF BENGAL: W OF CAR NIC
1882	1					1			SRI LANKA	SRI LANKA
1883	8	26				5		SIG_EQ	INDONESIA	KRAKATAU
1883	8	27	2	59		67		SIG_EQ	INDONESIA	KRAKATAU
1884	2					0			INDONESIA	KRAKATAU
1885	7	29				0			INDONESIA	AJERBANGIS, SUMATRA
1885	12	14				0			INDONESIA	BANDA ATJEH
1886	1	31				0			INDONESIA	KOETA RADJA (ATJEH)
1886						0			INDIAN OCEAN	BAY OF BENGAL
1889	8	16				0			INDONESIA	JAVA-S. JAVA, INDONESIA
1896	10	10				1			INDONESIA	SW. SUMATRA
1907	1	4	5	19		7		SIG_EQ	INDONESIA	SW. SUMATRA



Year	Mo	Dy	Hr	Mn		Runups	Slides	SIG EQ		Name
1908	2	6				1			INDONESIA	SW. SUMATRA
1909	6	3	18	41		0		SIG_EQ	INDONESIA	SUMATRA
1914	6	25	19	7		0		SIG_EQ	INDONESIA	INDONESIA
1917	1	21				0		SIG_EQ	INDONESIA	BALI SEA
1921	9	11				0		SIG_EQ	INDONESIA	S. JAVA SEA
1922	7	8				0			INDONESIA	LHOKNGA, ACEH
1926	6	28				0		SIG_EQ	INDONESIA	SW. SUMATRA
1928	3	26				0			INDONESIA	KRAKATAU
1930	3	17				0			INDONESIA	JAVA-S. JAVA, INDONESIA
1930	6	19				0			INDONESIA	JAVA-S. JAVA SEA
1930	7	19				0			INDONESIA	S. JAVA SEA
1931	9	25	5	59		0			INDONESIA	SW. SUMATRA
1935	5	31	11	12		1		SIG_EQ	INDIA	INDIA
1935	12	28	2	35		0		SIG_EQ	INDONESIA	SW. SUMATRA
1936	8	23	21	12		0		SIG_EQ	MALAYSIA	MALAY PENINSULA
1941	6	26	11	52		2		SIG_EQ	INDIA	ANDAMAN SEA, E. COAST INDIA
1948	6	2				0			MALAYSIA	MALAY PENINSULA
1949	5	9	13	36		0			MALAYSIA	MALAY PENINSULA
1955	5	17	14	49		0			MALAYSIA	MALAY PENINSULA
1957	9	26				0			INDONESIA	S. JAVA SEA
1958	4	22				0			INDONESIA	SW. SUMATRA
1963	12	16				0			INDONESIA	JAVA, INDONESIA
1964	4	2	1	11		0		SIG_EQ	INDONESIA	OFF NORTHWEST COAST OF INDONES
1967	4	12				3		SIG_EQ	MALAYSIA	MALAY PENINSULA
1981	12	31				0			INDIAN OCEAN	BAY OF BENGAL
1982	2	24	4	22		0			INDONESIA	JAVA TRENCH, INDONESIA
1985	4	13	1	6		0		SIG_EQ	INDONESIA	BALI ISLAND, INDONESIA
1994	2	15	17	8		0		SIG_EQ	INDONESIA	SOUTHERN SUMATRA
1994	6	2	18	17		15		SIG_EQ	INDONESIA	JAVA, INDONESIA
2000	6	18	14	44		1		SIG_EQ	INDIA	SOUTH INDIAN OCEAN
2002	9	13	22	28		0		SIG_EQ	INDIA	ANDAMAN ISLANDS, INDIA
2004	12	26	0	58	53.0	164		SIG_EQ	INDONESIA	OFF WEST COAST OF SUMATRA

Return to Tsunami Event Database Search

NOAA>NESDIS>NGDC>Hazards questions: Paula Dunbar

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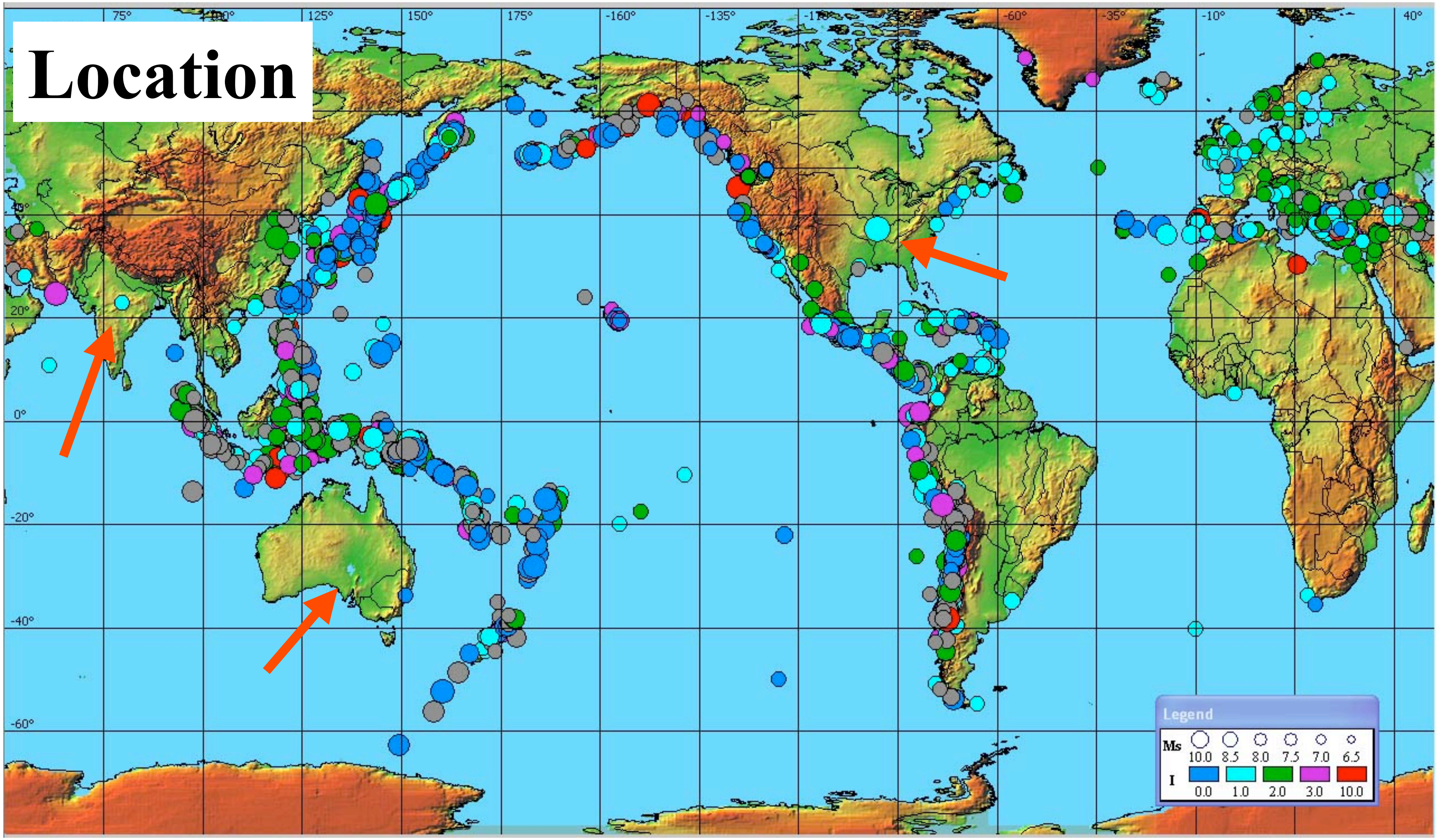
Last Modified on: Wednesday, 12-May-2004 08:07:32 MDT

What should we do?

1. To check RELIABILITY of data

- Location
- Source of tsunami
- Description
- Statistical reliability



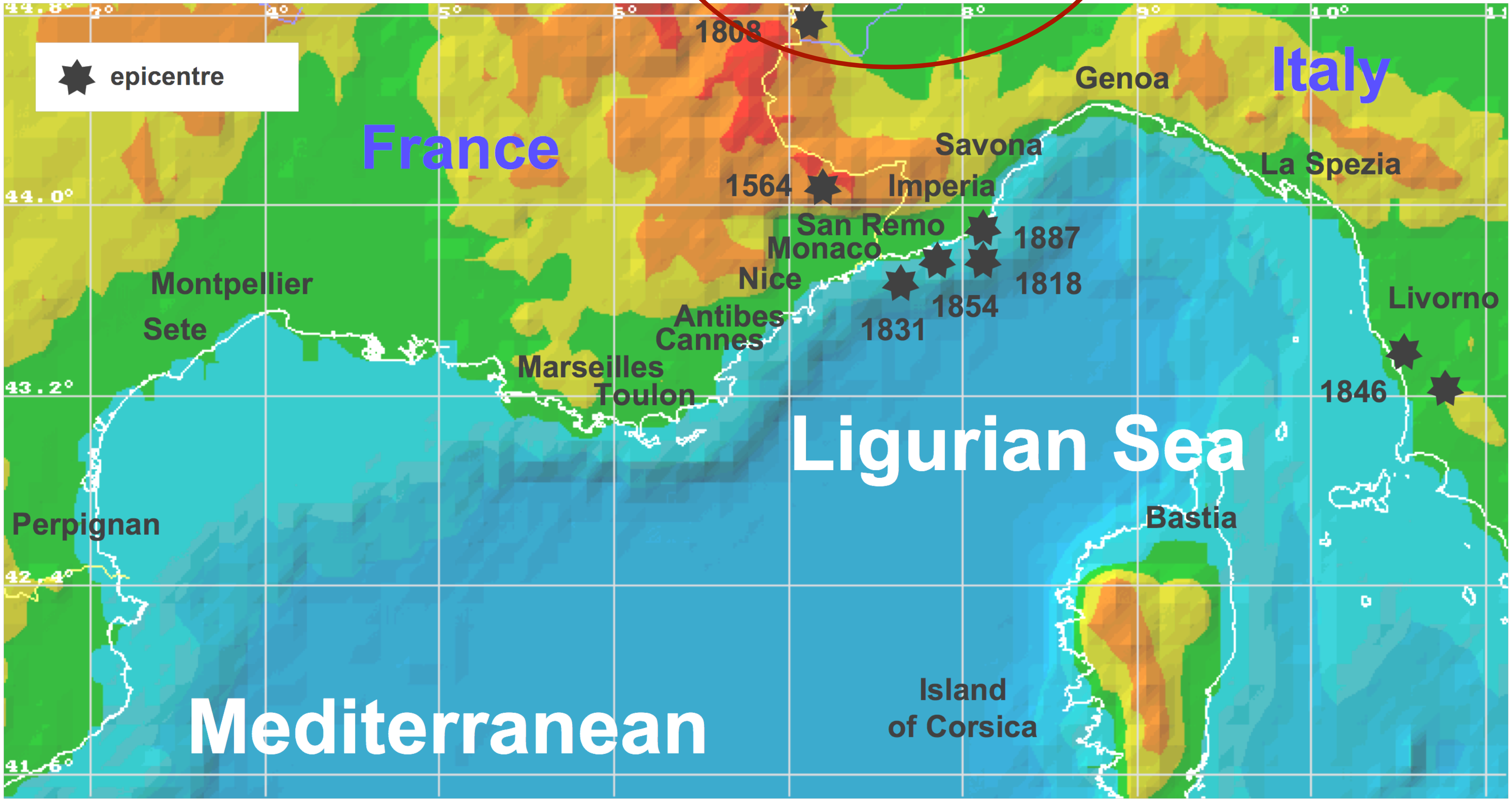
Geographical distribution of tsunamis in the World Ocean

The size of circles is proportional to the earthquake magnitude, density of gray tone – to the tsunami intensity

Gusiakov, 2005

Source of Tsunamis

Marseilles,
15 cm ?



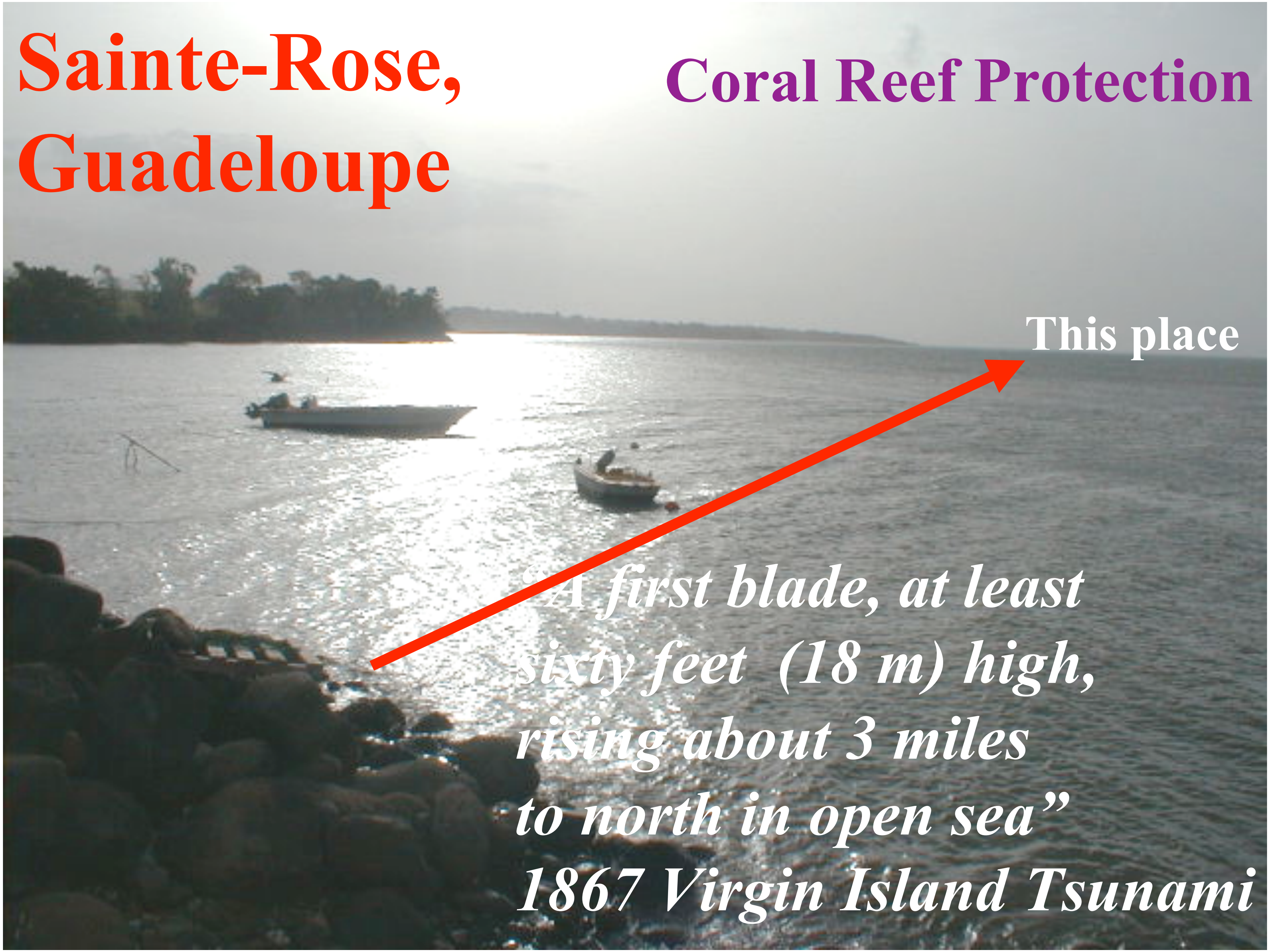
200 m !

Russia,
Kurile Islands,
November 4,1952

12 m

Sainte-Rose, Guadeloupe

Coral Reef Protection

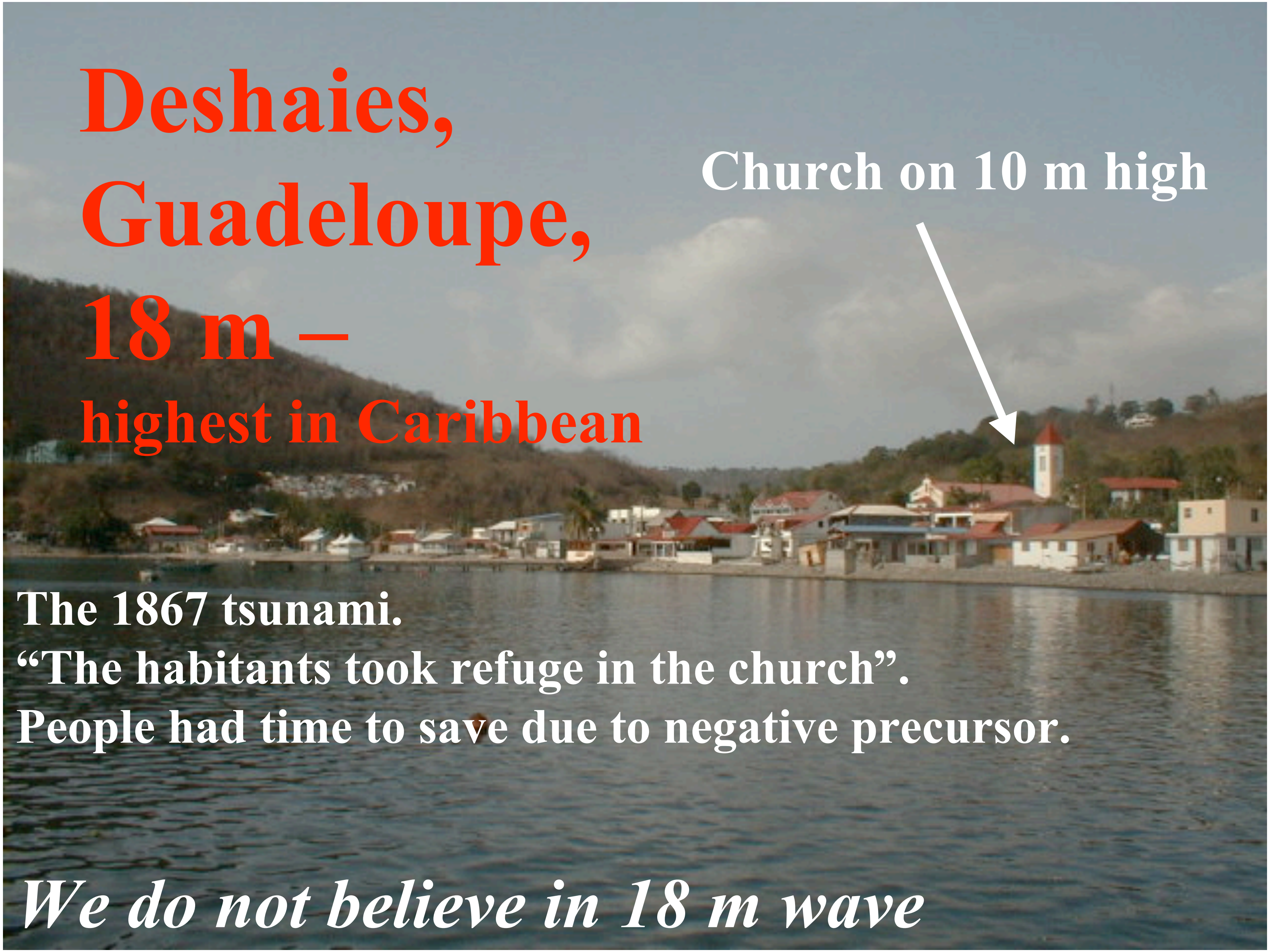


This place

"A first blade, at least sixty feet (18 m) high, rising about 3 miles to north in open sea"

1867 Virgin Island Tsunami

Deshaies, Guadeloupe, 18 m – highest in Caribbean



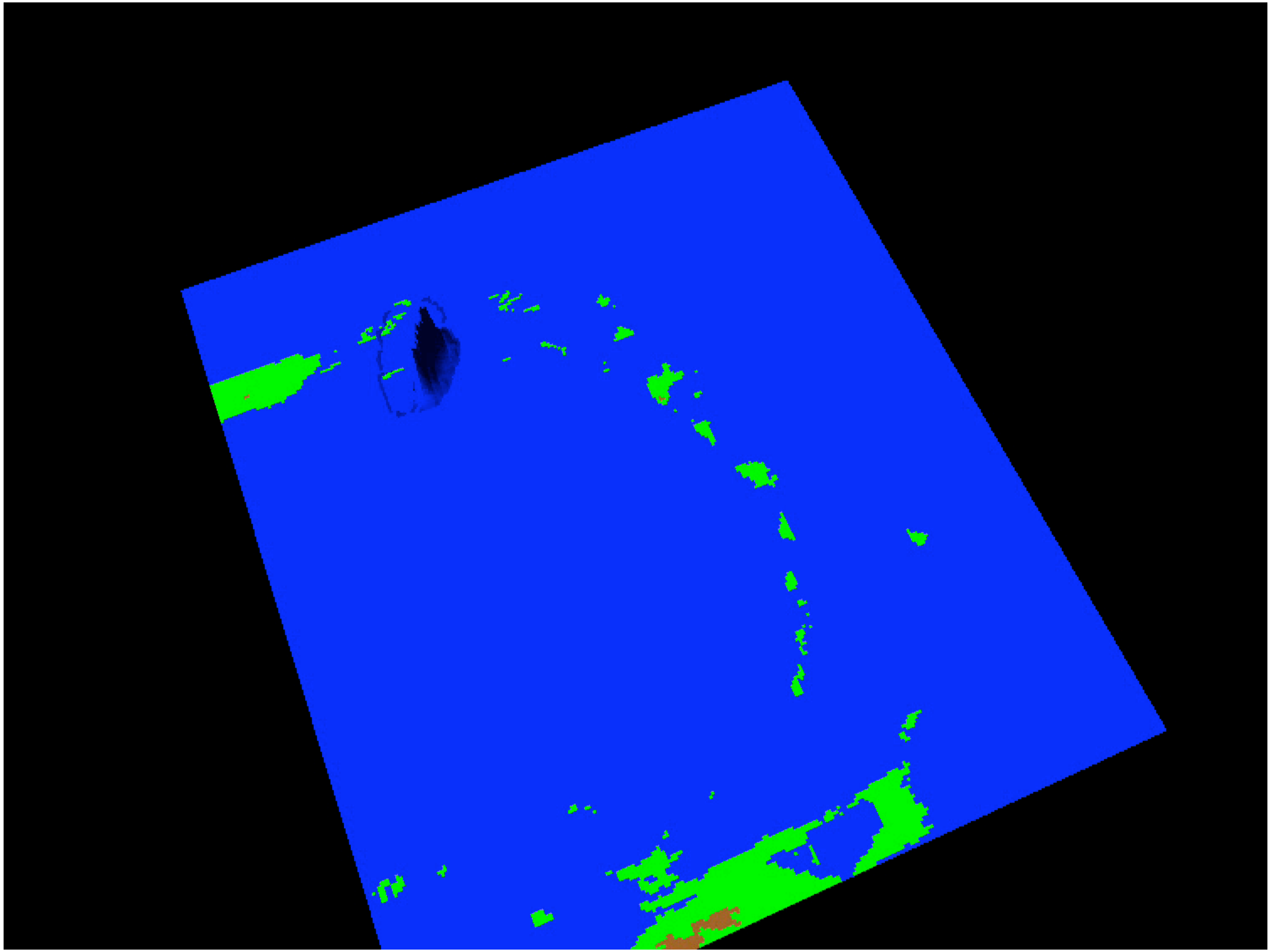
Church on 10 m high

The 1867 tsunami.
"The habitants took refuge in the church".
People had time to save due to negative precursor.

We do not believe in 18 m wave

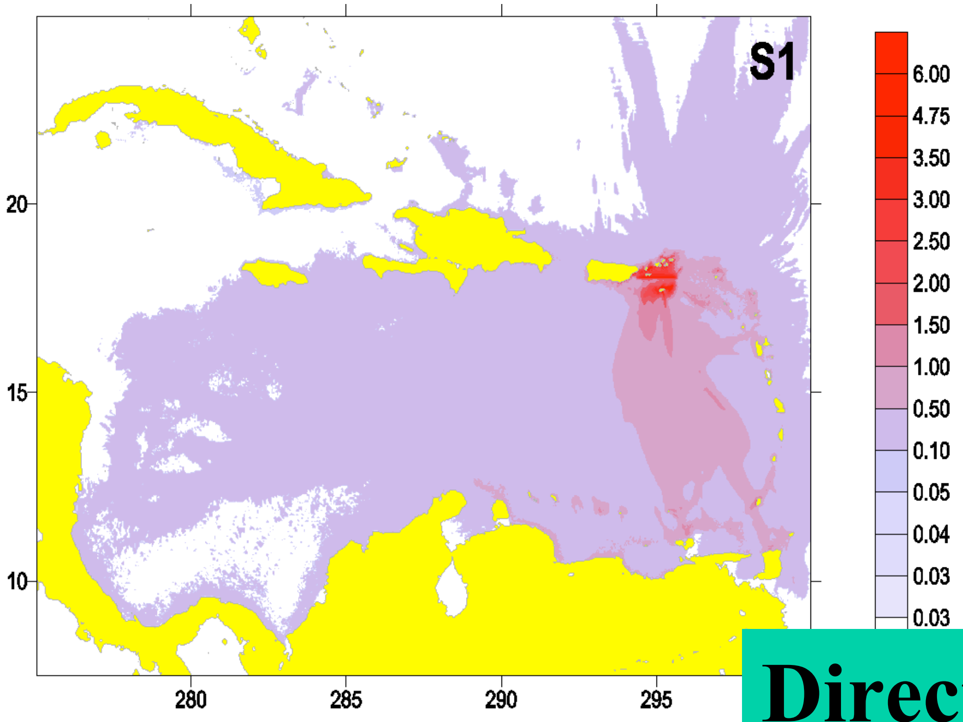
Correlation with numerical simulations (statistical reliability)

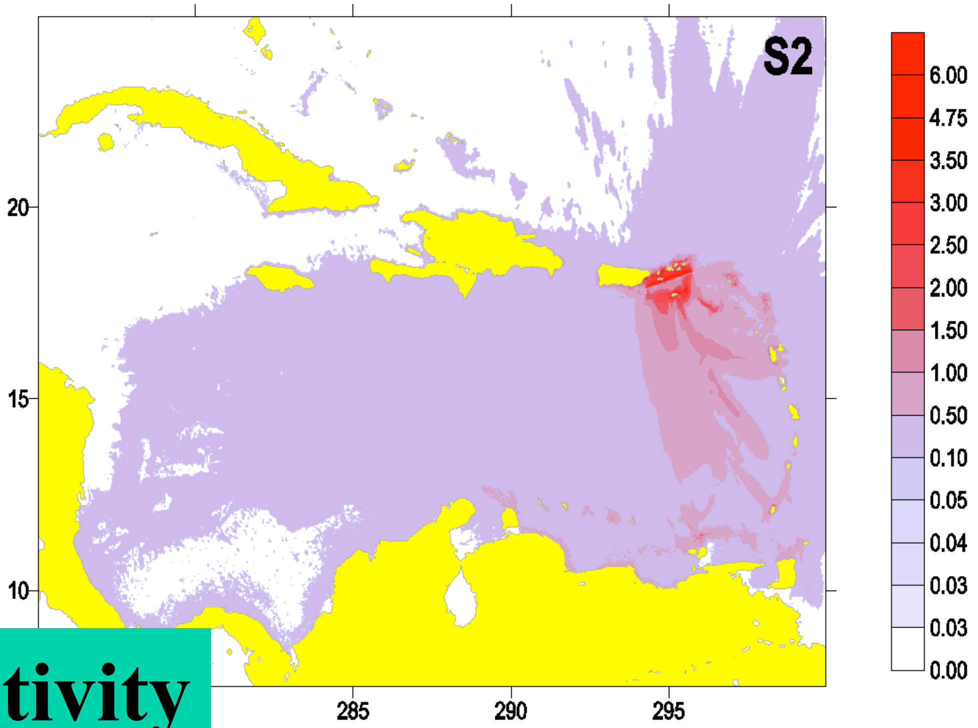
1867
Tsunami
at
Caribbean

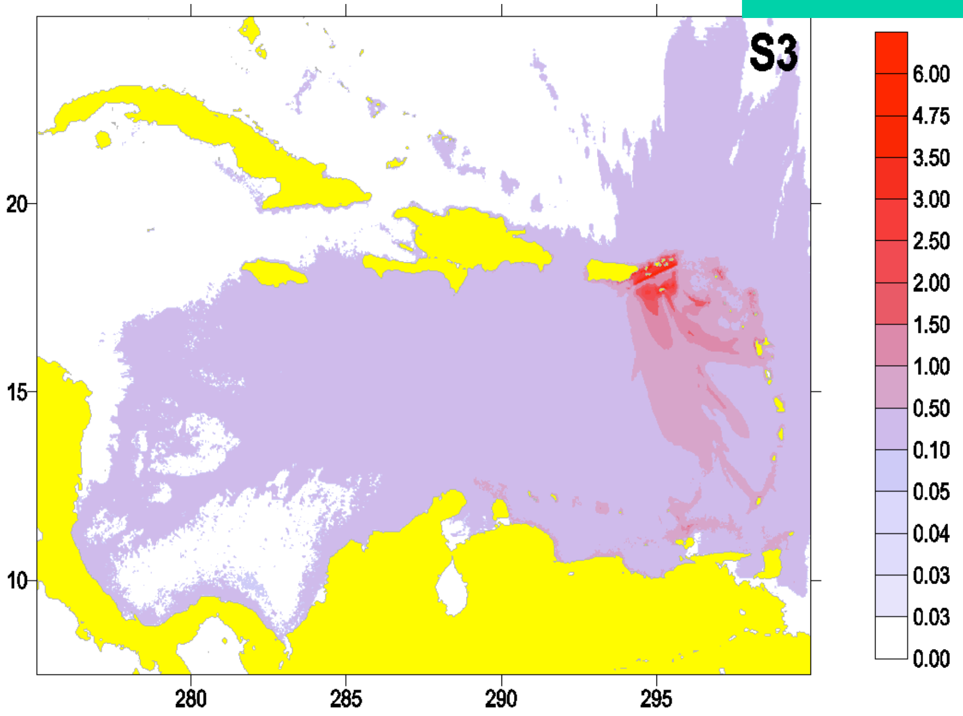


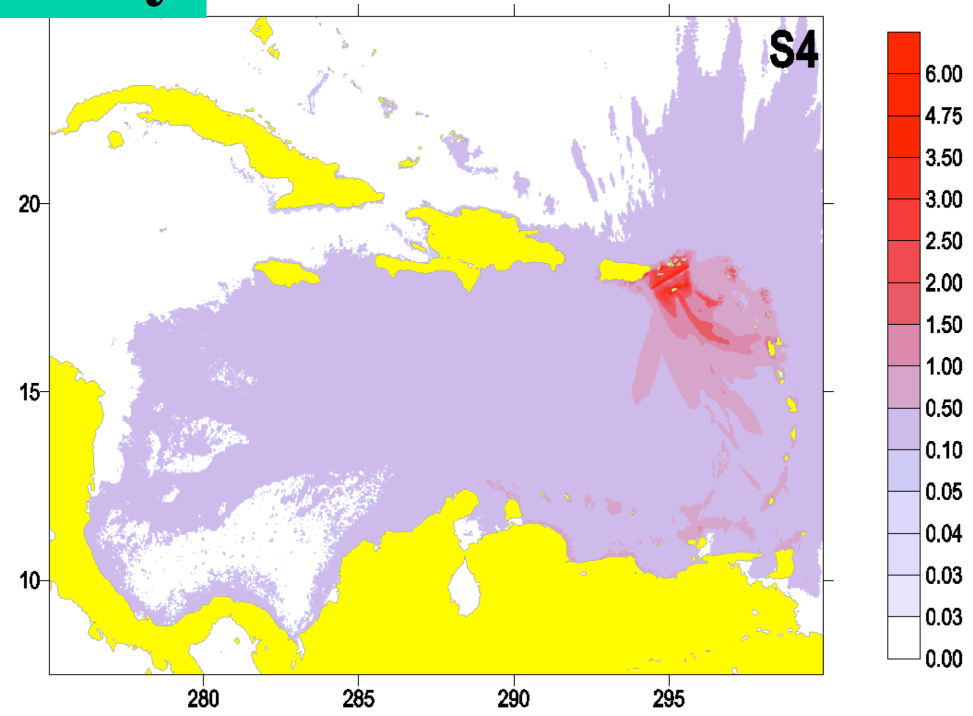
Zahibo,
Pelinovsky,
Yalciner,
et al, 2003

Directivity

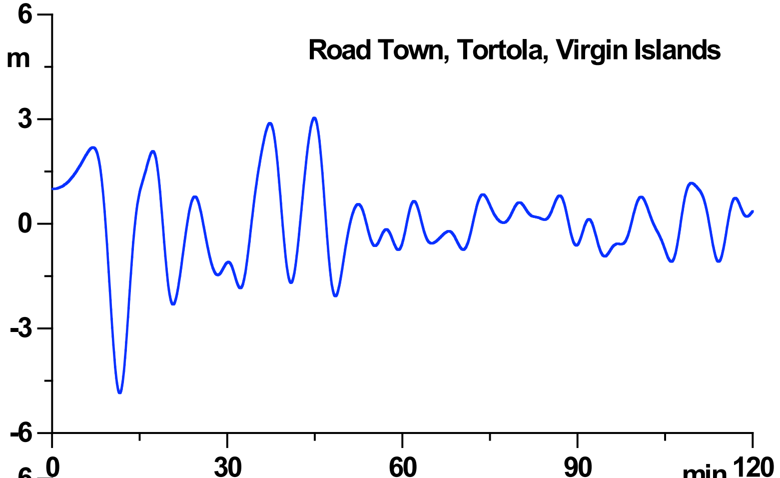


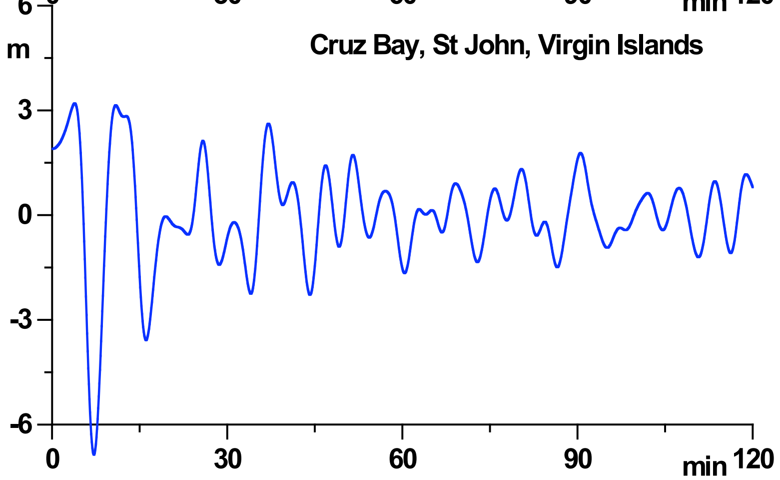


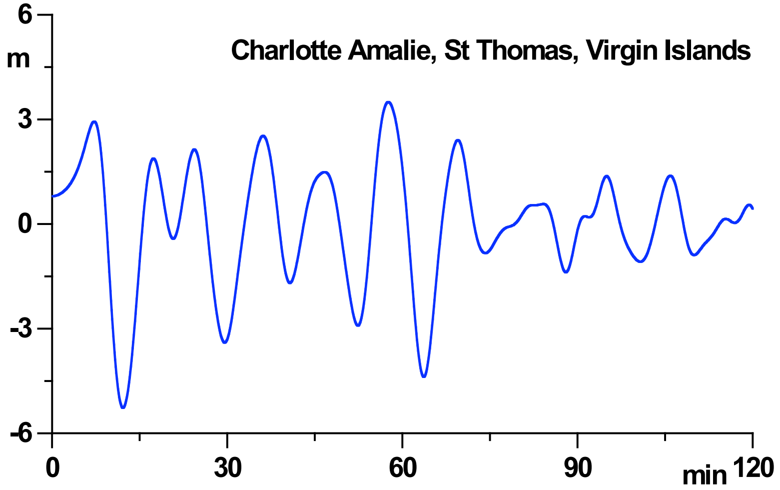


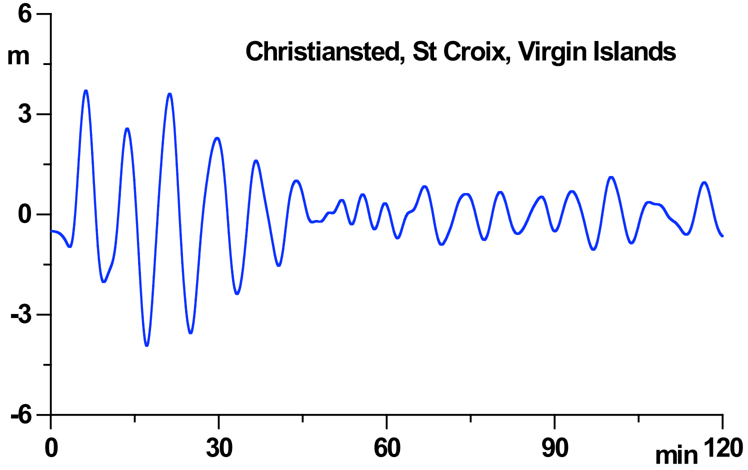


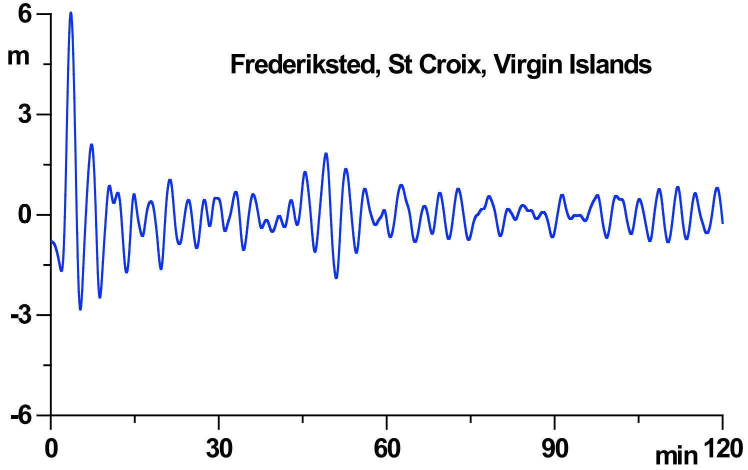
near epicenter

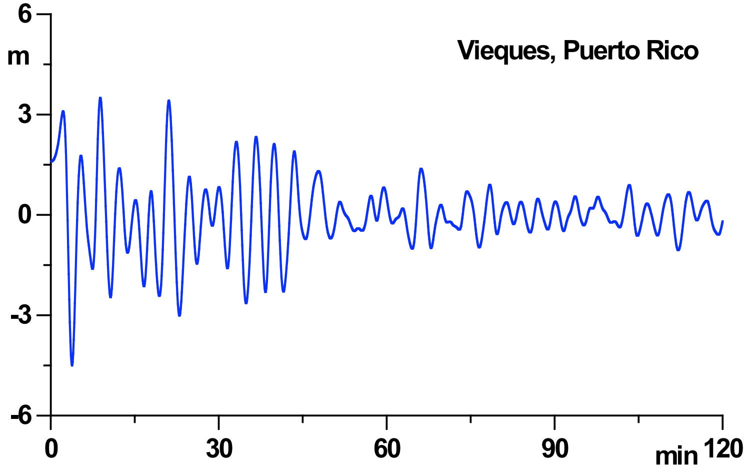




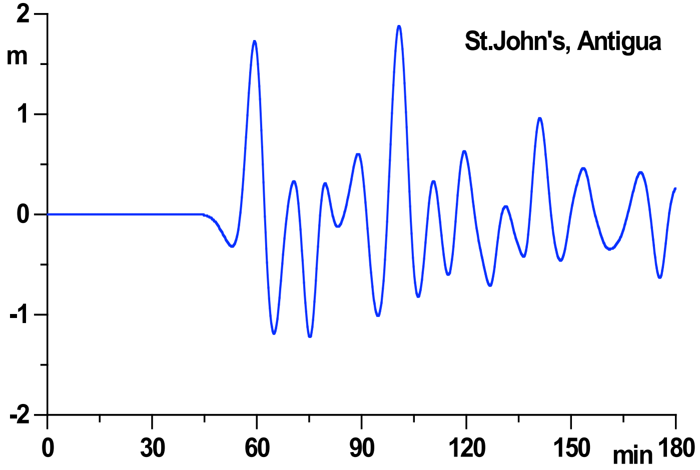


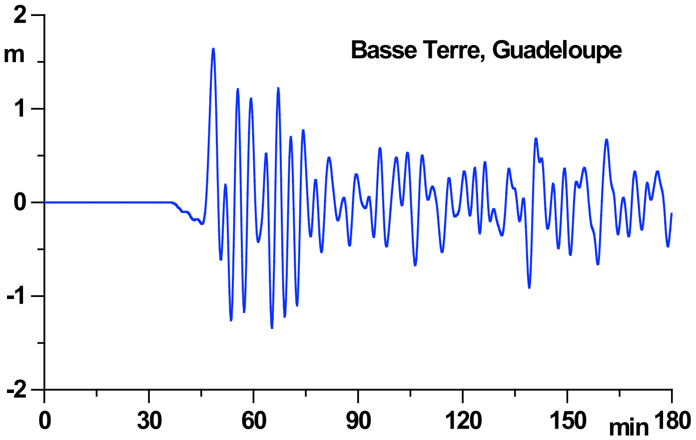


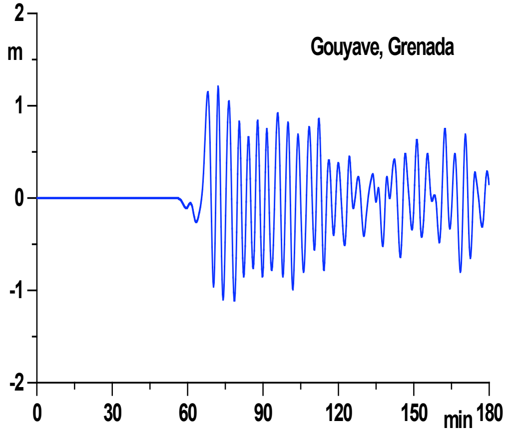


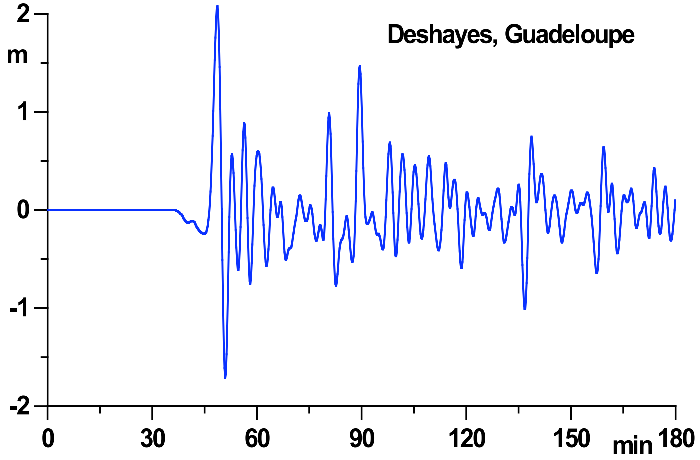


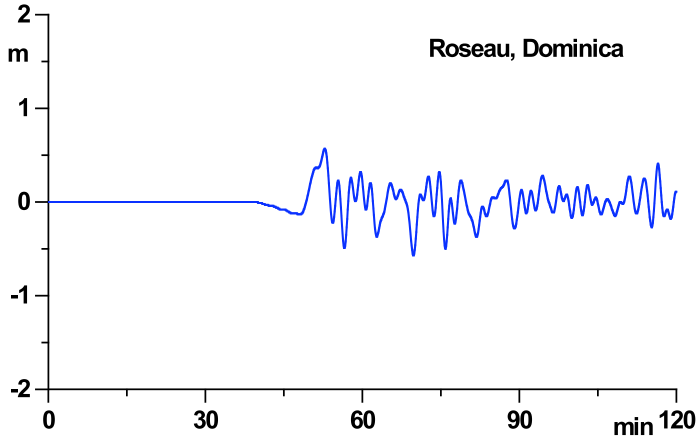
Lesser Antilles

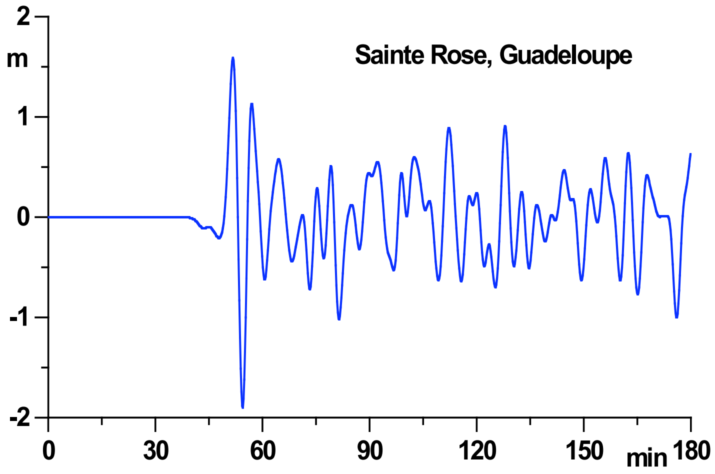


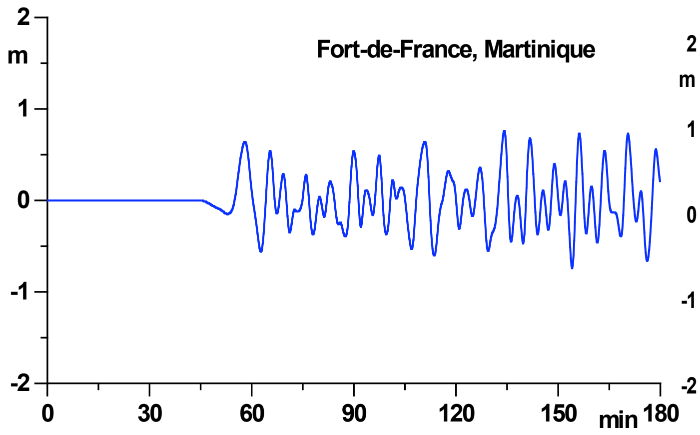


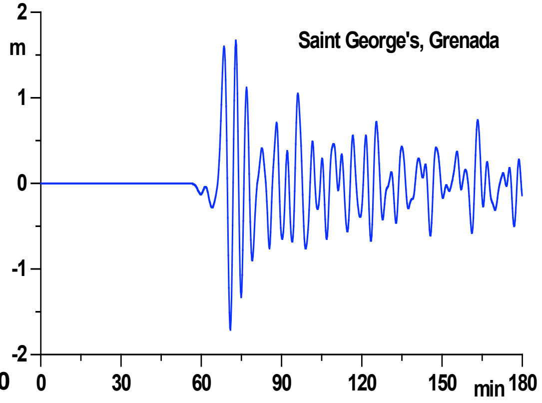


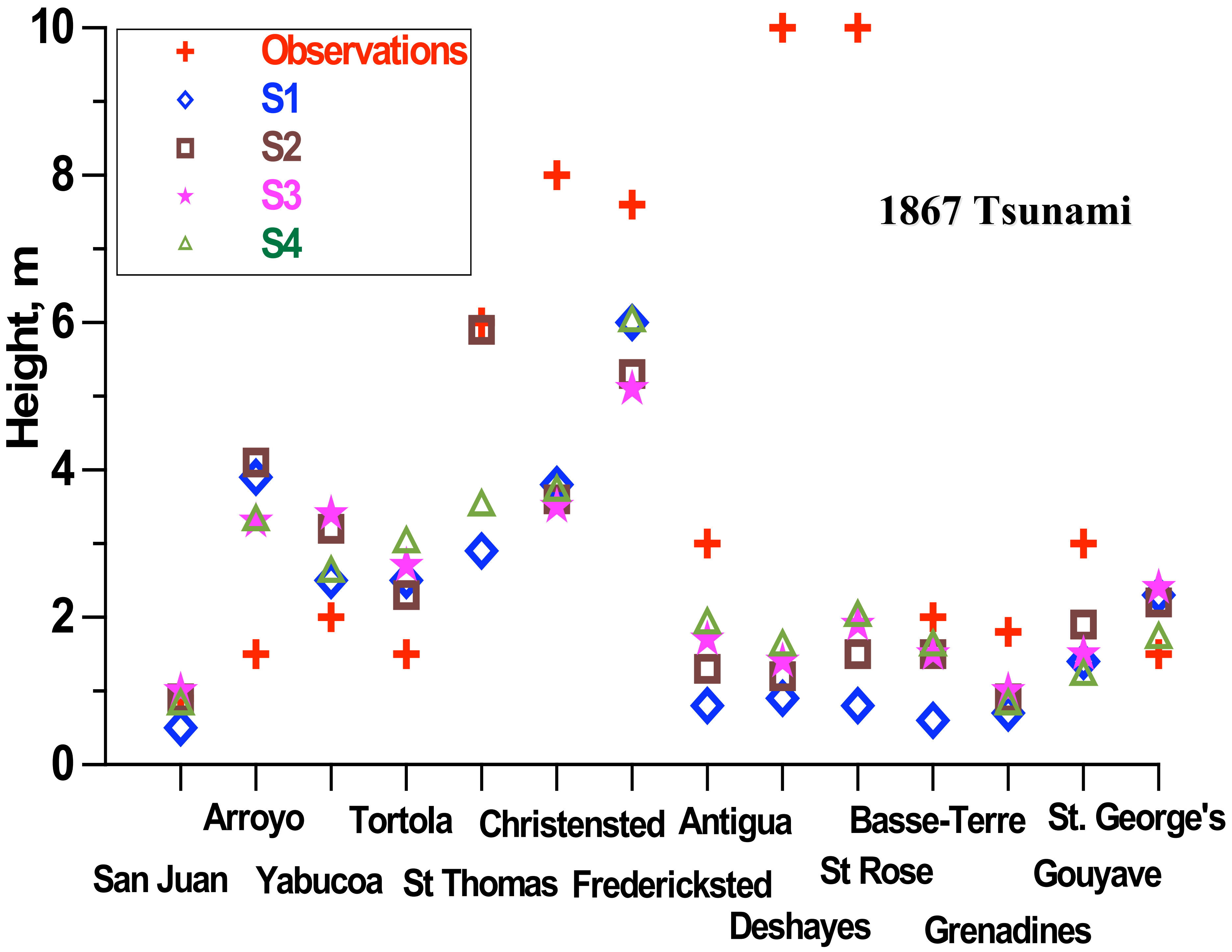




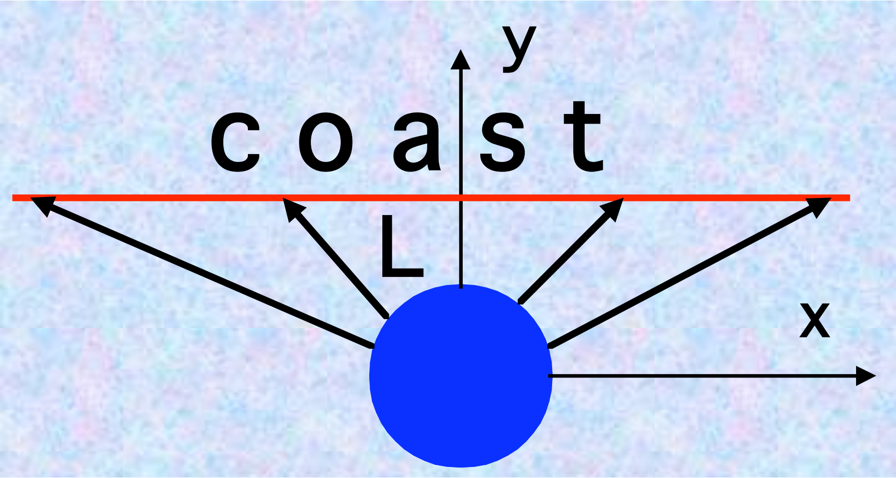


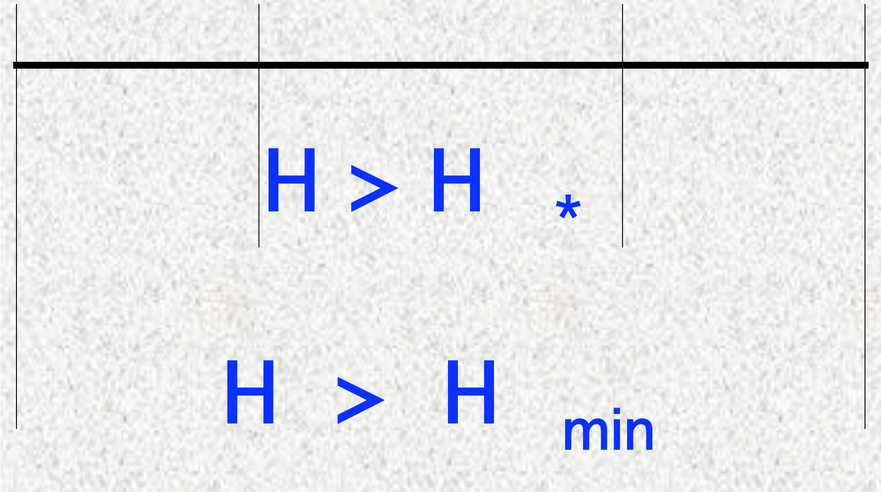





1867 Tsunami
Height, m
0
2
4
6
8
10
+ Observations
◇ S1
□ S2
★ S3
△ S4
San Juan
Arroyo
Yabucoa
Tortola
St Thomas
Christensted
Fredericksted
Antigua
Deshayes
St Rose
Basse-Terre
Grenadines
Gouyave
St. George's

Distribution Functions of Tsunamis
(statistical reliability)





Constant Depth

$$H = H_e \left(\frac{R_e}{R} \right)^{\alpha}$$

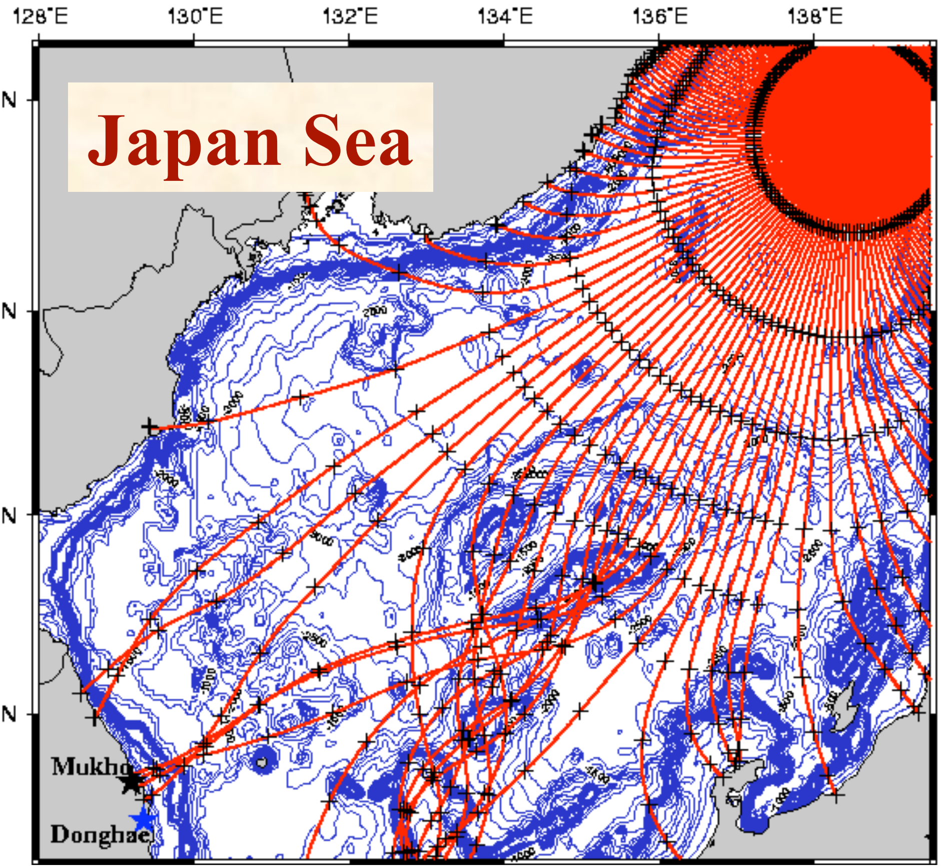
$$R = \sqrt{x^2 + L^2}$$

Probability:

$$P(H_*) = x(H>H_*)/x_{max}$$

$$P(H) = \sqrt{\frac{\left(\frac{H_{max}}{H}\right)^{2/\alpha} - 1}{\left(\frac{H_{max}}{H_{min}}\right)^{2/\alpha} - 1}}$$

Random Wave Paths



$$H = K\,H_e$$

or

$$\log H = \log K + \log H_e$$

$$K = \prod_i K_i$$ – random amplification

According to the central limit theorem logH is the gaussian process

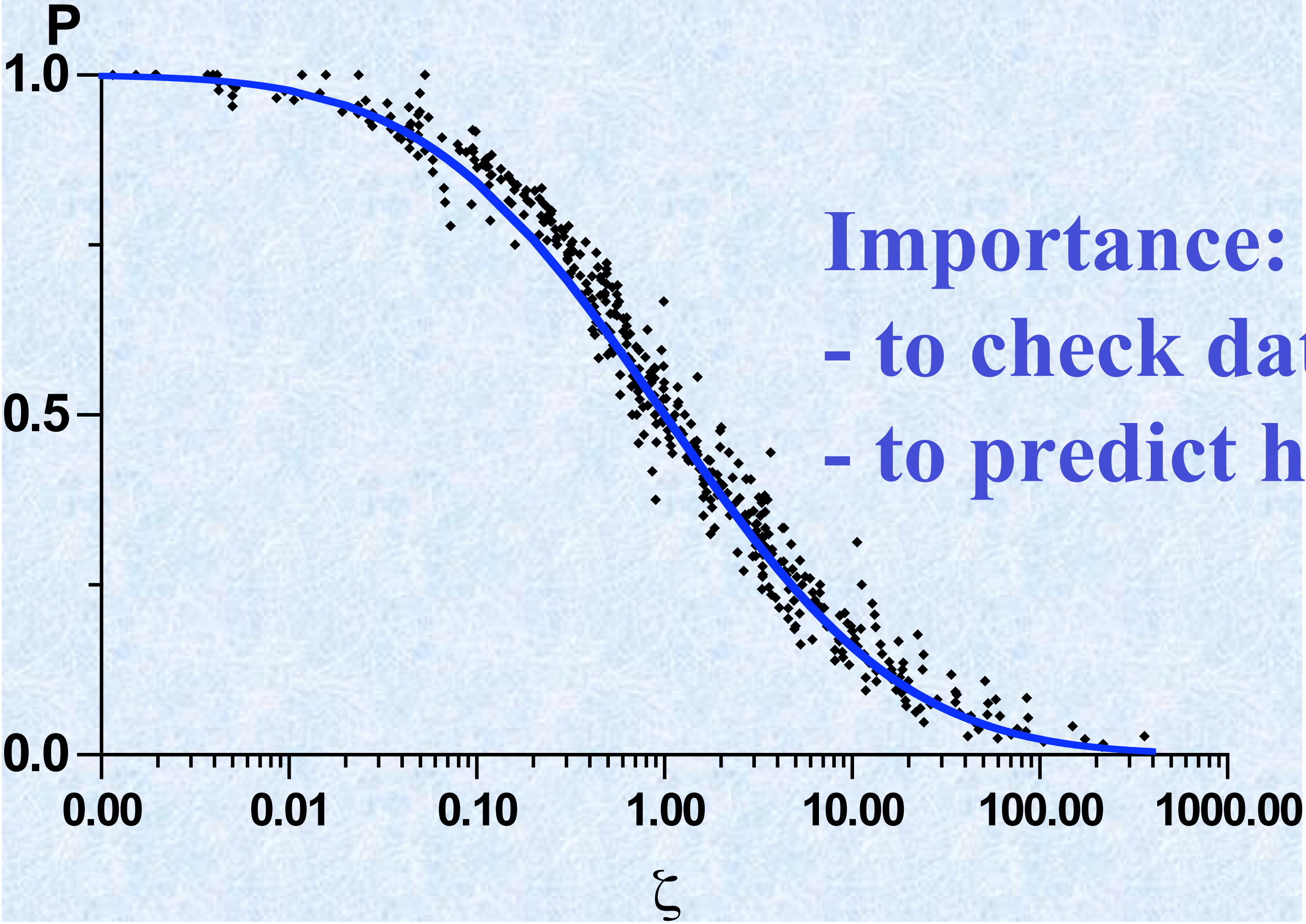
$$f(H) = \frac{1}{H\sigma\sqrt{2\pi}\ln 10}\exp\left(-\frac{(\log H - <\log H>)}{2\sigma^2}\right)$$

Distribution Functions of Tsunamis 1992-2000

$$P(\varsigma) = \frac{1}{\sqrt{2\pi}\,\ln 10}\int_{\varsigma}^{\infty}\exp\left(-\frac{1}{2}(\log\theta)^2\right)\frac{d\theta}{\theta}$$

$$\zeta = \left(\frac{H}{\bar{H}}\right)^{1/\sigma}$$

$$\bar{H} = 10^{a}$$



Importance:

- to check data and

- to predict huge height

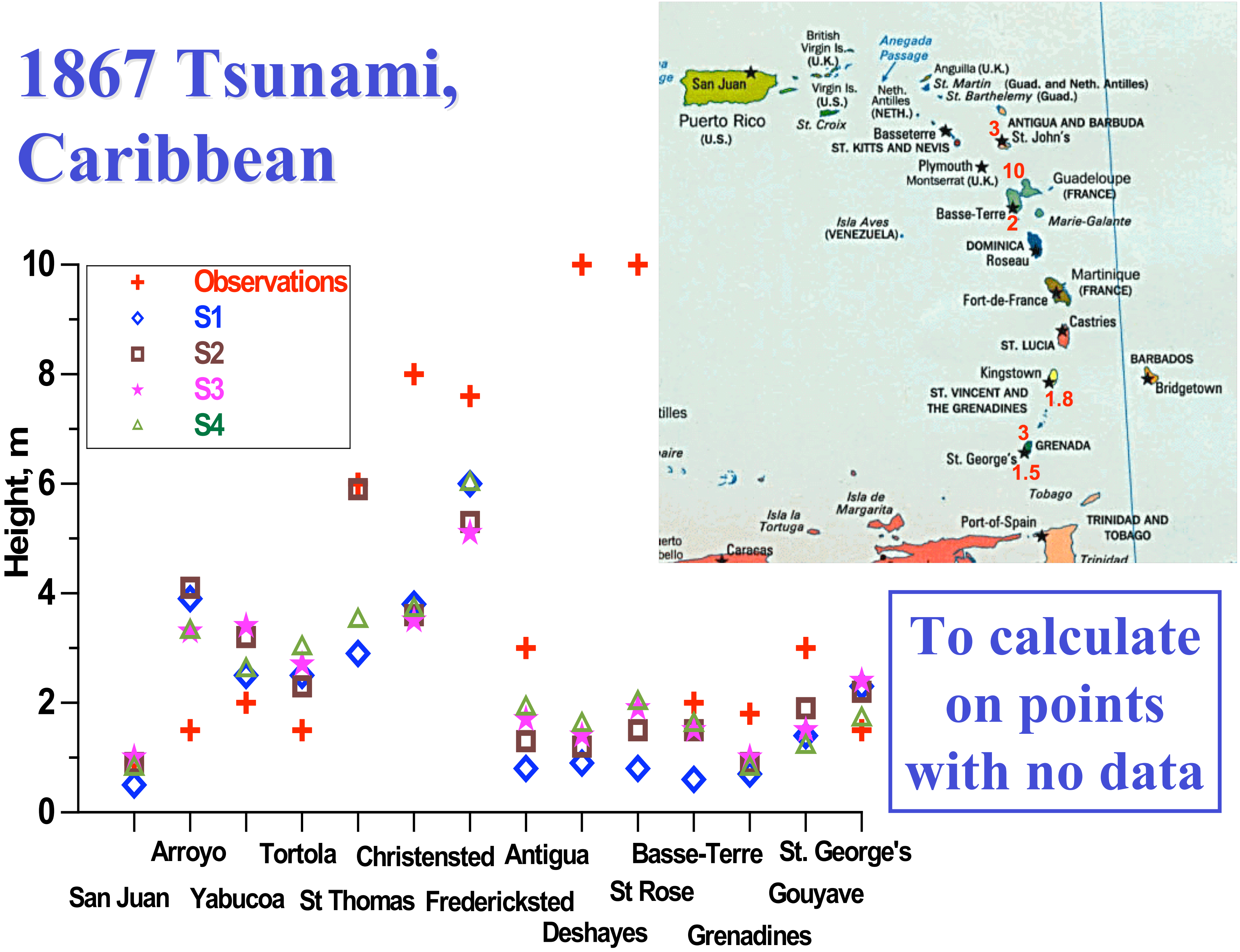
Choi, Pelinovsky, et al, 2002

What should we do?

1. To check RELIABILITY of data
2. To generate tsunami at other locations

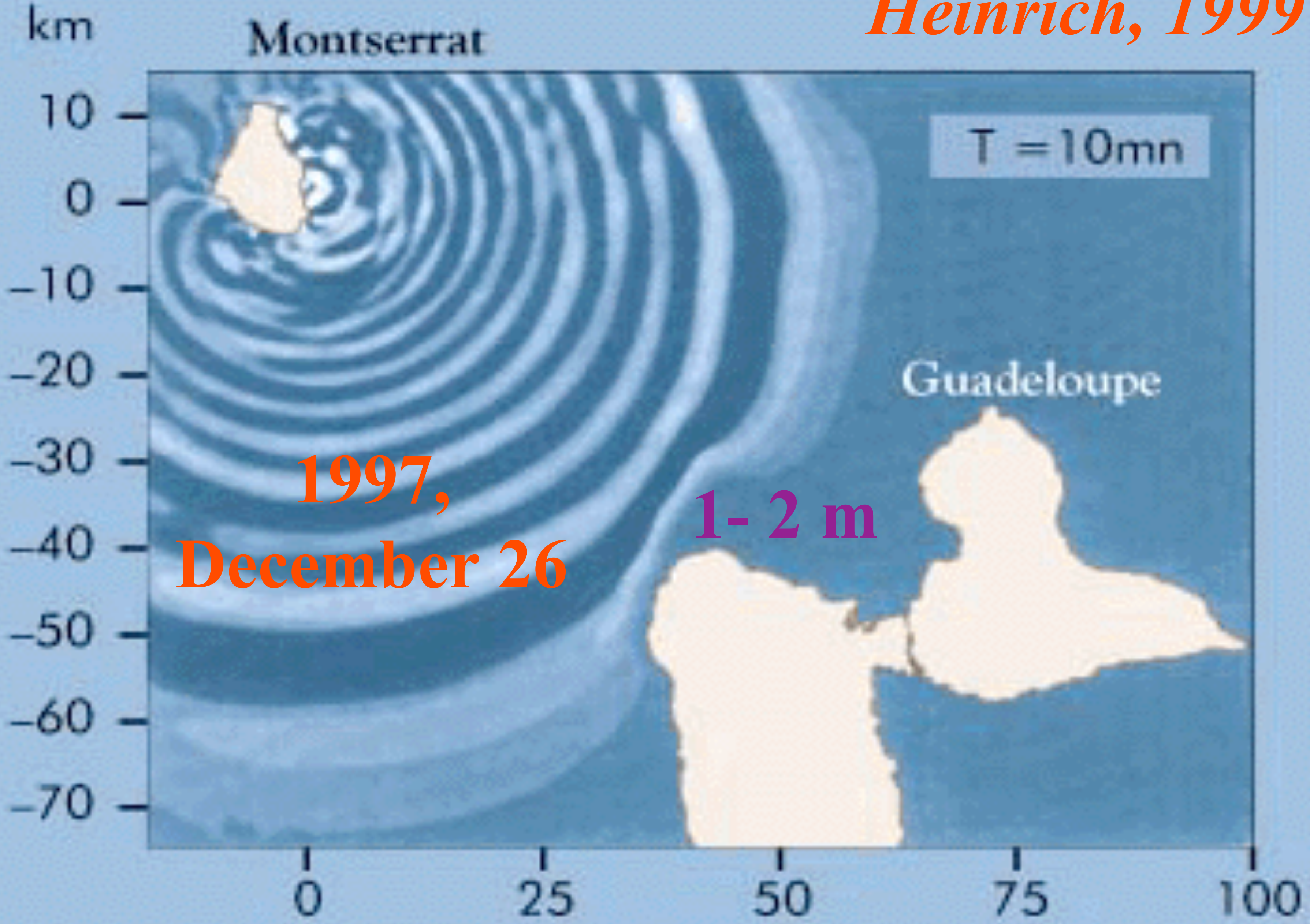
If tsunami modeling works,
why do not use it?

1867 Tsunami, Caribbean



To calculate on points with no data

Heinrich, 1999

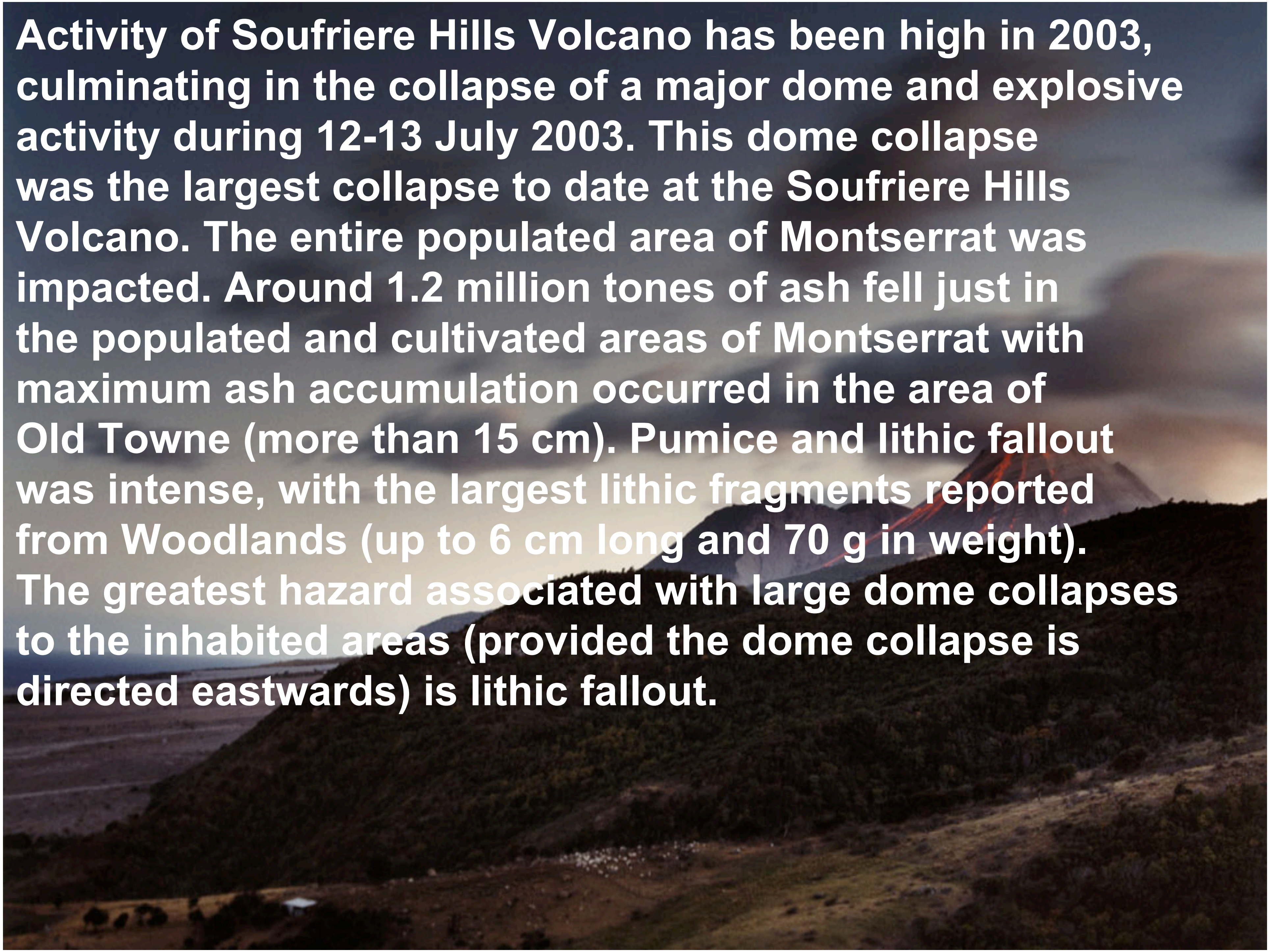


1997, December 26

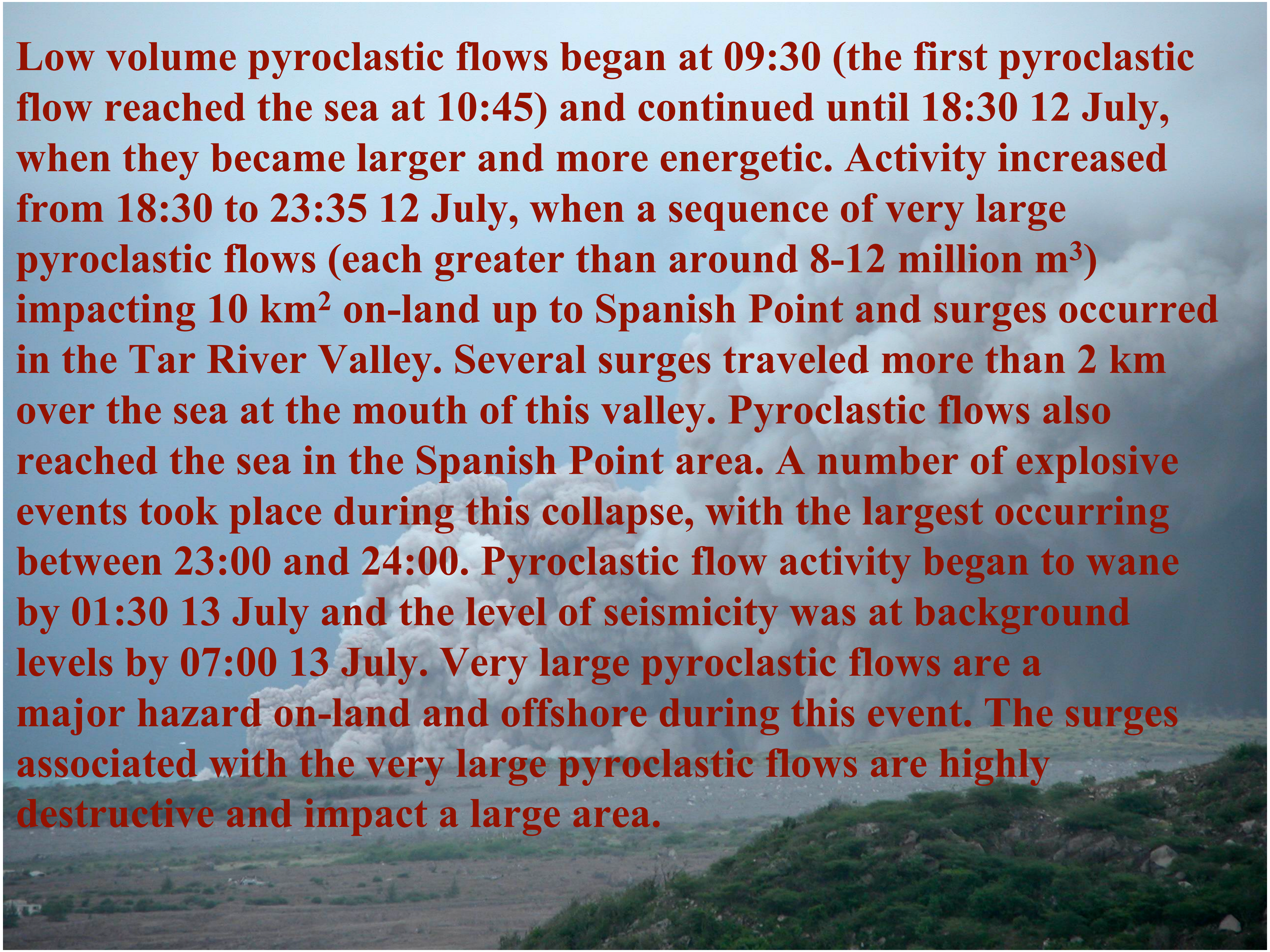
1- 2 m

No data of 1997 volcanic tsunami in Guadeloupe!

Montserrat, 2003 July 12

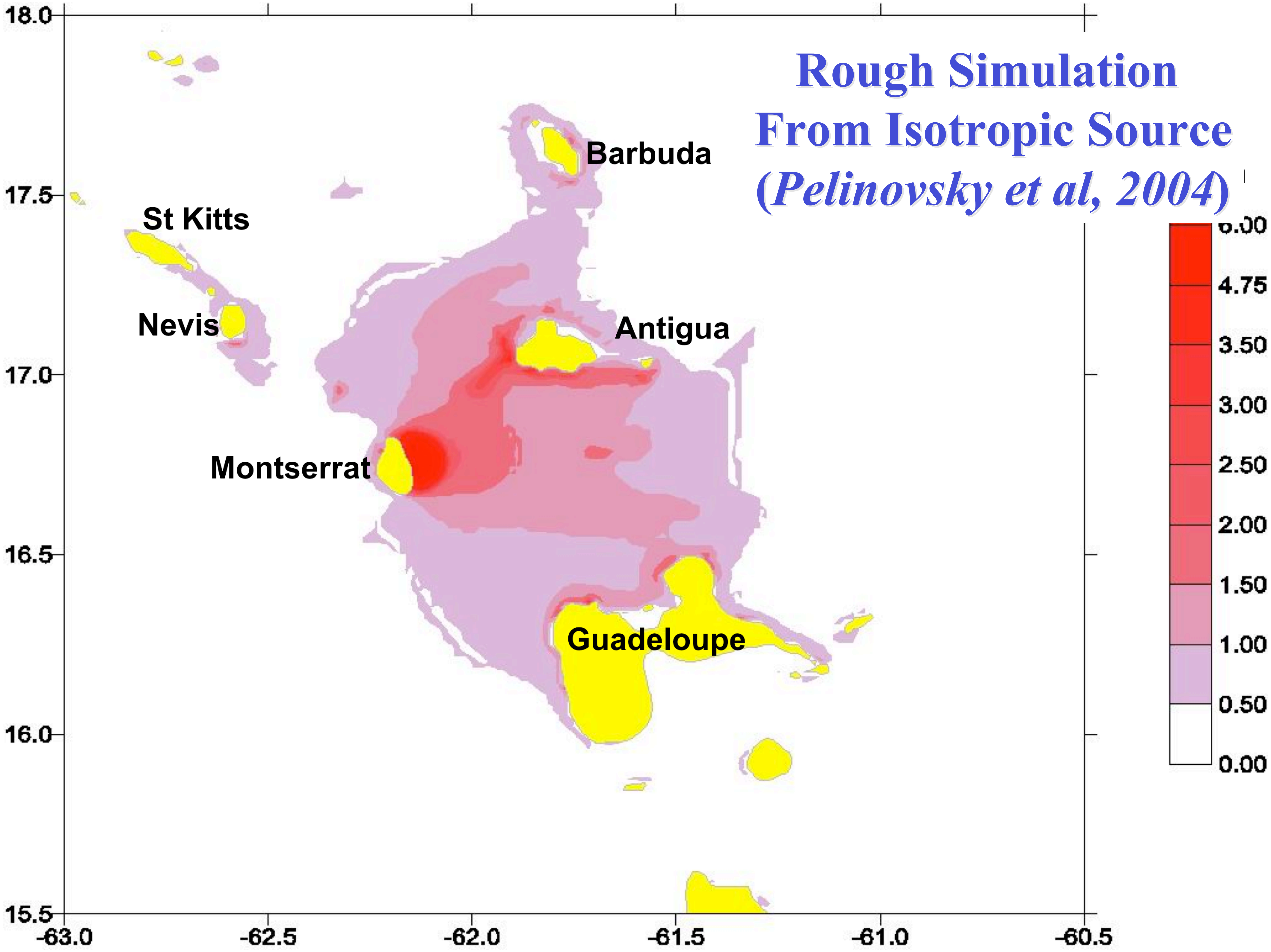


Activity of Soufriere Hills Volcano has been high in 2003, culminating in the collapse of a major dome and explosive activity during 12-13 July 2003. This dome collapse was the largest collapse to date at the Soufriere Hills Volcano. The entire populated area of Montserrat was impacted. Around 1.2 million tones of ash fell just in the populated and cultivated areas of Montserrat with maximum ash accumulation occurred in the area of Old Towne (more than 15 cm). Pumice and lithic fallout was intense, with the largest lithic fragments reported from Woodlands (up to 6 cm long and 70 g in weight). The greatest hazard associated with large dome collapses to the inhabited areas (provided the dome collapse is directed eastwards) is lithic fallout.

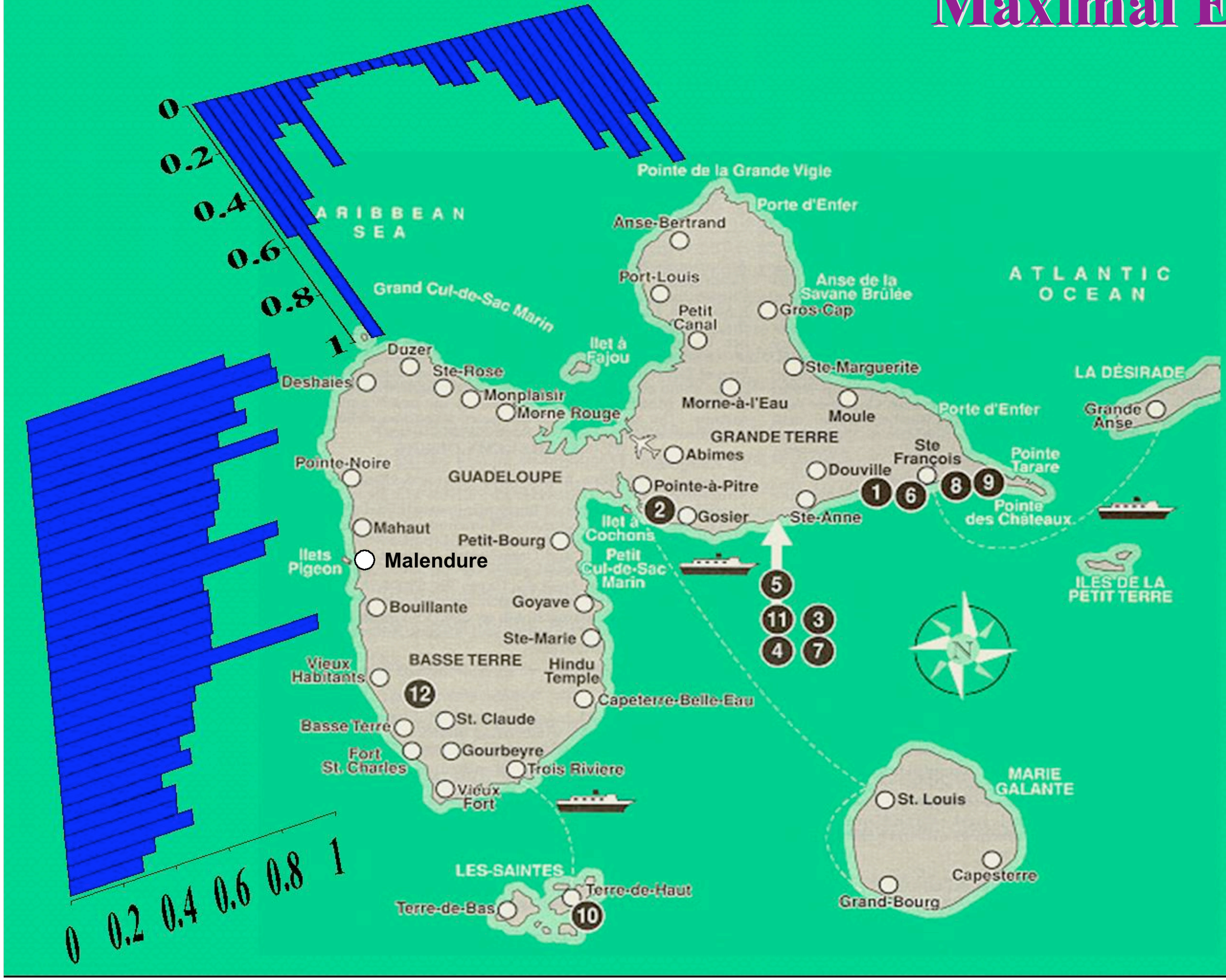


Low volume pyroclastic flows began at 09:30 (the first pyroclastic flow reached the sea at 10:45) and continued until 18:30 12 July, when they became larger and more energetic. Activity increased from 18:30 to 23:35 12 July, when a sequence of very large pyroclastic flows (each greater than around 8-12 million m^3) impacting 10 km^2 on-land up to Spanish Point and surges occurred in the Tar River Valley. Several surges traveled more than 2 km over the sea at the mouth of this valley. Pyroclastic flows also reached the sea in the Spanish Point area. A number of explosive events took place during this collapse, with the largest occurring between 23:00 and 24:00. Pyroclastic flow activity began to wane by 01:30 13 July and the level of seismicity was at background levels by 07:00 13 July. Very large pyroclastic flows are a major hazard on-land and offshore during this event. The surges associated with the very large pyroclastic flows are highly destructive and impact a large area.

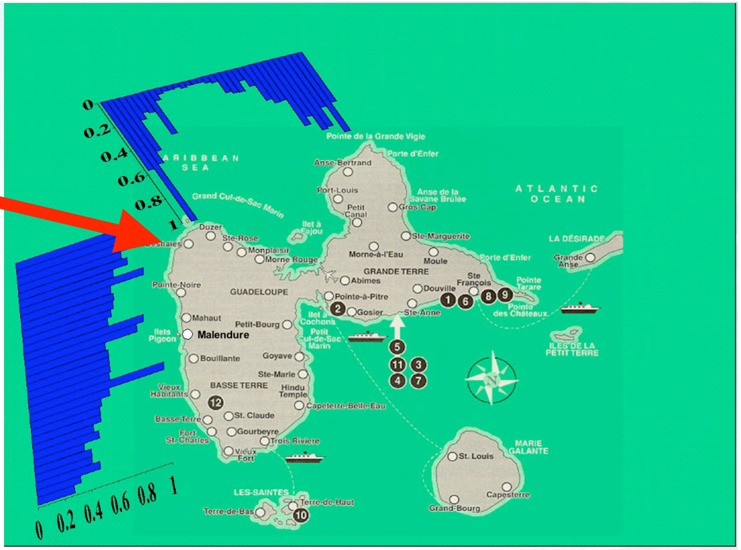
Rough Simulation From Isotropic Source (*Pelinovsky et al, 2004*)



Maximal Effect



Deshaies, Port



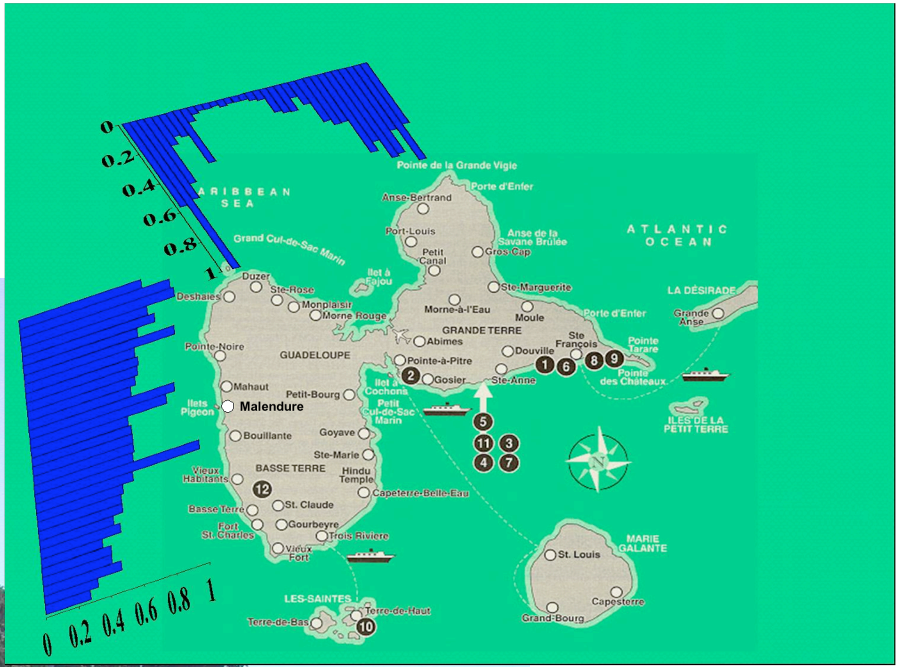
Boats were scattered

Deshaies

Near River Mouth, Overtopping

60 m upstream, where the boat was found near the bridge

Pontoon of Malendure overflowed (46 cm above sea level)



So, we may consider
the 1997 tsunami on Guadeloupe
as almost true tsunami
with height about 1m
and use it to estimate
tsunami frequency
for Guadeloupe,
but it was not reported!

What should we do?

1. To check RELIABILITY of data
2. To generate tsunami at other locations
3. Forecasting using real and computed events

Exceedance (Cumulative) Frequency

From **Statistics of Extremes (Gumbel)**

$n \sim exp(-R)$ or $n \sim R^{-m}$

Two-parameters from the dimension analysis

$$\boxed{n = n_0\, f(R/R_0)}$$

n_0 is $n(R = 0)$ is a frequency of tsunamigeneric events (earthquakes, etc)

It is common characteristics for several islands…

Two-parametric form of Cumulative Frequency

$$\boxed{n = n_0 \, f(R/R_0)}$$

R_0 is mean value of runup height for given point (function of seabed relief)

$$\boxed{R_0 = KH_0}$$

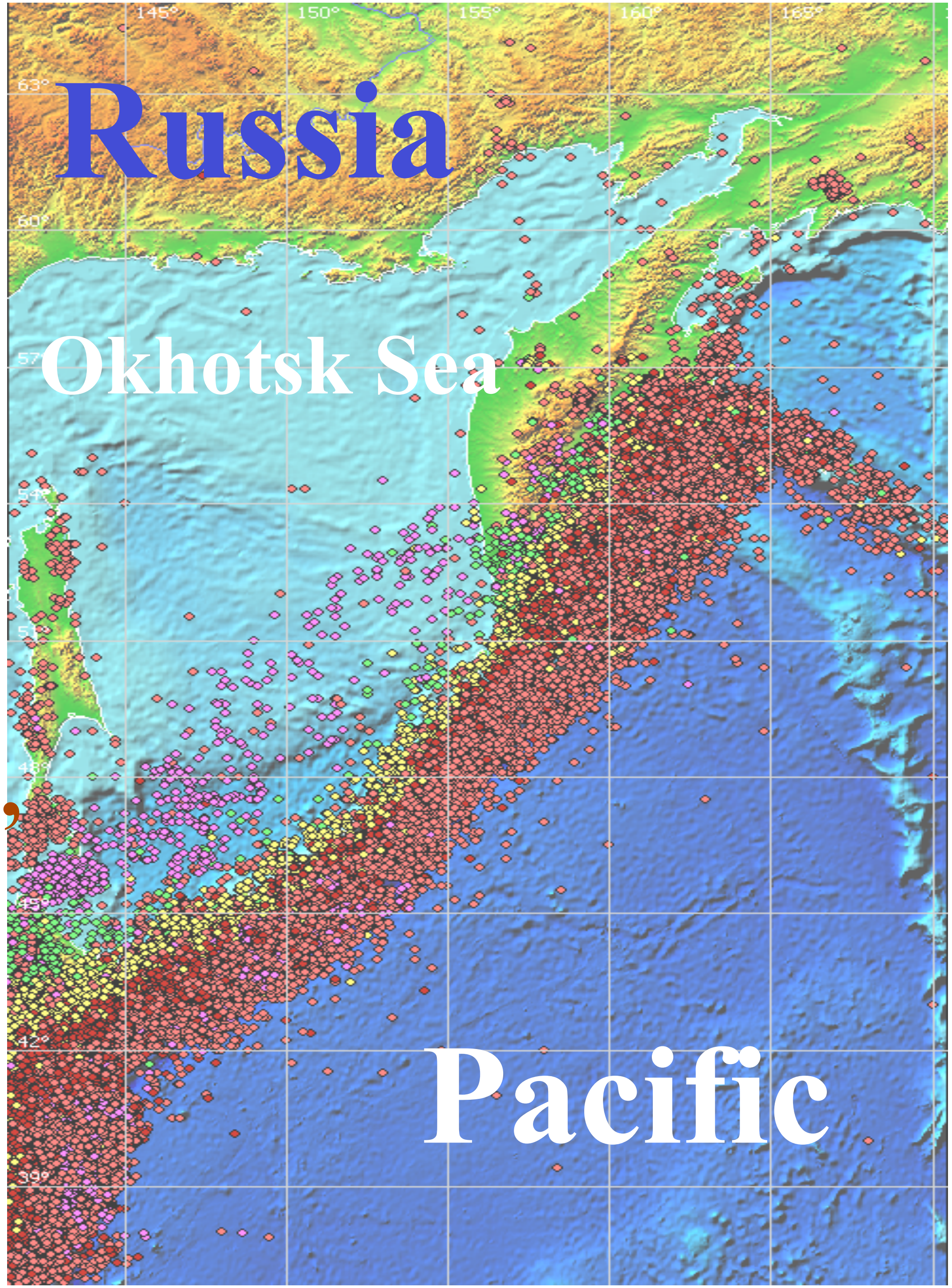
K is coefficient transformation from source

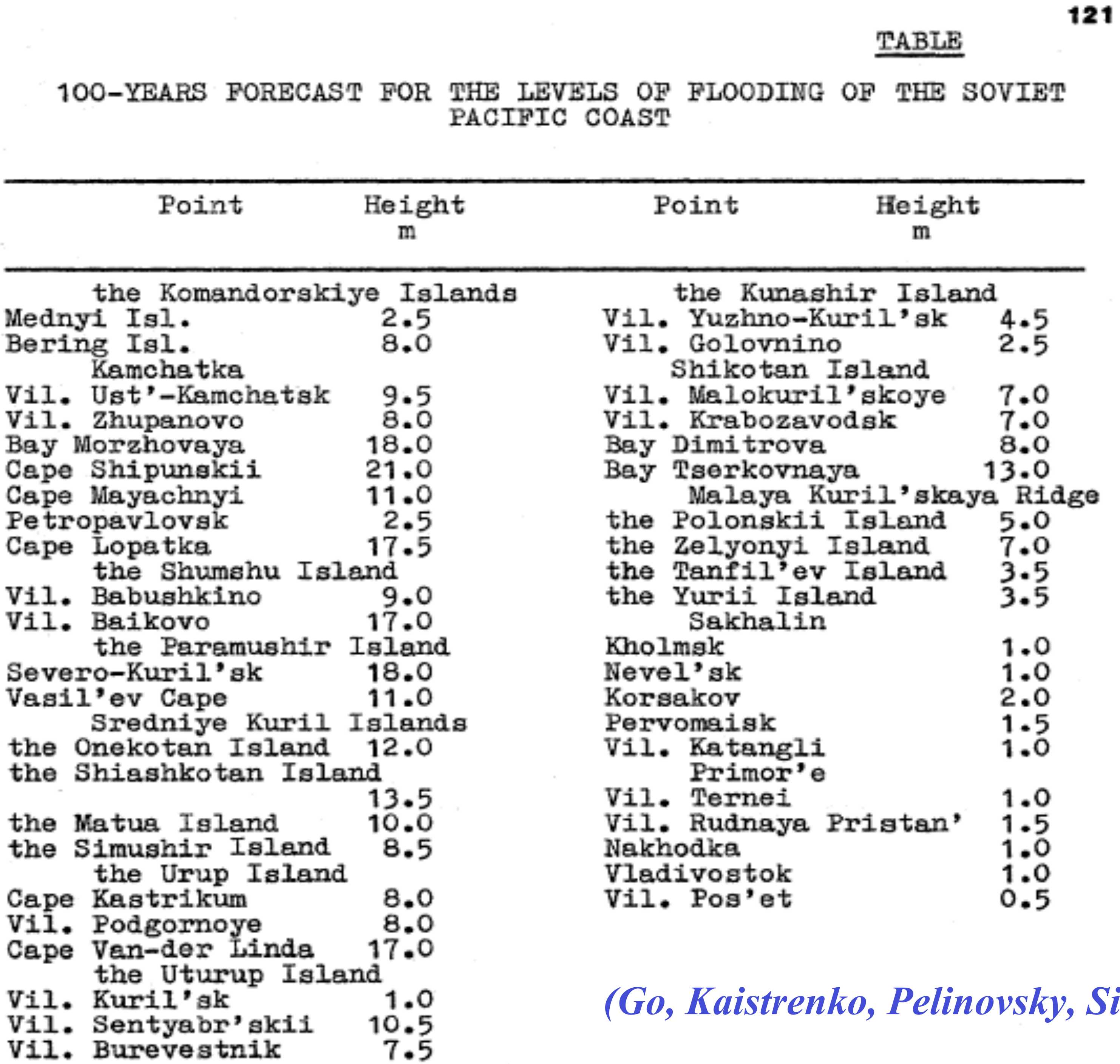
H_0 is water displacement in the source

$$\boxed{n = n_0\, f(R/KH_0)}$$

n_0 and H_0 – slightly varied

K is varied strongly, and numerically calculated





TABLE

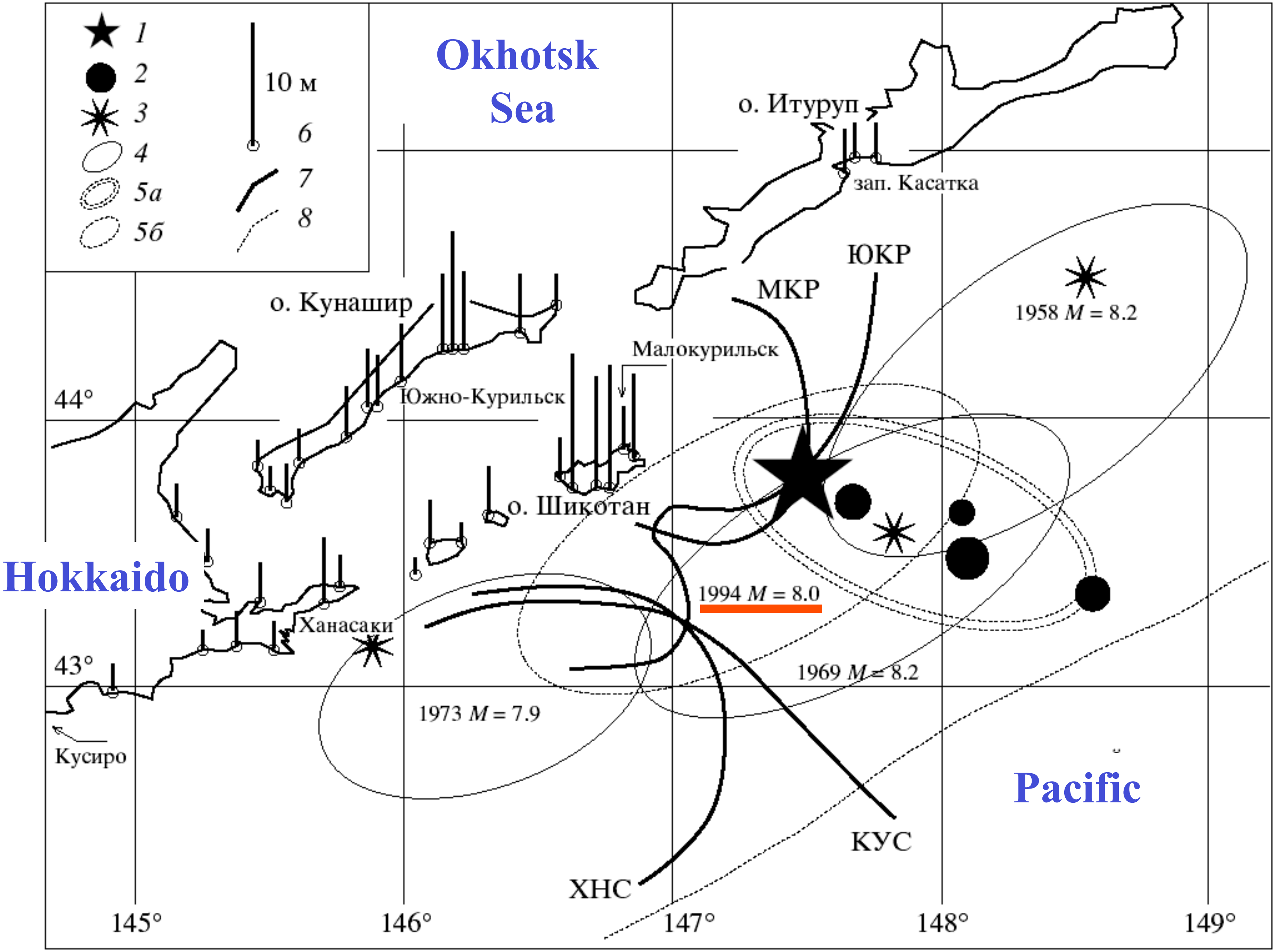
100-YEARS FORECAST FOR THE LEVELS OF FLOODING OF THE SOVIET PACIFIC COAST

Point	Height m	Point	Height m
the Komandorskiye Islands		the Kunashir Island	
Mednyi Isl.	2.5	Vil. Yuzhno-Kuril'sk	4.5
Bering Isl.	8.0	Vil. Golovnino	2.5
Kamchatka		Shikotan Island	
Vil. Ust'-Kamchatsk	9.5	Vil. Malokuril'skoye	7.0
Vil. Zhupanovo	8.0	Vil. Krabozavodsk	7.0
Bay Morzhovaya	18.0	Bay Dimitrova	8.0
Cape Shipunskii	21.0	Bay Tserkovnaya	13.0
Cape Mayachnyi	11.0	Malaya Kuril'skaya Ridge	
Petropavlovsk	2.5	the Polonskii Island	5.0
Cape Lopatka	17.5	the Zelyonyi Island	7.0
the Shumshu Island		the Tanfil'ev Island	3.5
Vil. Babushkino	9.0	the Yurii Island	3.5
Vil. Baikovo	17.0	Sakhalin	
the Paramushir Island		Kholmsk	1.0
Severo-Kuril'sk	18.0	Nevel'sk	1.0
Vasil'ev Cape	11.0	Korsakov	2.0
Sredniye Kuril Islands		Pervomaisk	1.5
the Onekotan Island	12.0	Vil. Katangli	1.0
the Shiashkotan Island	13.5	Primor'e	
the Matua Island	10.0	Vil. Ternei	1.0
the Simushir Island	8.5	Vil. Rudnaya Pristan'	1.5
the Urup Island		Nakhodka	1.0
Cape Kastrikum	8.0	Vladivostok	1.0
Vil. Podgornoye	8.0	Vil. Pos'et	0.5
Cape Van-der Linda	17.0		
the Uturup Island			
Vil. Kuril'sk	1.0		
Vil. Sentyabr'skii	10.5		
Vil. Burevestnik	7.5		

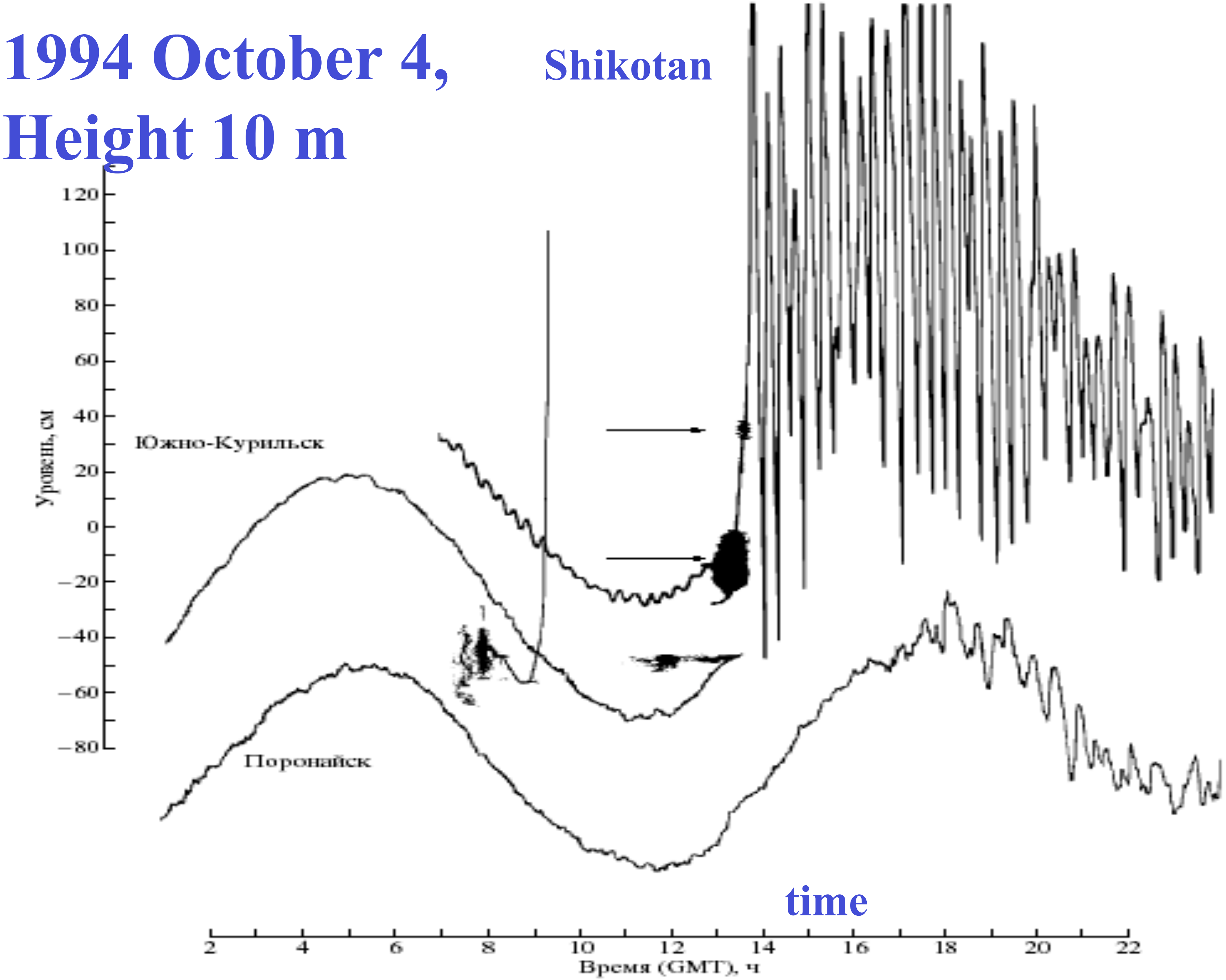
(Go, Kaistrenko, Pelinovsky, Simonov, 1988)

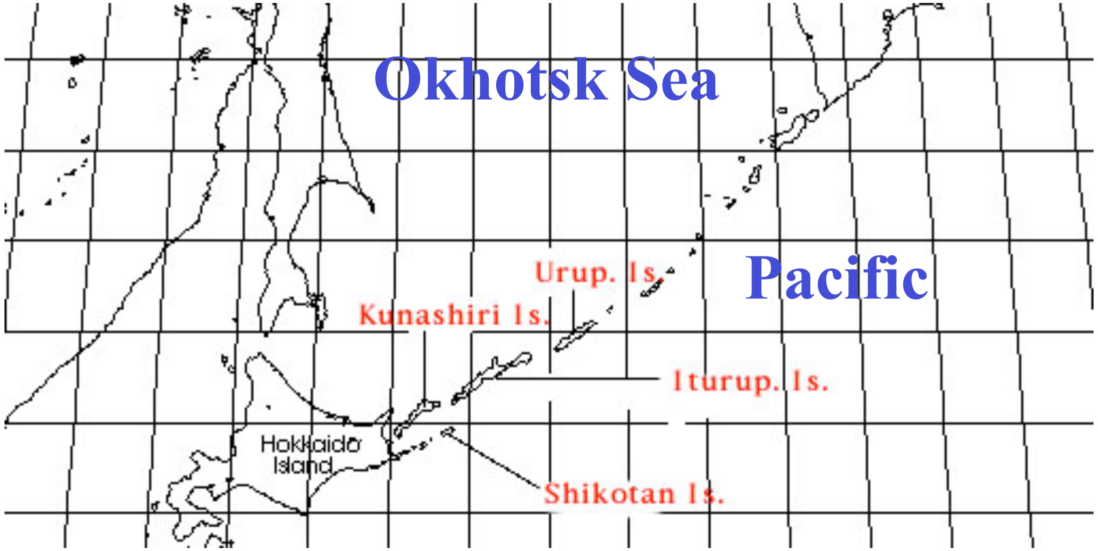
Tsunami Forecasting for 100 years

$$n = n_0 f(R/KH_0)$$


1
2
3
4
5а
5б
10 м
6
7
8
Okhotsk Sea
о. Итуруп
зап. Касатка
ЮКР
МКР
1958 M = 8.2
о. Кунашир
Малокурильск
Южно-Курильск
44°
о. Шикотан
Hokkaido
1994 M = 8.0
Ханасаки
43°
1969 M = 8.2
1973 M = 7.9
Кусиро
Pacific
КУС
ХНС
145°
146°
147°
148°
149°

1994 October 4, Height 10 m





1994 October 4, Height 10 m

Kurile Islands	Height, m	
	prediction	measured
Буревестник (о. Итуруп)	7,5	2,5
Южно-Курильск (о. Кунашир)	4,5	3,5
Головнино (о. Кунашир)	2,5	1,5
Малокурильское (о. Шикотан)	7,0	3,0
б. Димитрова (о. Шикотан)	8,0 ↔	9,5
б. Церковная (о. Шикотан)	13,0	7,9
о. Юрий	3,0 ↔	3,5
о. Зеленый	7,0	1,5
о. Полонского	5,0	4,0

1994 tsunami did not exceed predicted for 100 years

Tsunami Risk Map – effective for 80%

This approach is

effective,

but

NOT universal method,

if NO enough data…

Choi, Pelinovsky, 1999-2005

Earthquakes in Korea with M > 7.0

NO TSUNAMI

LOCAL TSUNAMIS

June 26, 1681 at Yijo Sillok, tsunami affected Yangyang ("sea water rush up like boiled water") and Gangweon-do ("sea water regressed and sea bottom appeared in the length of over 100 steps at one place, and 50 to 60 steps at another places")

July 25, 1643, tsunami recorded 7 km east from Ulsan, "water surface violently moved like a boiled water, and it swells had come from the open sea, sea bottom can be appeared"

8 tsunamis arrived from the Yellow sea during 1400 – 1700

1. Haeju (23/08 1407),
2. Inchon (6/08 1434),
3. Chungcheong-Do (24/09 1519),
4. Ansan (21/10 1556),
5. Jeolla-Do (9/12 1649),
6. Phyeong’an-Do (31/07 1668),
7. Chungcheong-Do (12/09 1700),
8. Cholsan, and Phyeong’an Buk-Do(25/07, 1668).

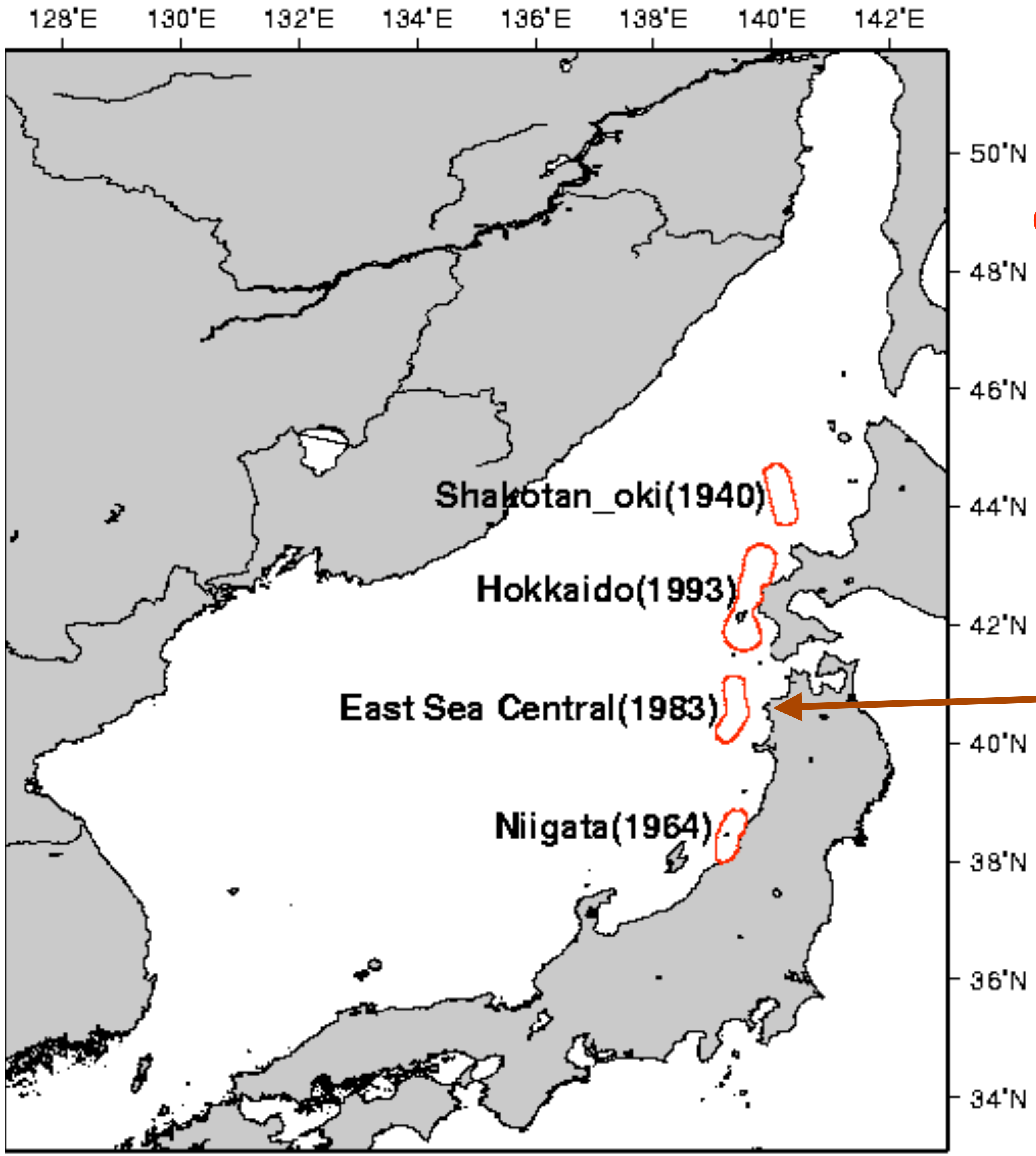
Korean Peninsula

802191 (R00141) 7-93

11 tsunamis from Japan

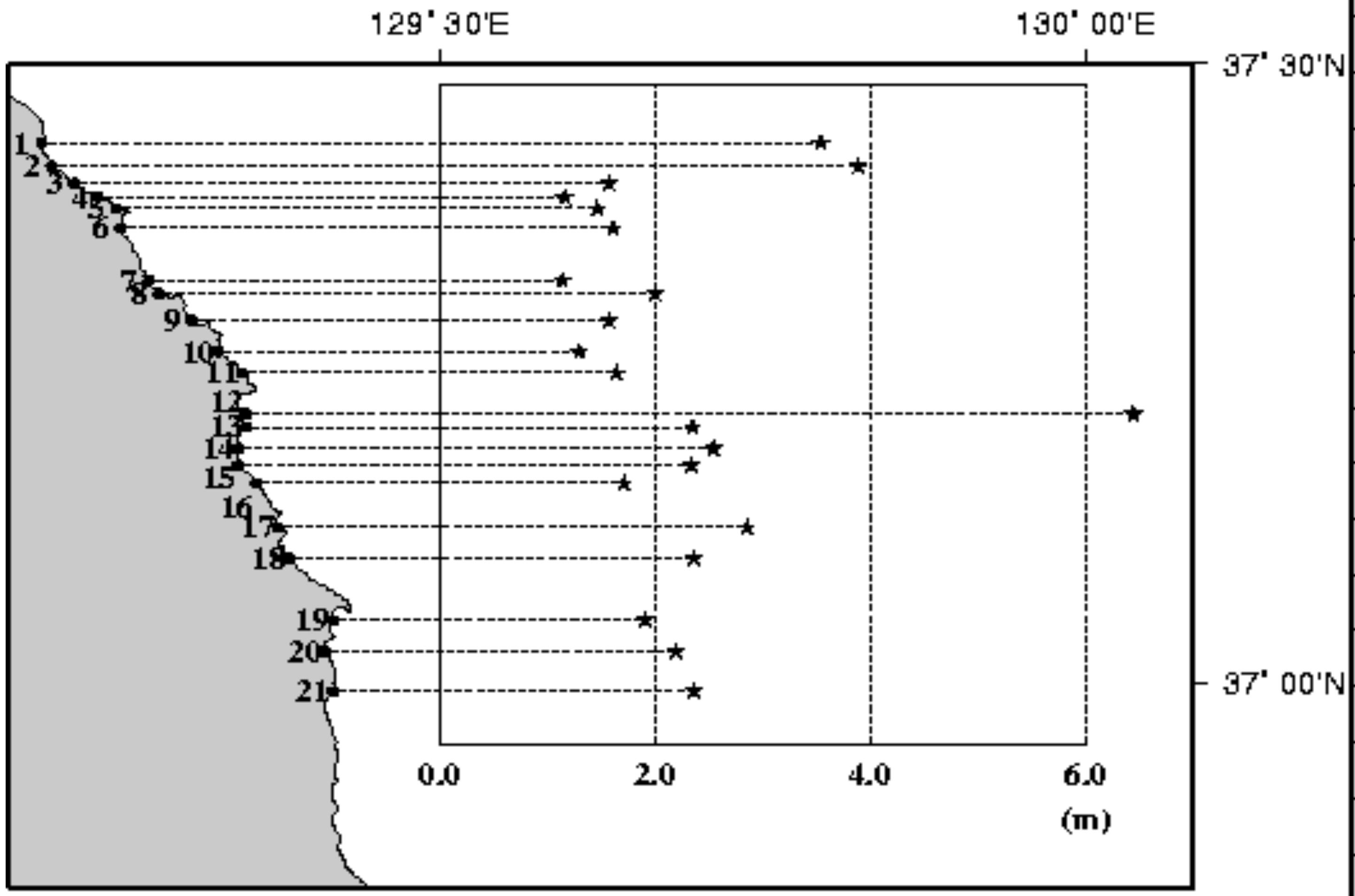
1. Gangwon-Do (1/12 1580)
2. Gangwon-Do (5/12 1681)
3. Gangwon-Do (27/05 1681)
4. Gyeongsang-Do (31/07 1636)
5. Gyeongsang-Do (25/07 1643)
6. M =6.9 August 1741
7. 2/06 1940 Mukho (H=1.2 m) and Ulleung Island (2 m)
8. 16/06 1964 Pusan (14 cm)
9. 26/05 1983 Imwon (6.5 m)
10. 21/06/1983
11. 12/07 1993 Bugu (2.5 m)

Tsunamis on Korean coast in 20th century



+ aftershock

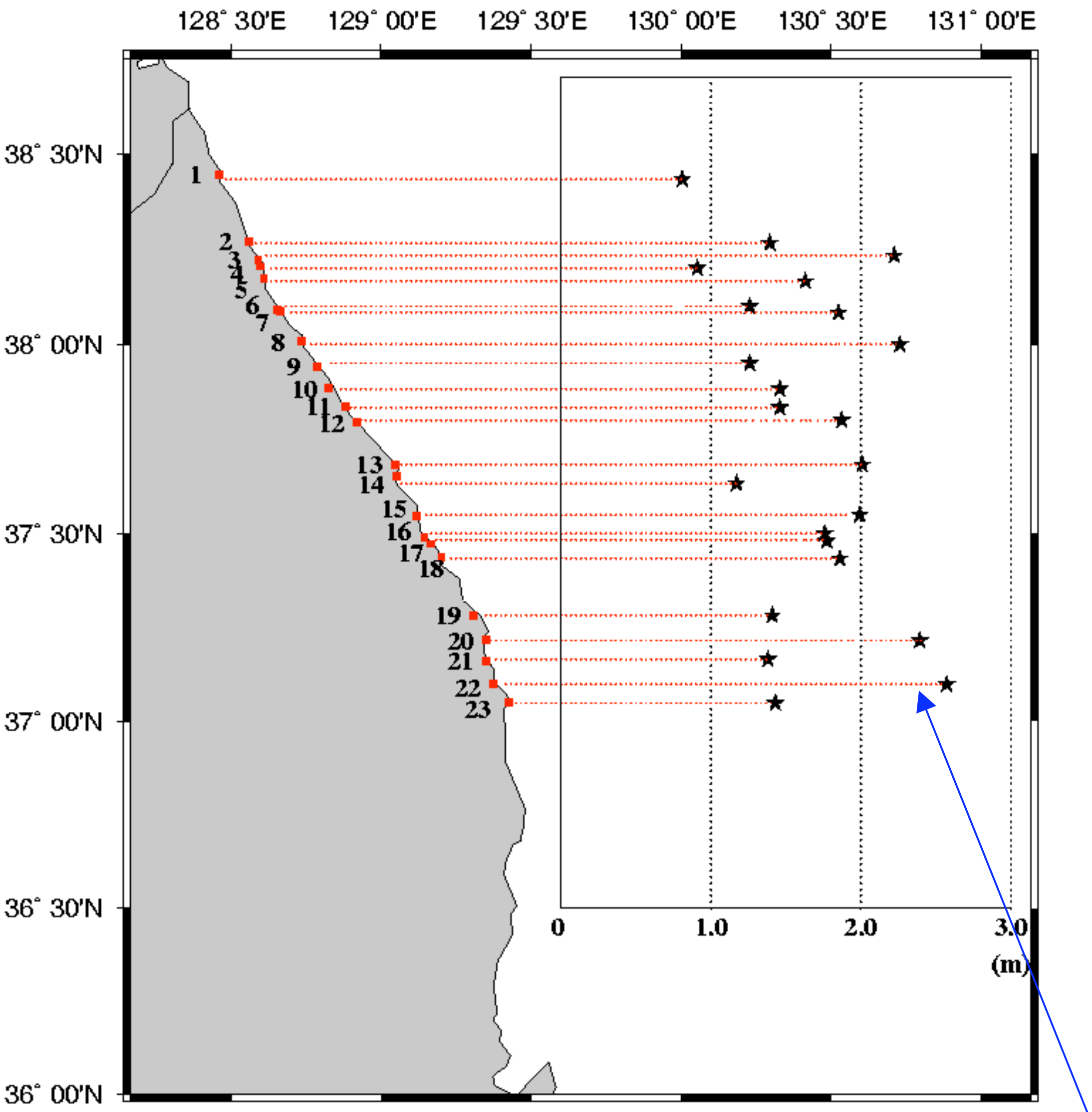
May 26, 1983



Tsunami Heights

Name of Points	Height (meter)
1. Samchuk Port	3.54
2. Geunduk	3.89
3. Namapo	1.58
4. GungchunBeach	1.16
5. Gungchun	1.47
6. Chogok	1.61
7. Yonghwa Beach	1.14
8. Yonhwa Port	2.00
9. Jangho Port	1.57
10. Galnam Port	1.30
11. Shinnam Port	1.65
12. Imwon Port	6.44
13. Biwha Port	2.35
14. Nogok Port	2.54
15. Jakjin Port	2.34
16. Hosan Port	1.72
17. Nagok Beach	2.85
18. Bugu Port	2.37
19. Chukbyun Port	1.91
20. Onyang Port	2.20
21. Eubnam Port	2.36

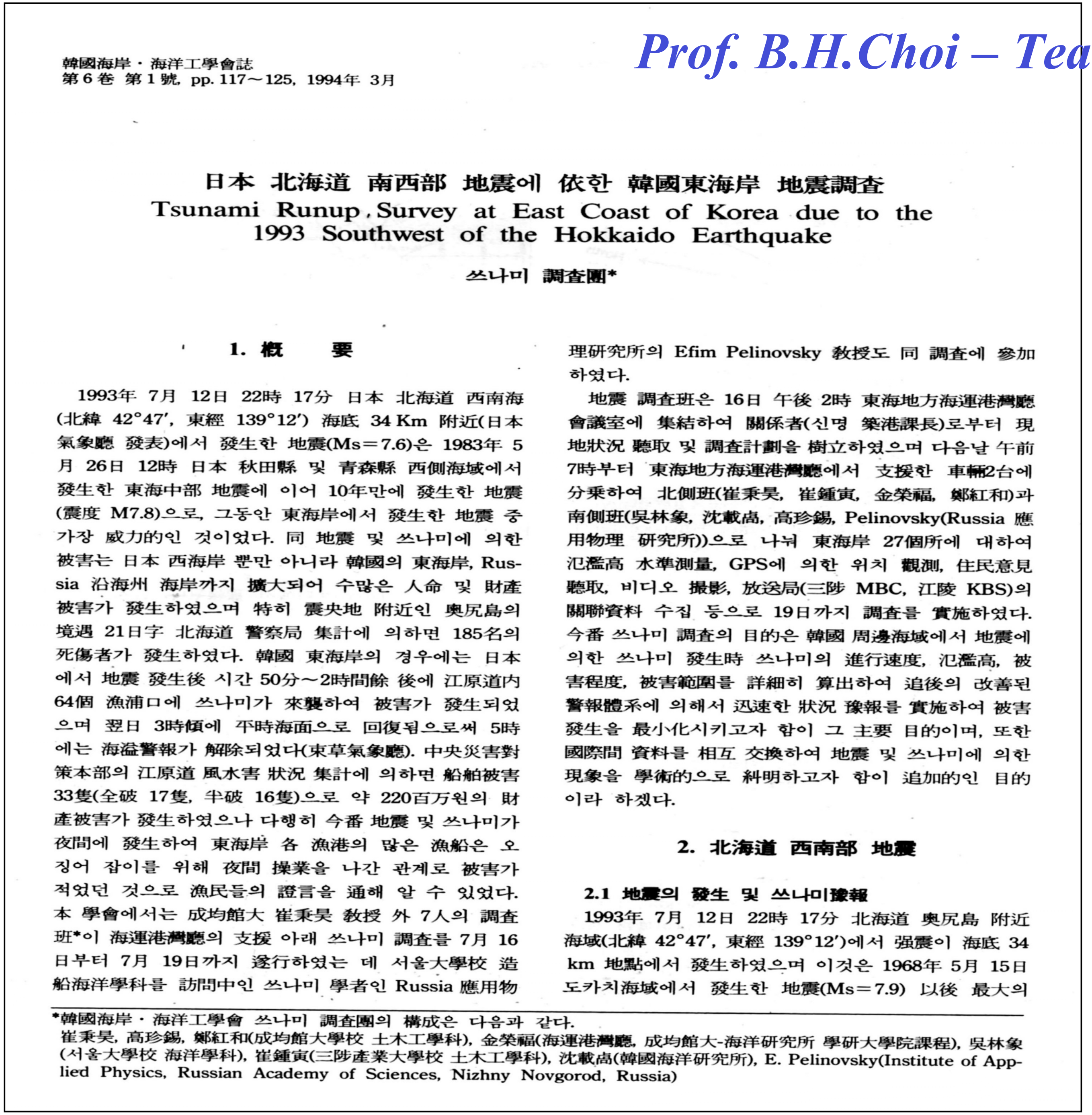
July 12, 1993



Tsunami heights

Name of points	Height (meter)
1. Geojin Port	0.81
2. Ayajin Port	1.39
3. Sajin Port	2.22
4. Sockcho	0.91
5. Daepo Port	1.63
6. Osan Port	1.26
7. Susan Port	1.85
8. Gisamun	2.26
9. Namae Port	1.26
10. Jumunjin Port	1.46
11. Sachunjin Port	1.46
12. Gangmun	1.87
13. Jungdongjin	2.01
14. Gumjin Port	1.17
15. Mukho Port	1.99
16. Donghae Port	1.76
17. Chuam Beach	1.77
18. Samchuk Port	1.86
19. Jangho Port	1.41
20. Imwon Port	2.39
21. Hosan Port	1.38
22. Bugu	2.57
23. Junkbyun Port	1.43

Prof. B.H.Choi – Team Leader



韓國海岸・海洋工學會誌
第6卷 第1號, pp. 117～125, 1994年 3月

日本 北海道 南西部 地震에 依한 韓國東海岸 地震調査
Tsunami Runup Survey at East Coast of Korea due to the 1993 Southwest of the Hokkaido Earthquake

쓰나미 調査團*

1. 槪要

1993年 7月 12日 22時 17分 日本 北海道 西南海(北緯 42°47′, 東經 139°12′) 海底 34 Km 附近(日本氣象廳 發表)에서 發生한 地震(Ms＝7.6)은 1983年 5月 26日 12時 日本 秋田縣 및 青森縣 西側海域에서 發生한 東海中部 地震에 이어 10年만에 發生한 地震(震度 M7.8)으로, 그동안 東海岸에서 發生한 地震 중 가장 威力的인 것이었다. 同 地震 및 쓰나미에 의한 被害는 日本 西海岸 뿐만 아니라 韓國의 東海岸, Russia 沿海州 海岸까지 擴大되어 수많은 人命 및 財產被害가 發生하였으며 特히 震央地 附近인 奧尻島의 境遇 21日字 北海道 警察局 集計에 의하면 185名의 死傷者가 發生하였다. 韓國 東海岸의 경우에는 日本에서 地震 發生後 시간 50分～2時間餘 後에 江原道内 64個 漁浦口에 쓰나미가 來襲하여 被害가 發生되었으며 翌日 3時傾에 平時海面으로 回復됨으로써 5時에는 海溢警報가 解除되었다(東草氣象廳). 中央災害對策本部의 江原道 風水害 狀況 集計에 의하면 船舶被害 33隻(全破 17隻, 半破 16隻)으로 약 220百万원의 財產被害가 發生하였으나 다행히 今番 地震 및 쓰나미가 夜間에 發生하여 東海岸 各 漁港의 많은 漁船은 오징어 잡이를 위해 夜間 操業을 나간 관계로 被害가 적었던 것으로 漁民들의 證言을 通해 알 수 있었다. 本 學會에서는 成均館大 崔秉昊 教授 外 7人의 調査班*이 海運港灣廳의 支援 아래 쓰나미 調査를 7月 16日부터 7月 19日까지 遂行하였는 데 서울大學校 造船海洋學科를 訪問中인 쓰나미 學者인 Russia 應用物理研究所의 Efim Pelinovsky 教授도 同 調査에 參加하였다.

地震 調査班은 16日 午後 2時 東海地方海運港灣廳 會議室에 集結하여 關係者(신명 築港課長)로부터 現地狀況 聽取 및 調査計劃을 樹立하였으며 다음날 午前 7時부터 東海地方海運港灣廳에서 支援한 車輛2台에 分乘하여 北側班(崔秉昊, 崔鍾寅, 金榮福, 鄭紅和)과 南側班(吳林象, 沈載卨, 高珍錫, Pelinovsky(Russia 應用物理 研究所))으로 나눠 東海岸 27個所에 대하여 氾濫高 水準測量, GPS에 의한 위치 觀測, 住民意見聽取, 비디오 撮影, 放送局(三陟 MBC, 江陵 KBS)의 關聯資料 수집 등으로 19日까지 調査를 實施하였다. 今番 쓰나미 調査의 目的은 韓國 周邊海域에서 地震에 의한 쓰나미 發生時 쓰나미의 進行速度, 氾濫高, 被害程度, 被害範圍를 詳細히 算出하여 追後의 改善된 警報體系에 의해서 迅速한 狀況 豫報를 實施하여 被害發生을 最小化시키고자 함이 그 主要 目的이며, 또한 國際間 資料를 相互 交換하여 地震 및 쓰나미에 의한 現象을 學術的으로 糾明하고자 함이 追加的인 目的이라 하겠다.

2. 北海道 西南部 地震

2.1 地震의 發生 및 쓰나미豫報

1993年 7月 12日 22時 17分 北海道 奧尻島 附近海域(北緯 42°47′, 東經 139°12′)에서 强震이 海底 34 km 地點에서 發生하였으며 이것은 1968年 5月 15日 도카치海域에서 發生한 地震(Ms＝7.9) 以後 最大의

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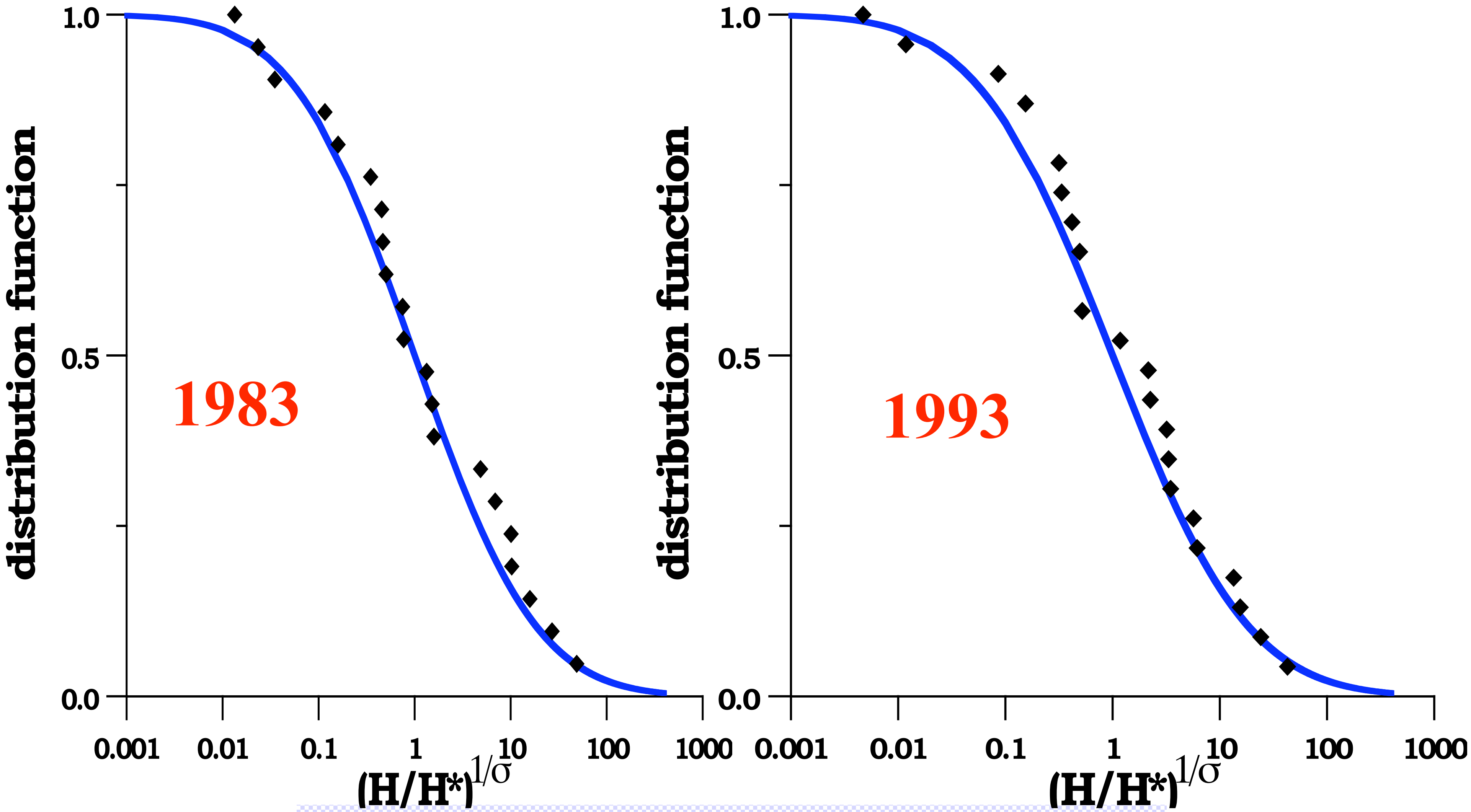
*韓國海岸・海洋工學會 쓰나미 調査團의 構成은 다음과 같다.
崔秉昊, 高珍錫, 鄭紅和(成均館大學校 土木工學科), 金榮福(海運港灣廳, 成均館大-海洋研究所 學研大學院課程), 吳林象(서울大學校 海洋學科), 崔鍾寅(三陟產業大學校 土木工學科), 沈載卨(韓國海洋研究所), E. Pelinovsky(Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia)

Korean Events



$$f(R) = \frac{1}{R\sigma\sqrt{2\pi}\ln 10}\exp\left(-\frac{(\log R - m)^2}{2\sigma^2}\right)$$

Numerical Simulation is important for:

- To calculate tsunami heights from known tsunamis at points where no data (objectively or subjectively)
- To calculate tsunami heights from hypothetic earthquakes (synthetic catalogue)

Developed model have to be tested on historical data and it is why field surveys are organized

Tsunami Catalogue for Korean Eastern Coast

should include:

1. Two nearest tsunamis (1643 and 1681)
2. Eleven distant tsunamis

   (1580-1741 and 1940-1993)

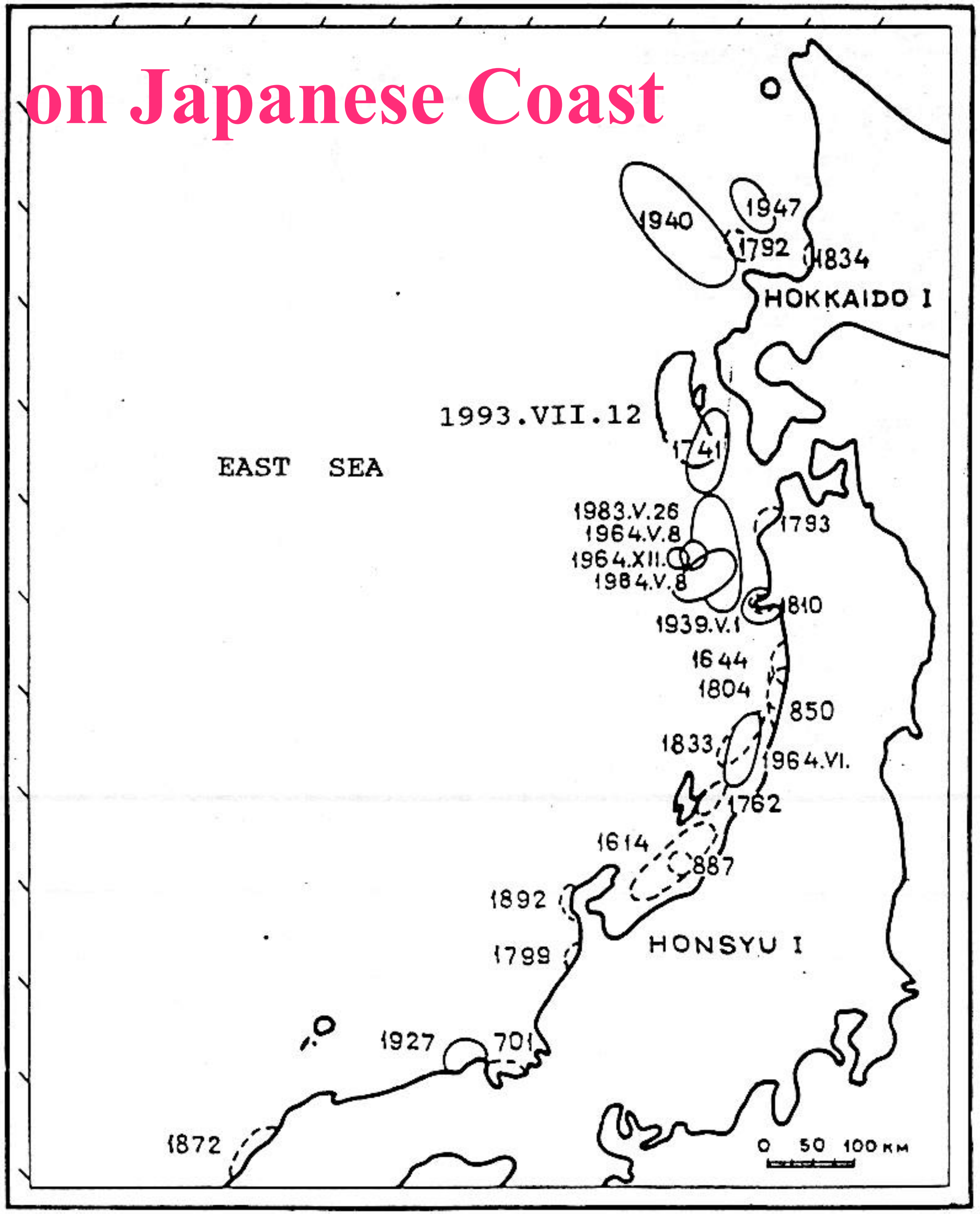
No good information of events before 20th century

We will consider events of 20th century

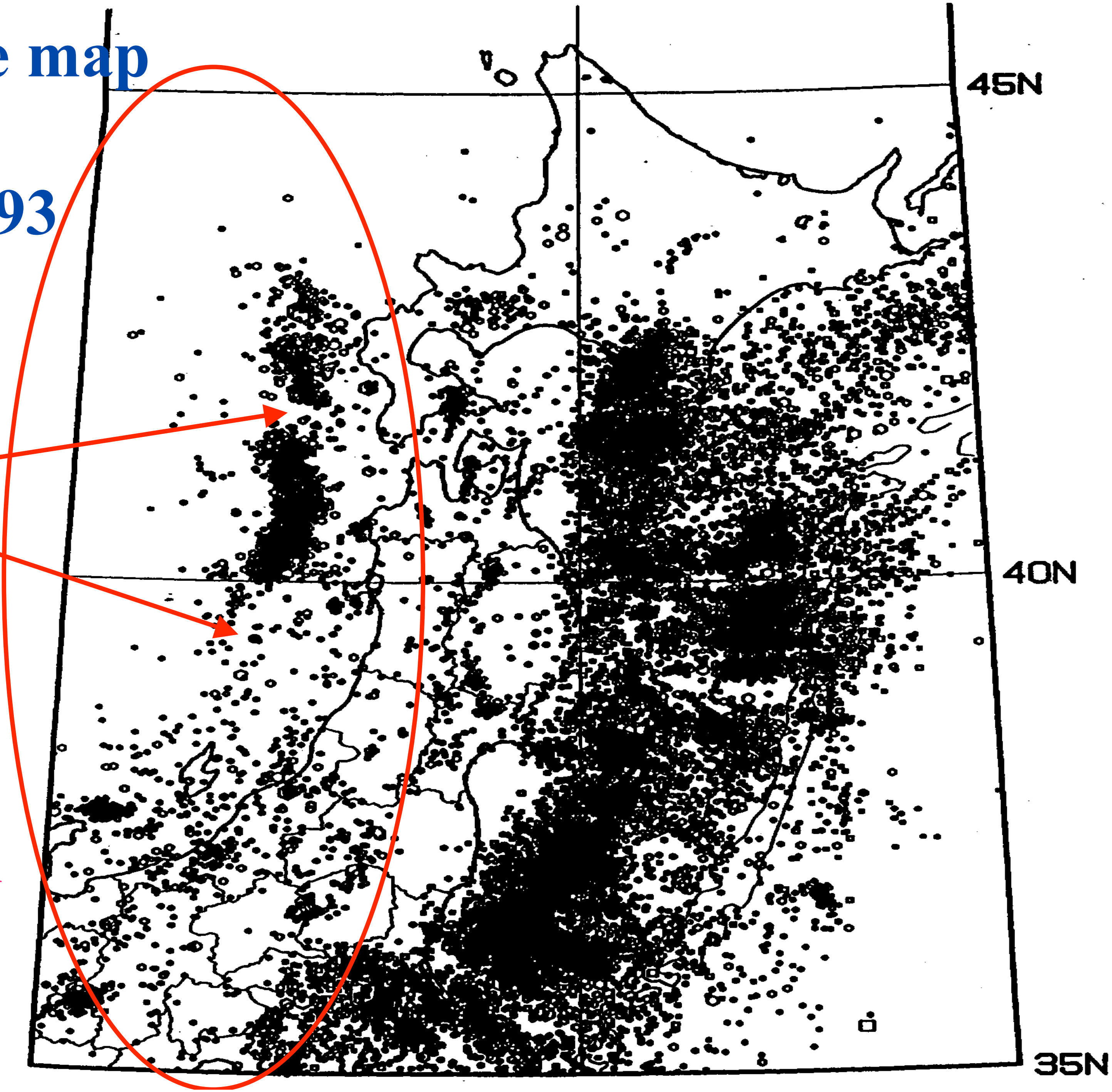
Tsunami sources on Japanese Coast

But most of them do not affect Korean Coast

So, we should seek the sources of forthcoming events



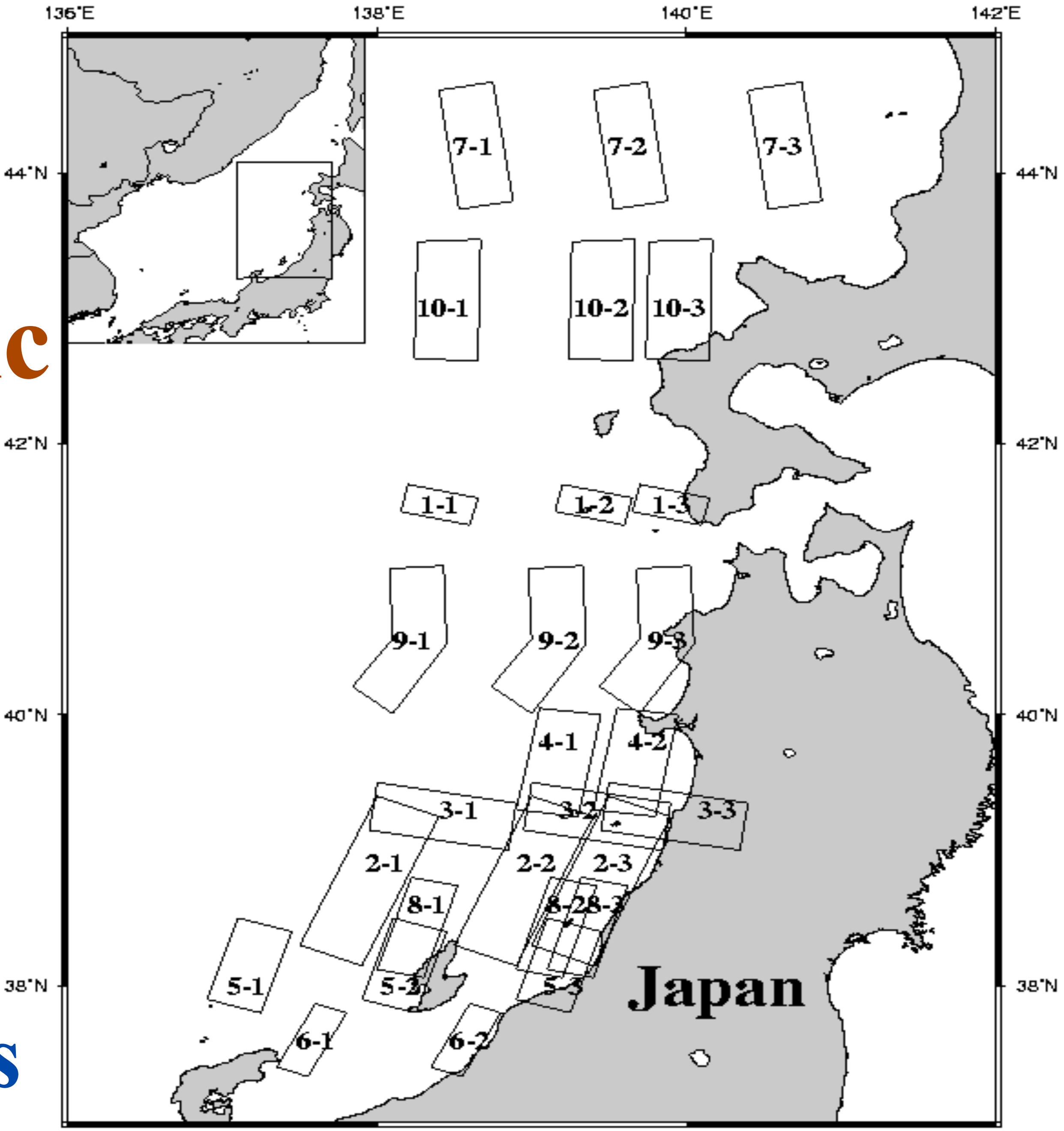
Earthquake map of Japan for 1926-1993



Seismic Gaps

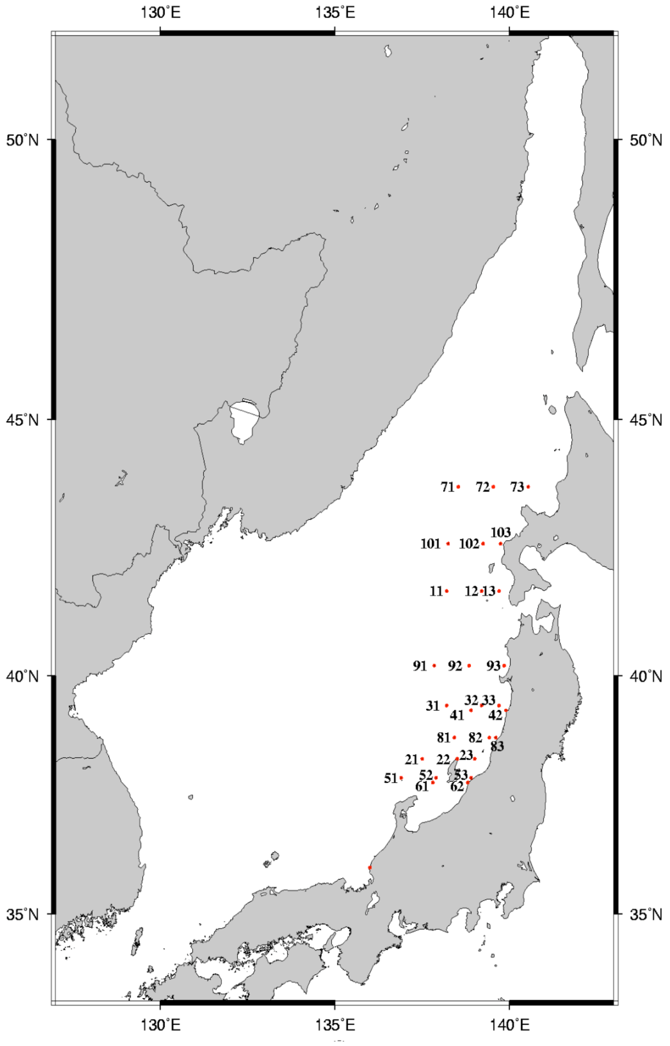
Tsunami Generation for Korea

Hypothetic Tsunami Sources



28 events, including 4 real events

Epicenters of hypothetical



Fault parameters for hypothetic earthquakes

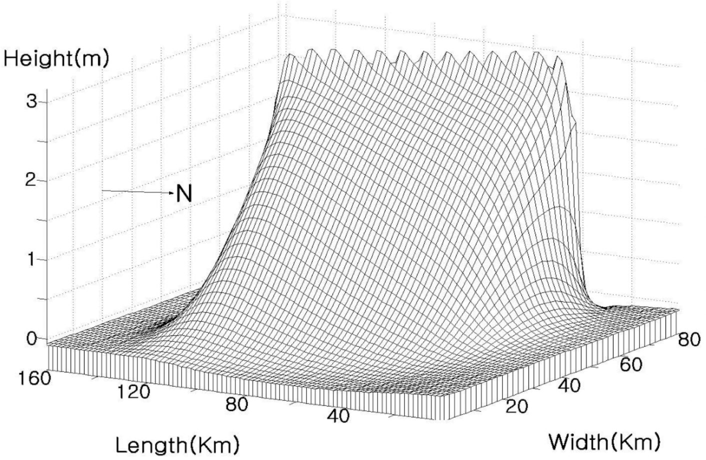
N	Length (Km)	Dislocation (m)	Width (Km)	Slip angle (°)	Strike (°)	Dip angle (°)
1	45	2.3	25	100	110	45
2	140	5.0	50	90	23	35
3	100	4.1	50	90	105	45
4	70	2.0	20	75	23	45
5	70	3.2	40	90	15	20
6	60	1.9	20	90	190	55
7	100	5.35	35	90	347	40
8	80	7.81	30	90	189	56
9	40 60	7.6 3.05	30 30	90 80	22 355	40 25
10	100	3.7	50	84	1	24

28 events, including 4 real events

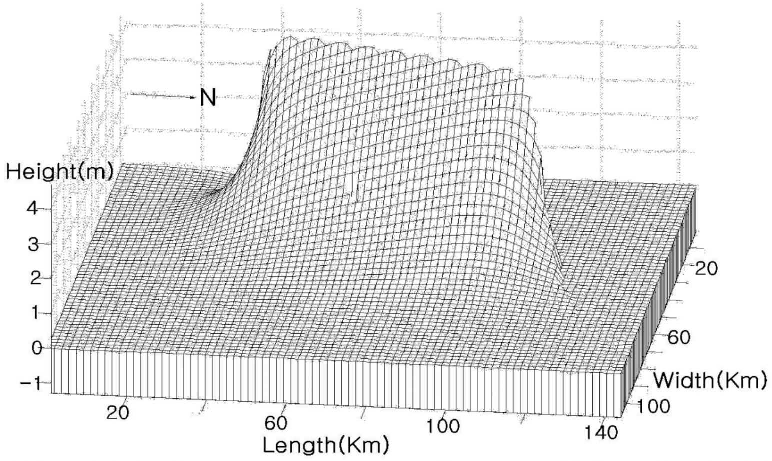
Synthetic Catalogue

SOURCES

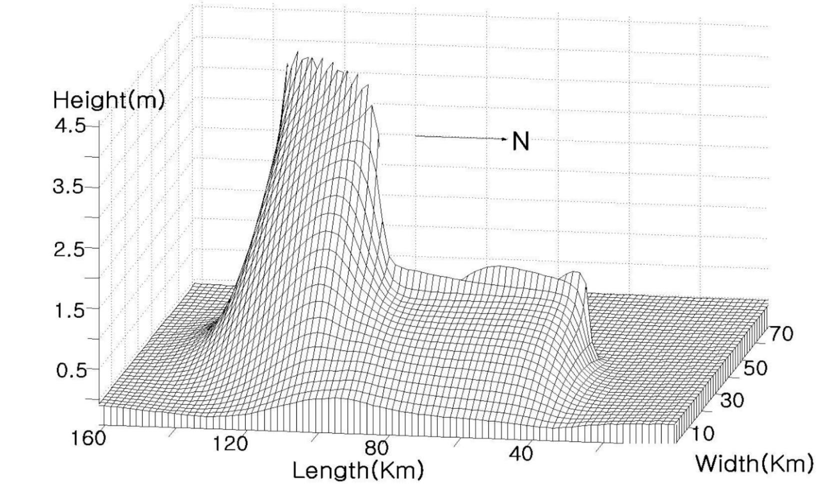
Shakotan-oki earthquake(1940)



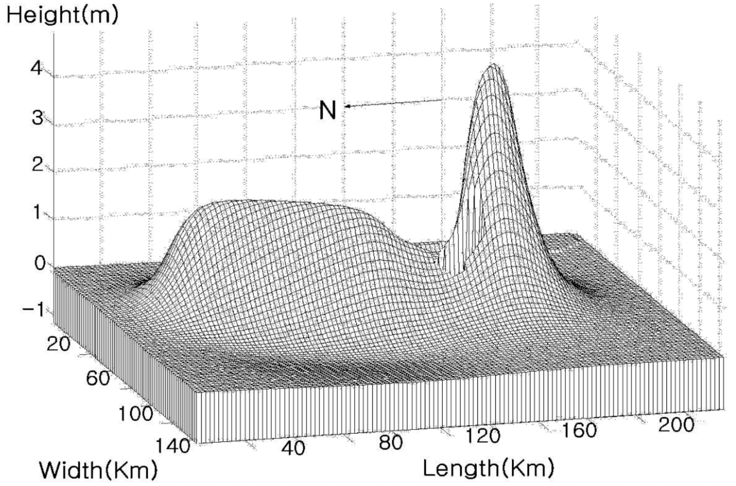
Nigata earthquake(1964)



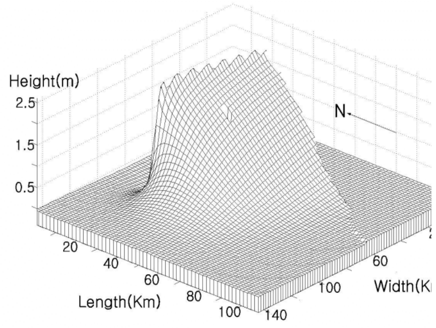
Central East Sea earthquake(1983)



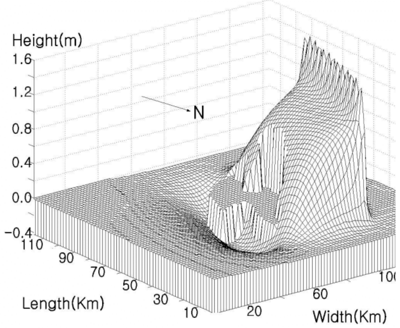
Hokkaido earthquake(1993)



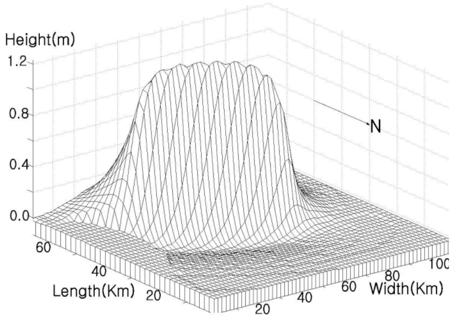
CASE 032



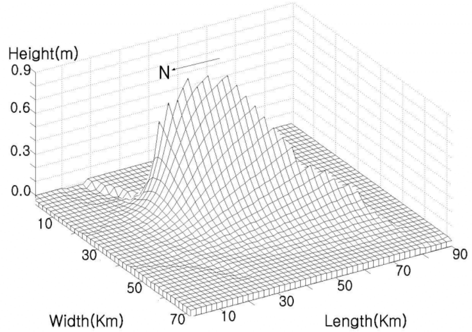
CASE 052



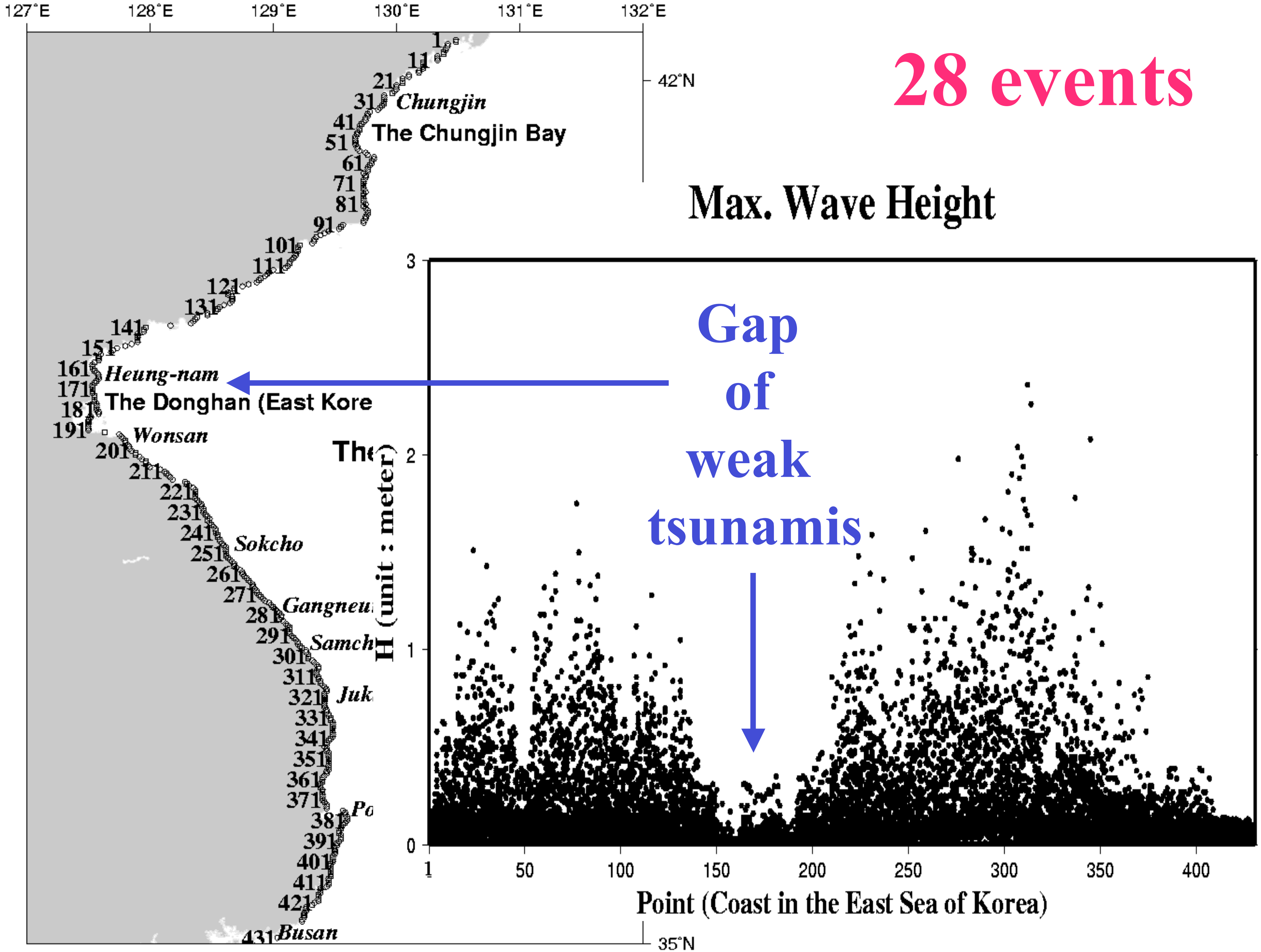
CASE 012



CASE 062

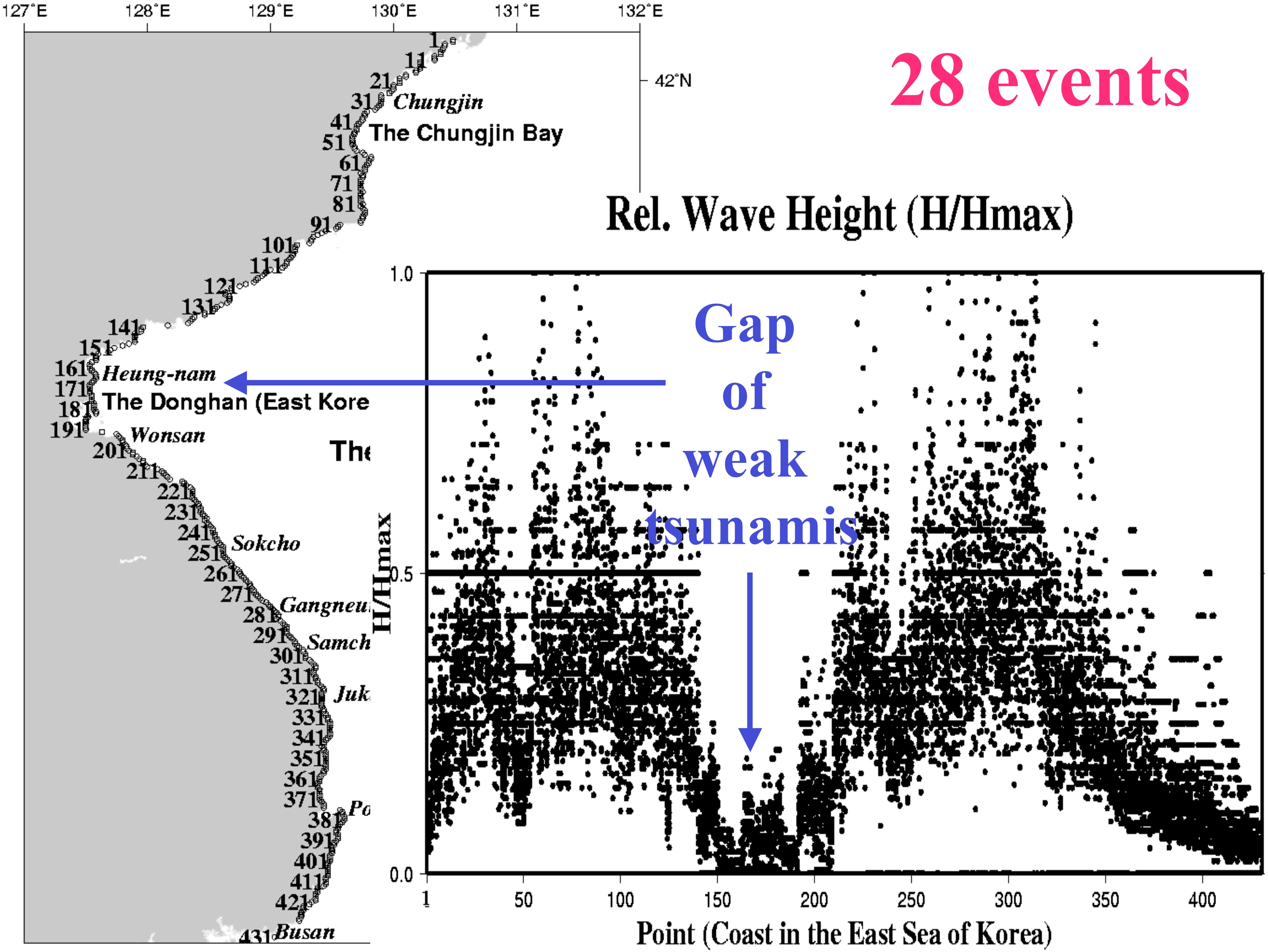


28 events



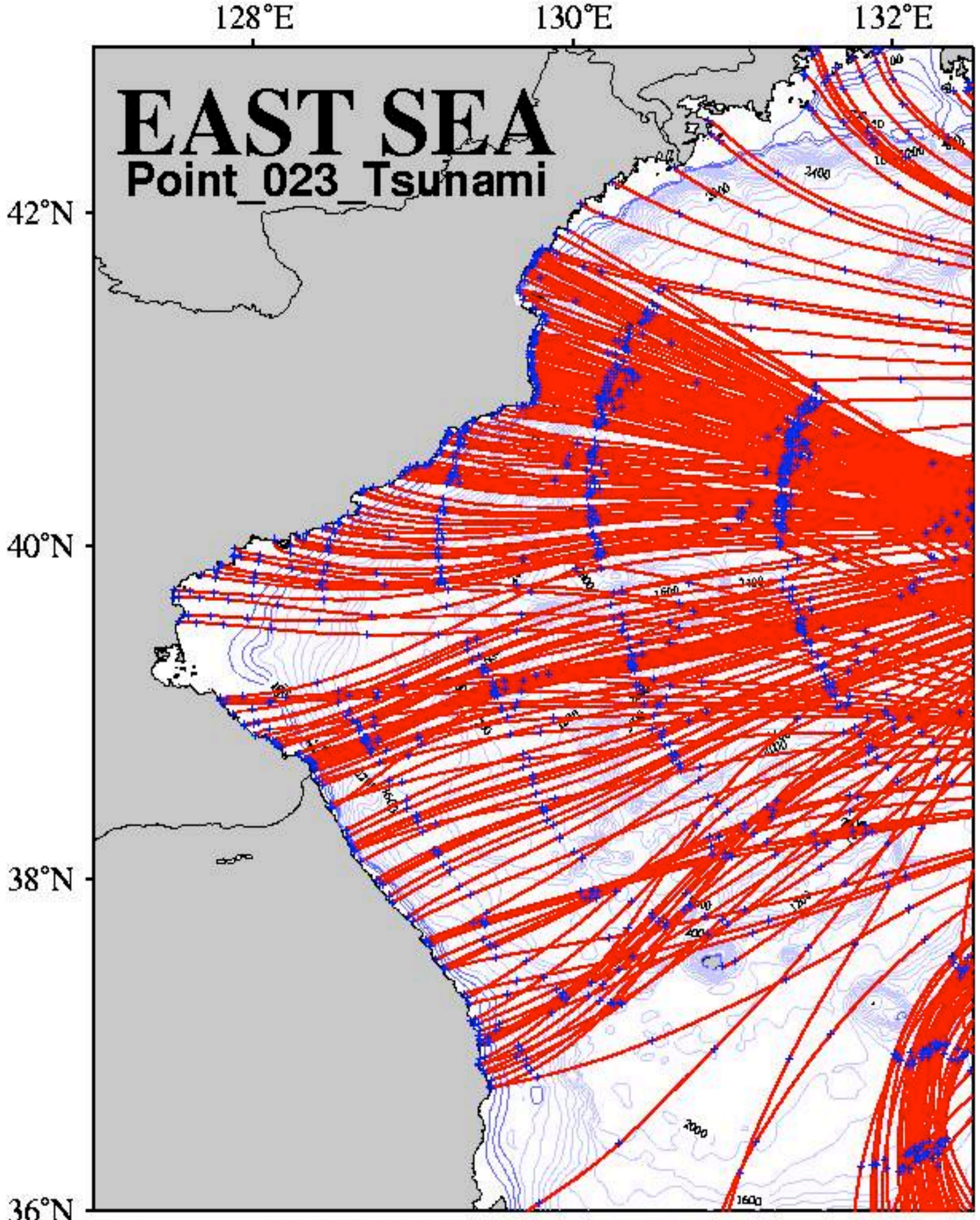
Gap
of
weak
tsunamis

28 events

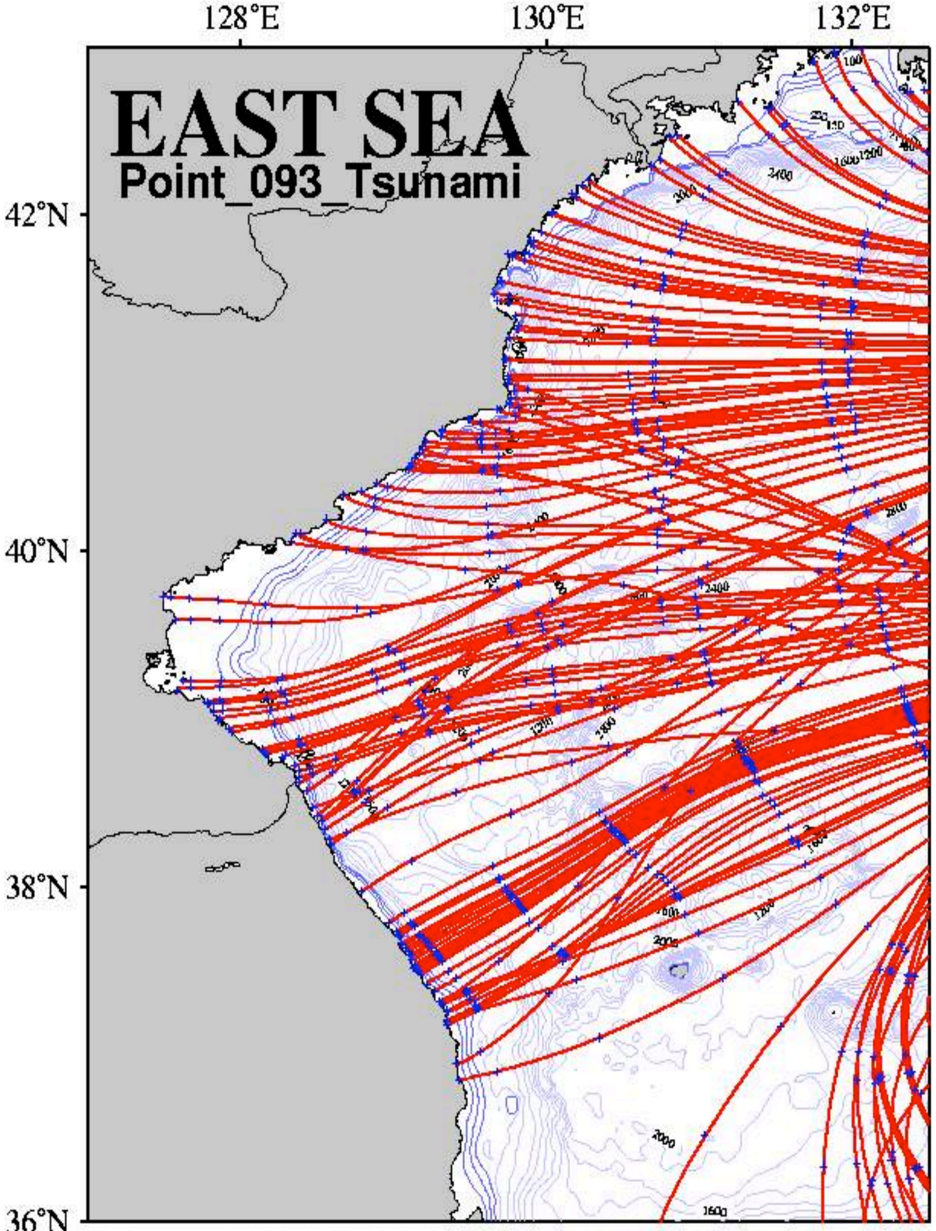


Gap of weak tsunamis

Protection of Donghan Bay

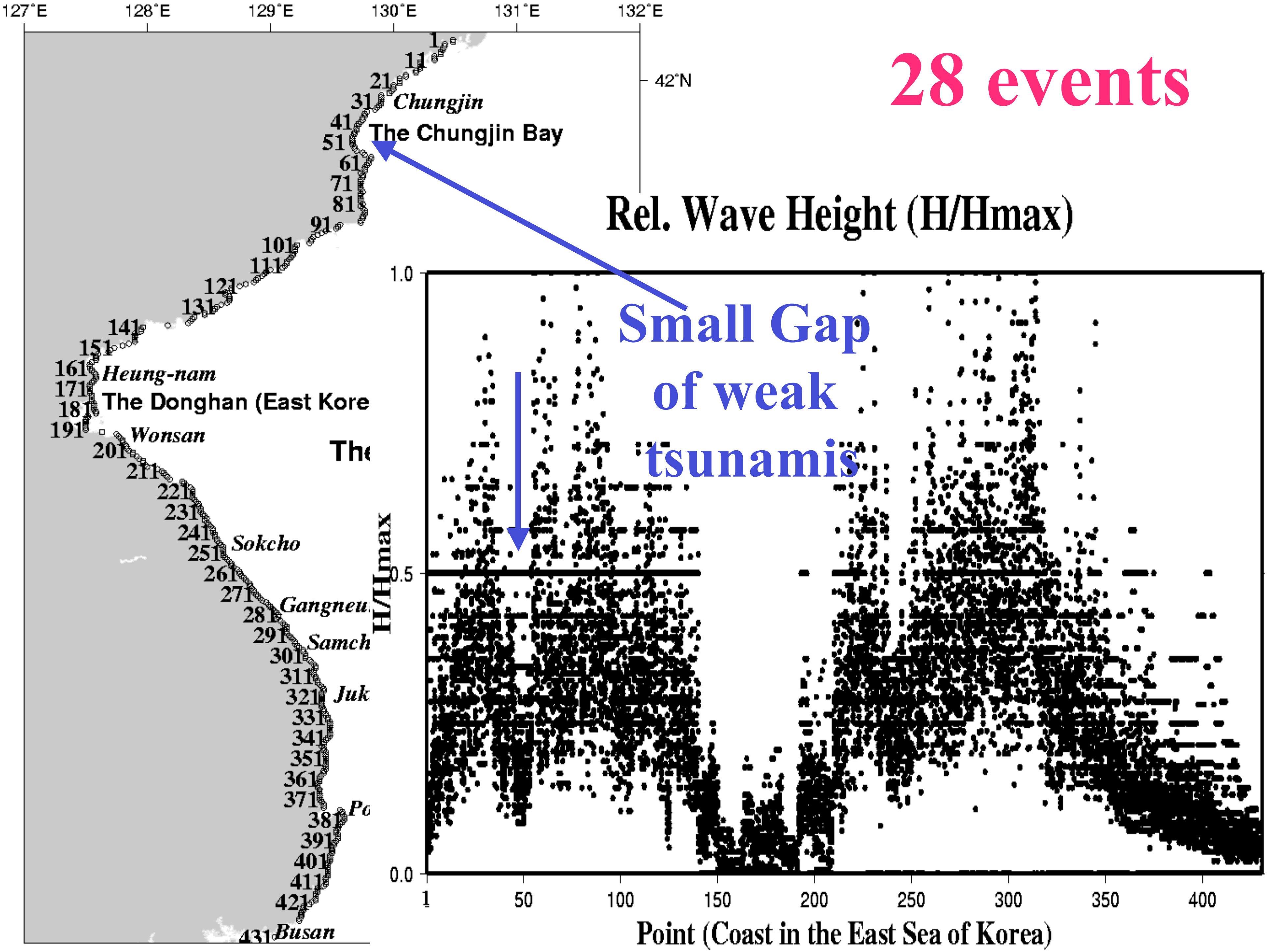


Epicenter : 138.70E,38.30N



Epicenter1:139.14E,40.21N;Epicenter2:139.32E,40.54N

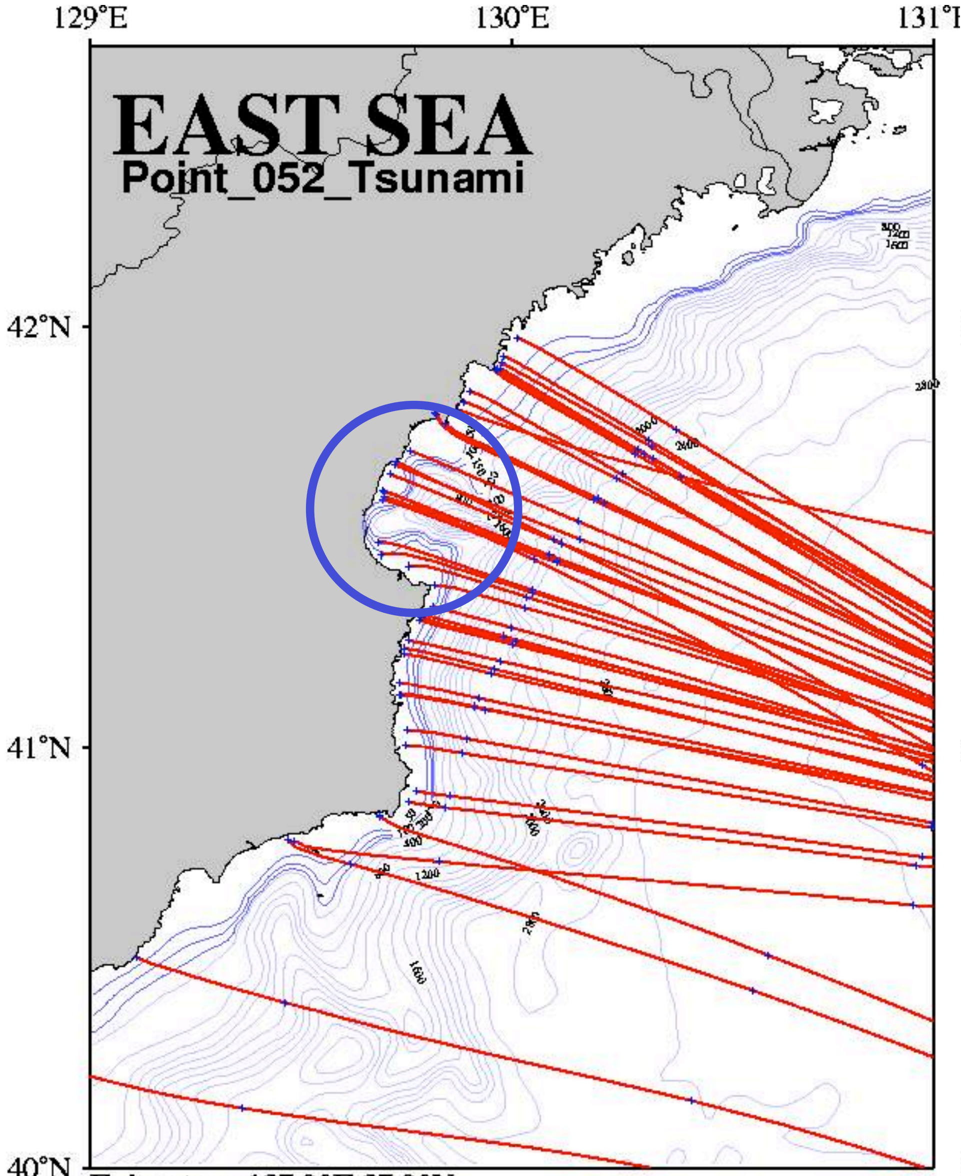
28 events



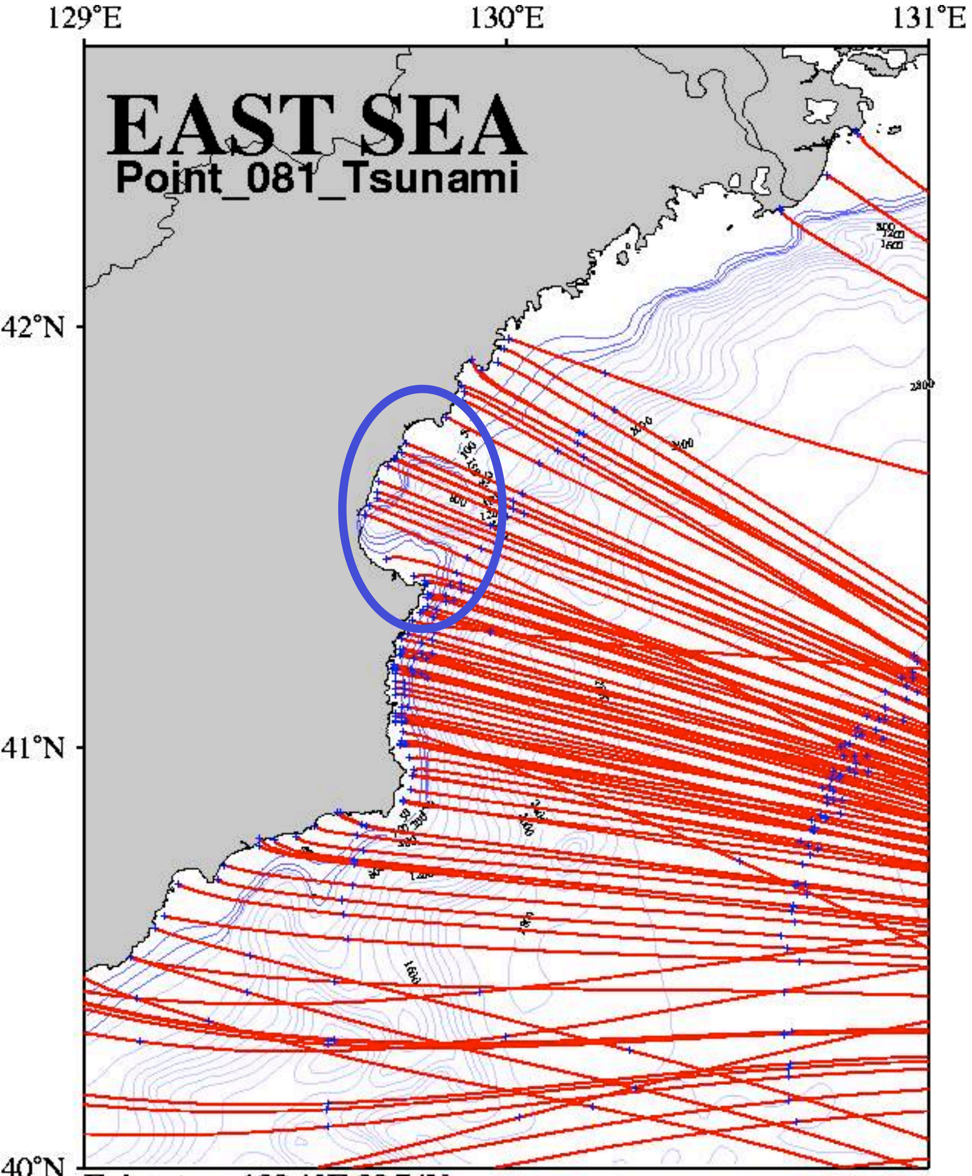
Rel. Wave Height (H/Hmax)

Small Gap of weak tsunamis

Protection of Chungjin Bay

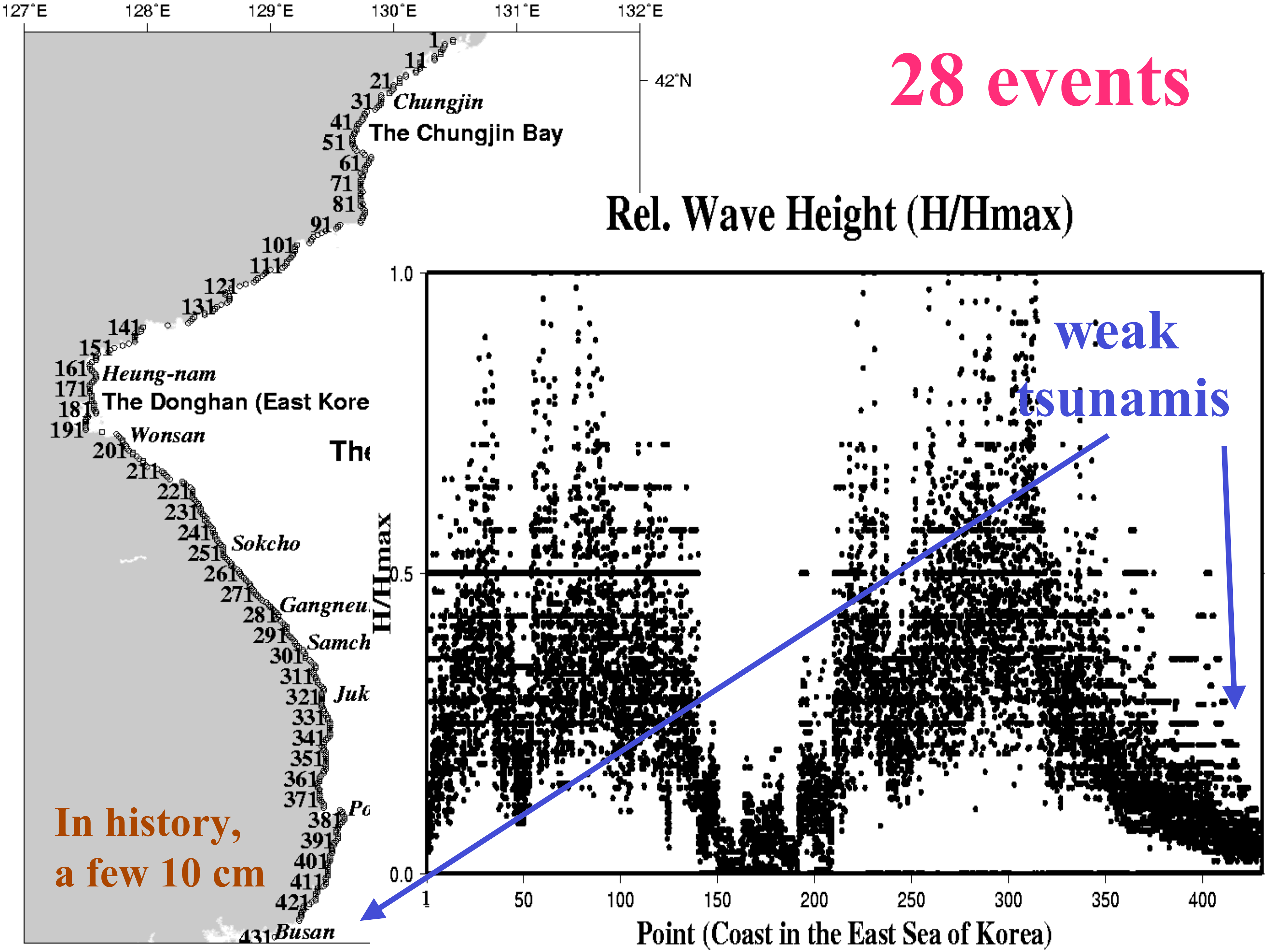


Epicenter : 137.90E,37.90N



Epicenter : 138.42E,38.74N

28 events



weak tsunamis

In history, a few 10 cm

For each point – series contained 28 values of wave heights

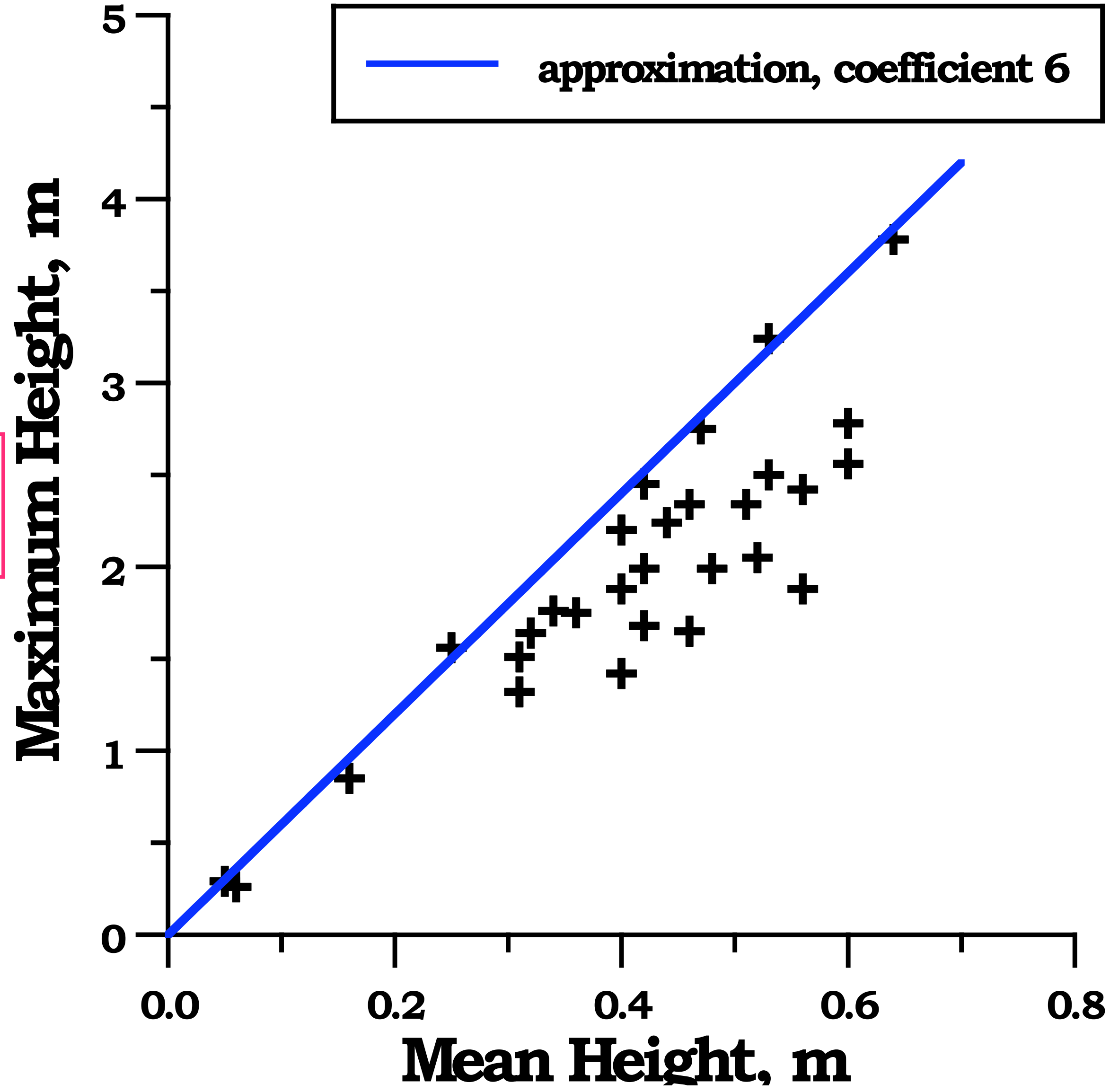
It characterizes by H_{mean} and H_{max}

H_{mean} is stable to variation of earthquake parameters

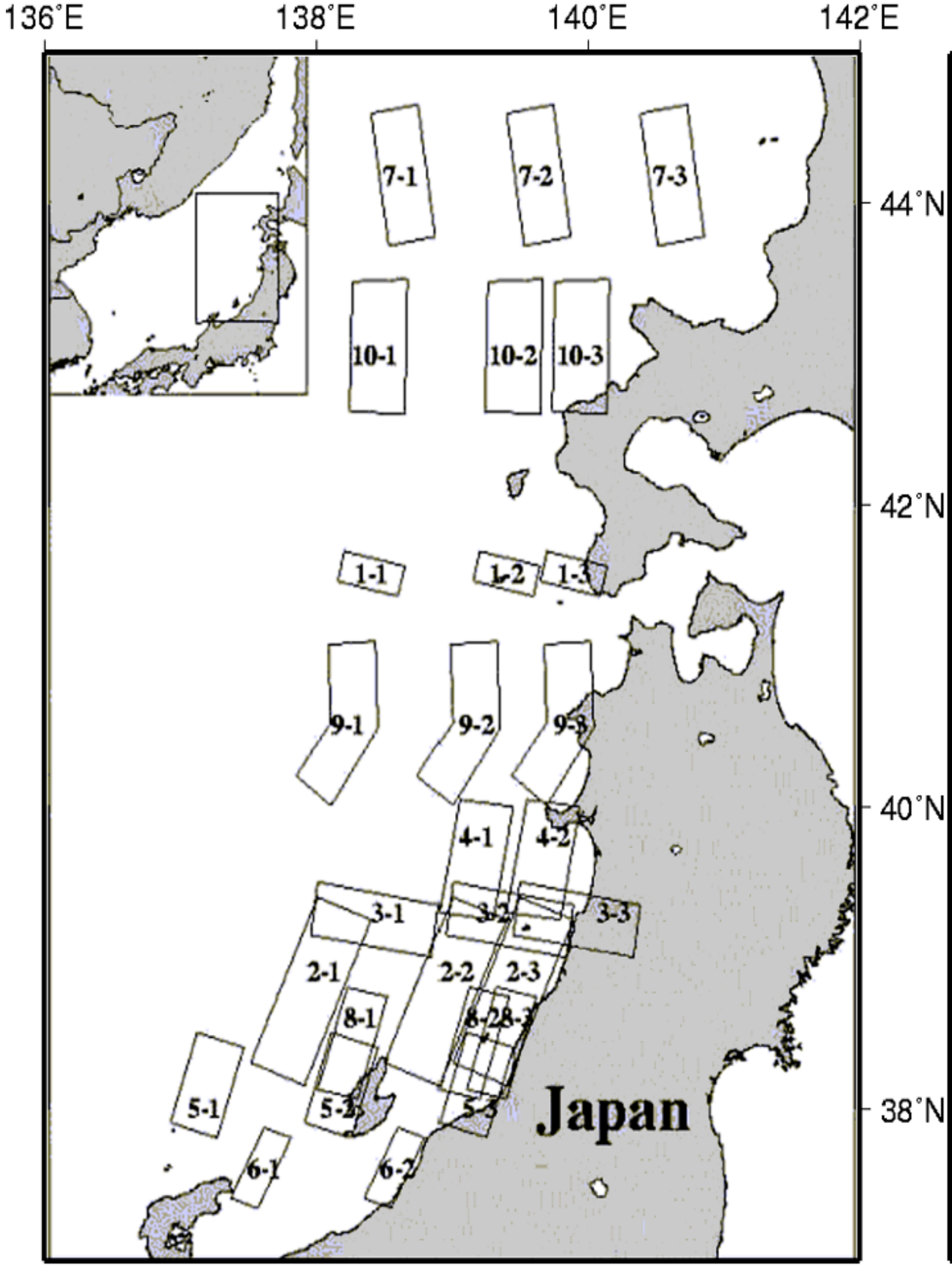
H_{max} is unstable

Thus, upper limit of tsunami height

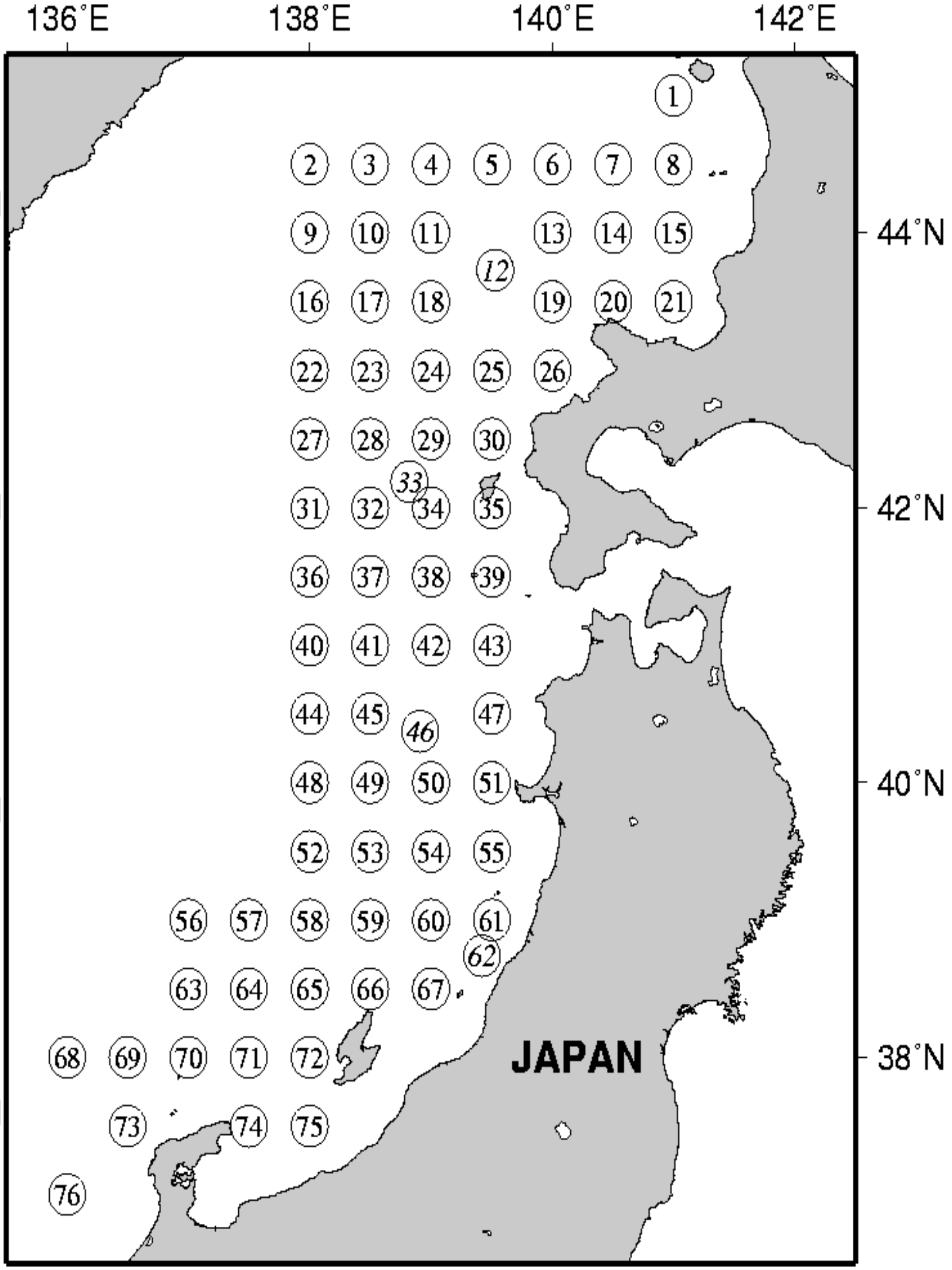
$Max(H)=6H_{mean}$ is stable



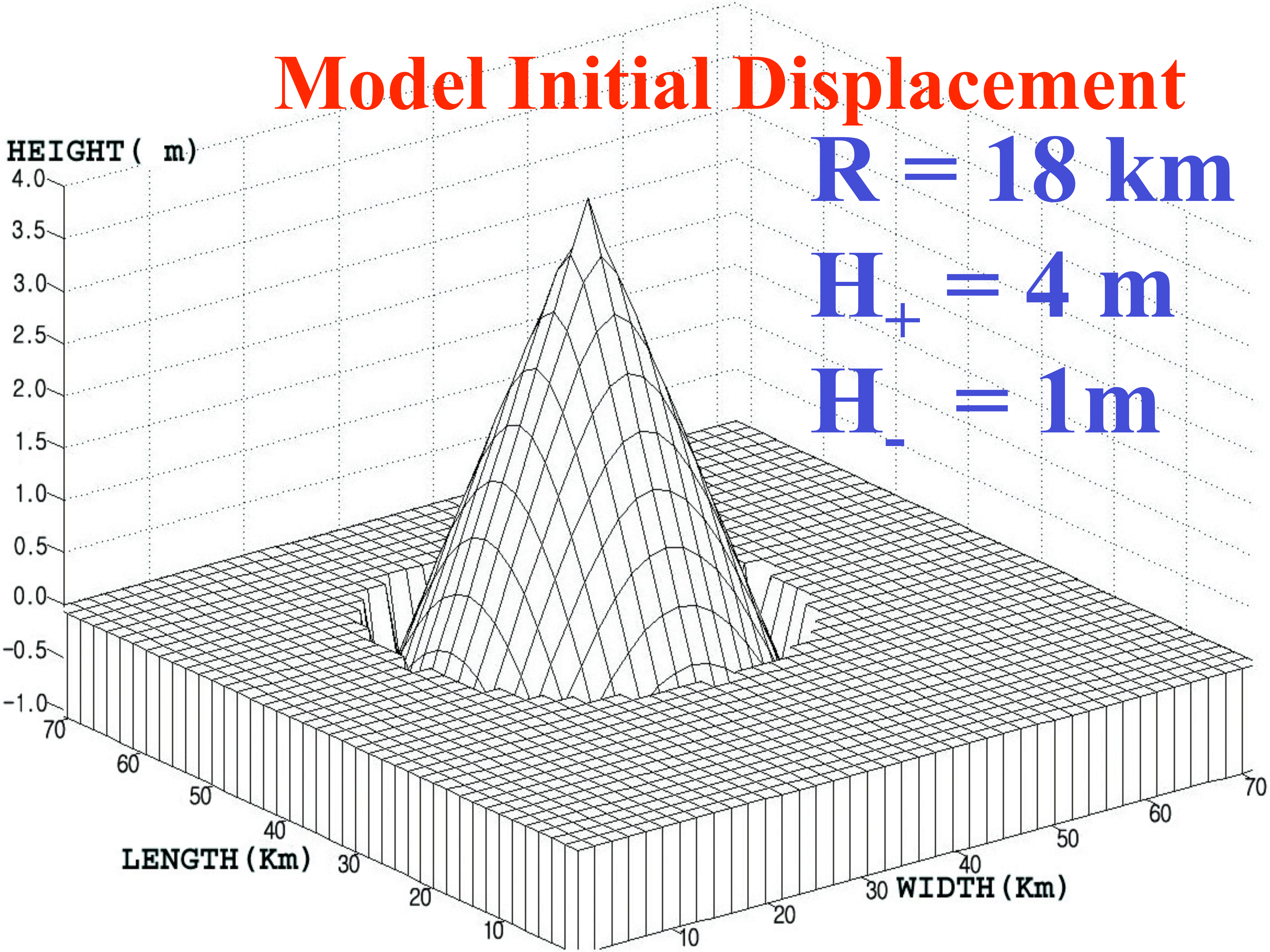
Seismic Source (28)



Model Source (76)



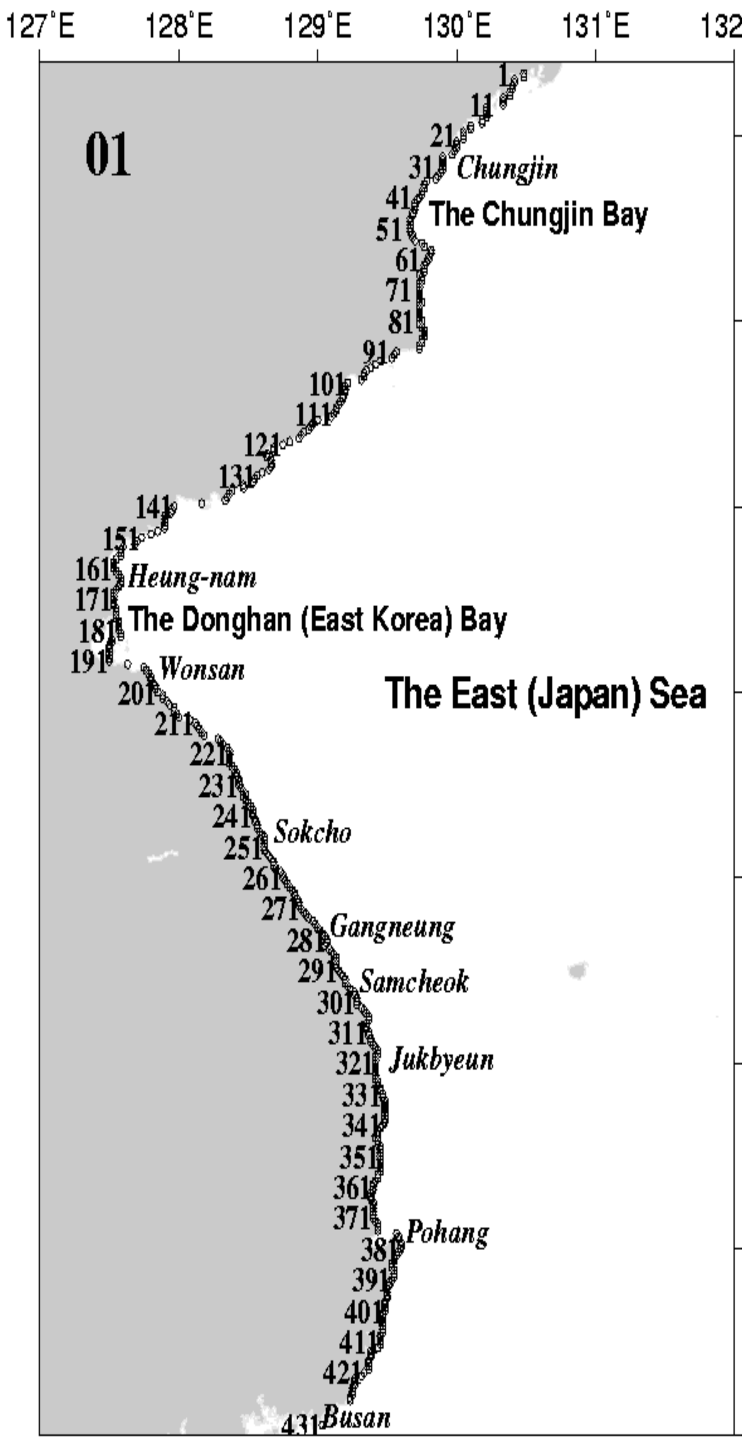
Model Initial Displacement



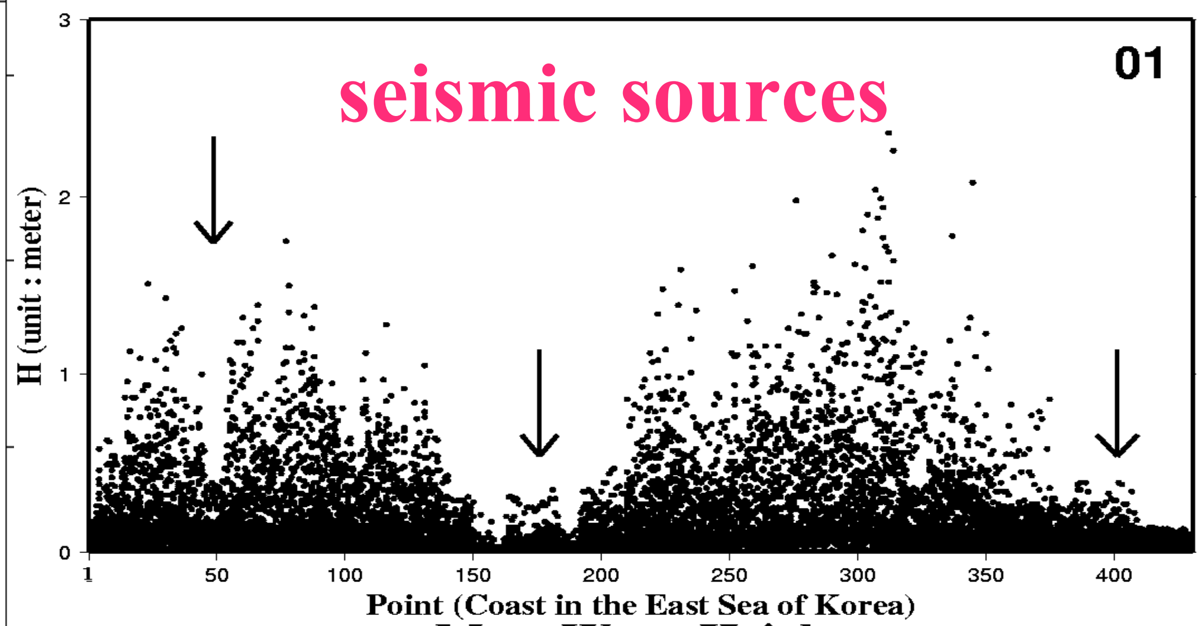
$R = 18$ km

$H_+ = 4$ m

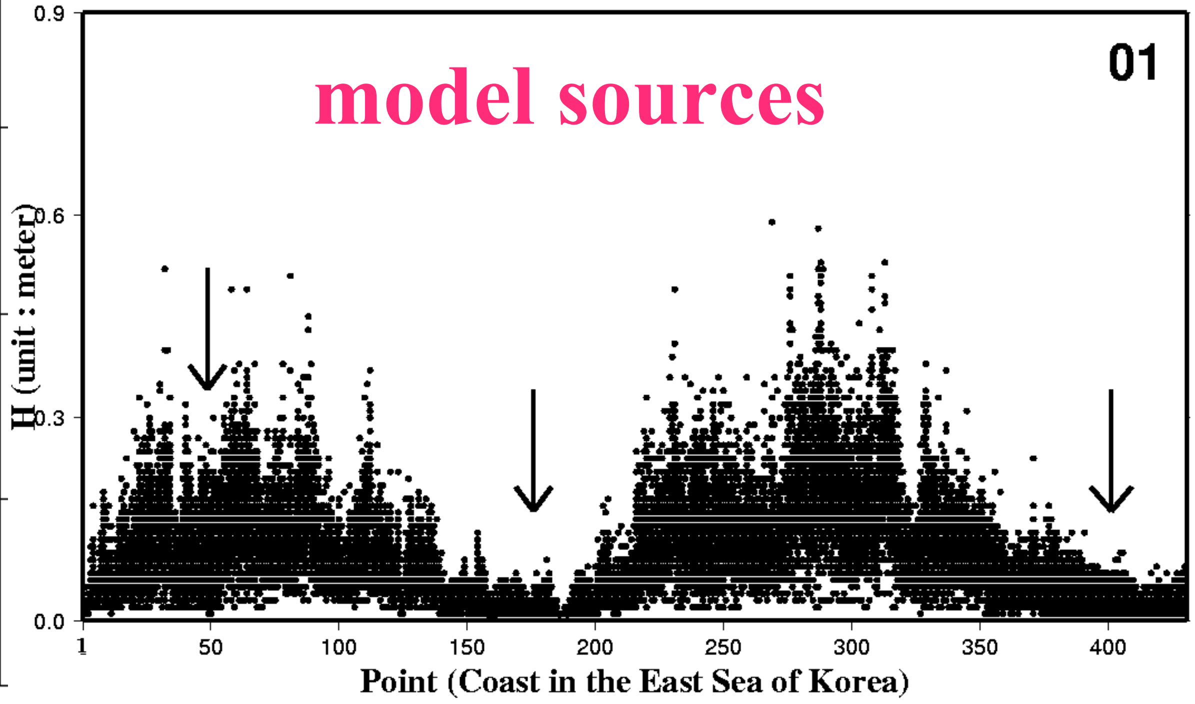
$H_- = 1$m

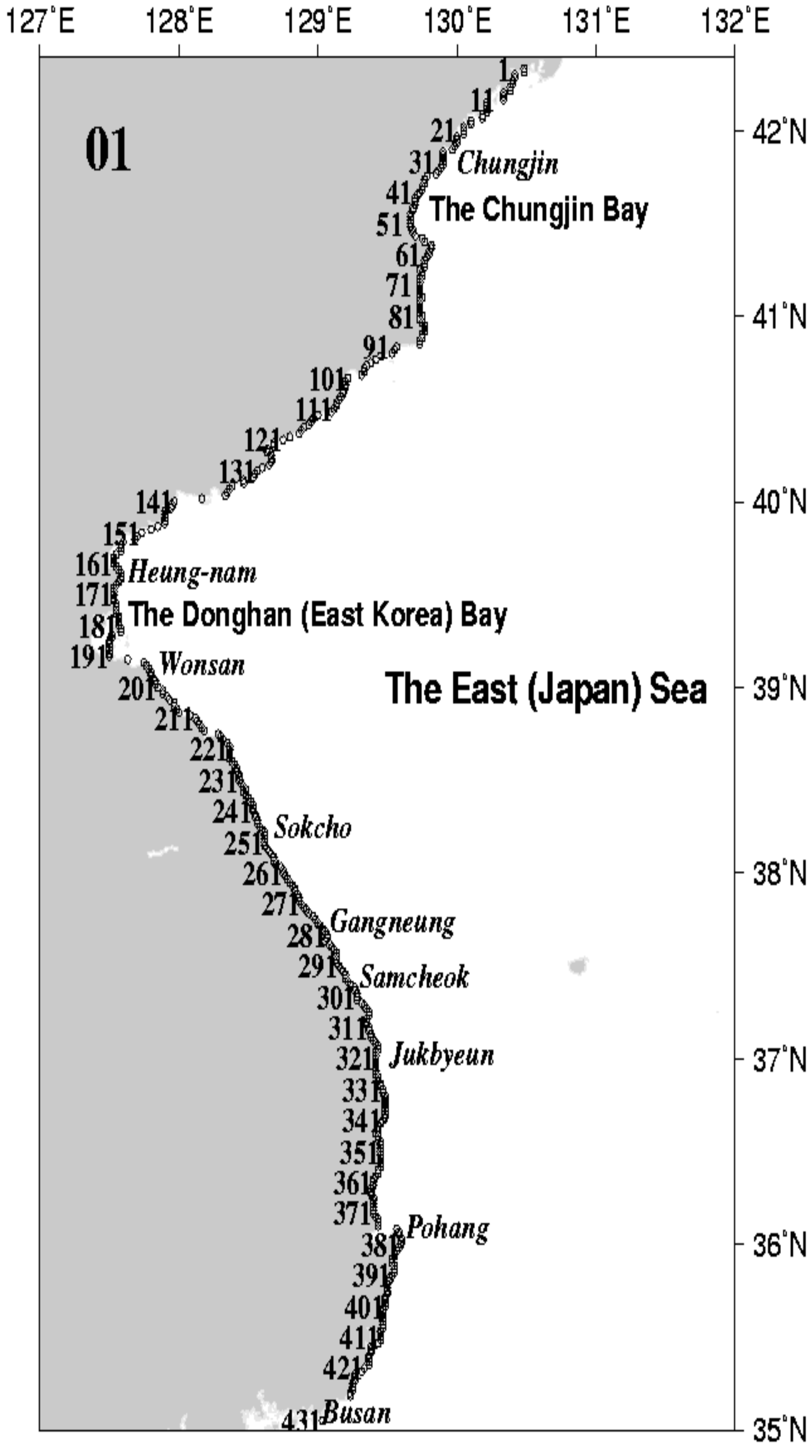


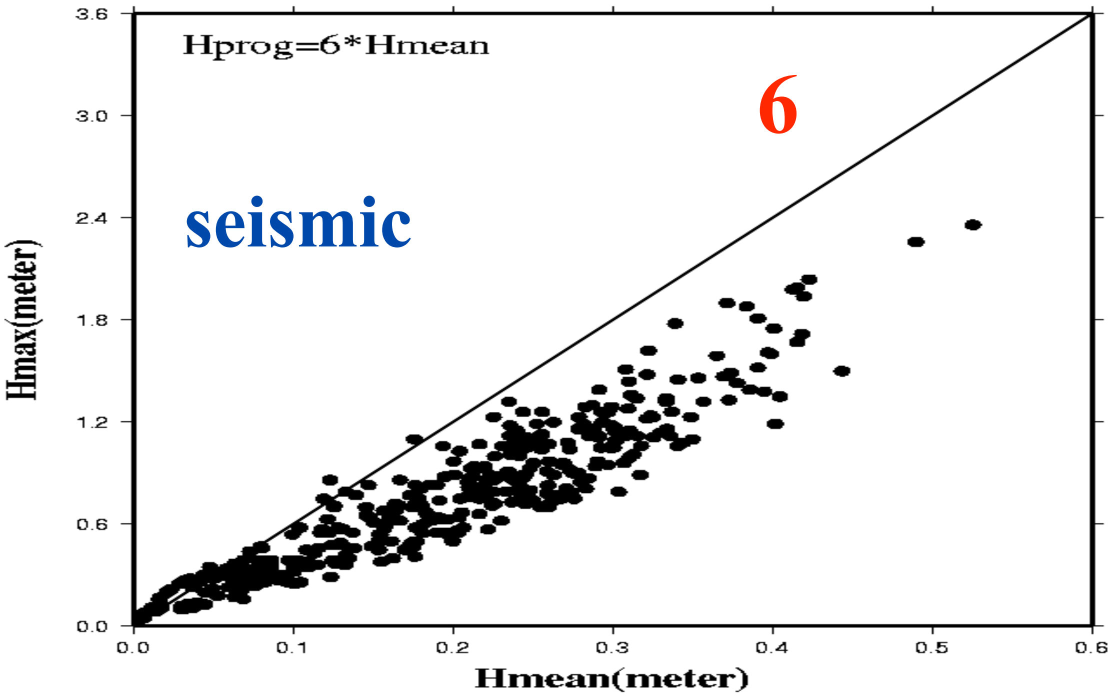
Max. Wave Height



Max. Wave Height

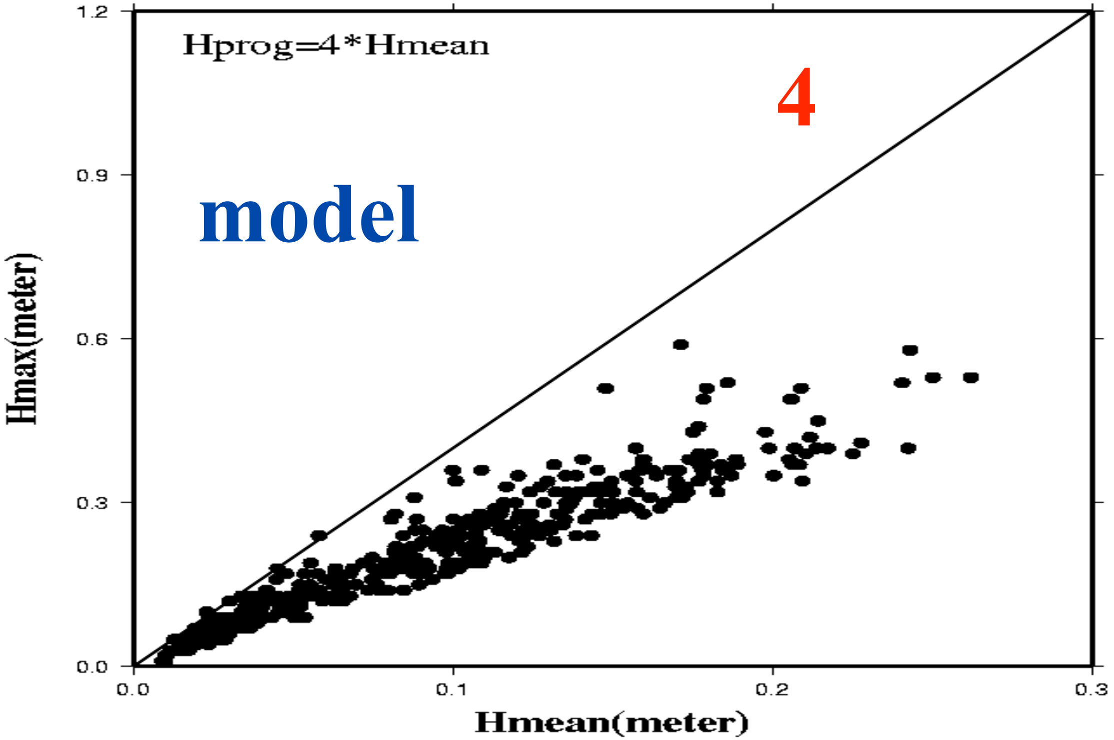






6

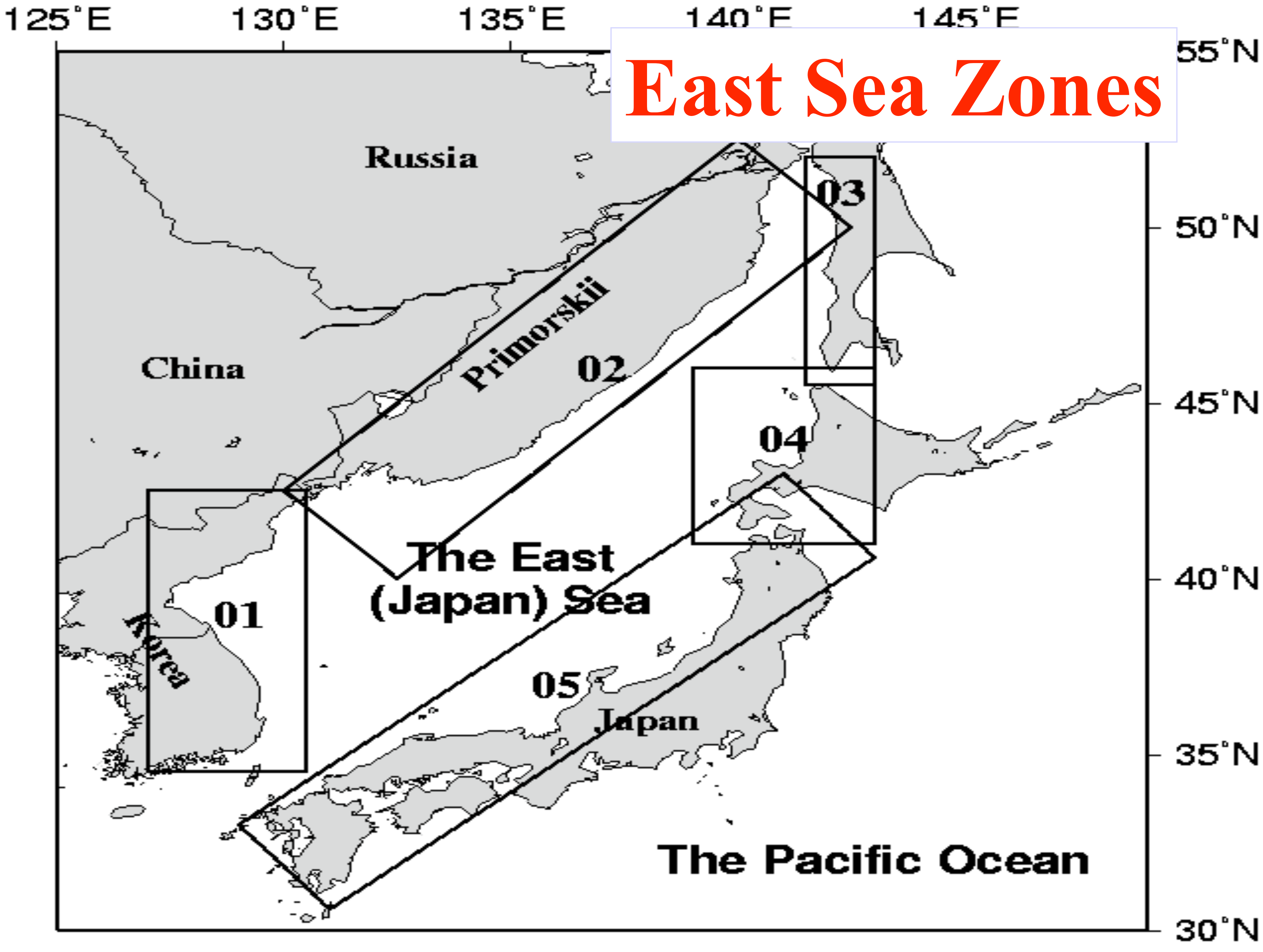
seismic

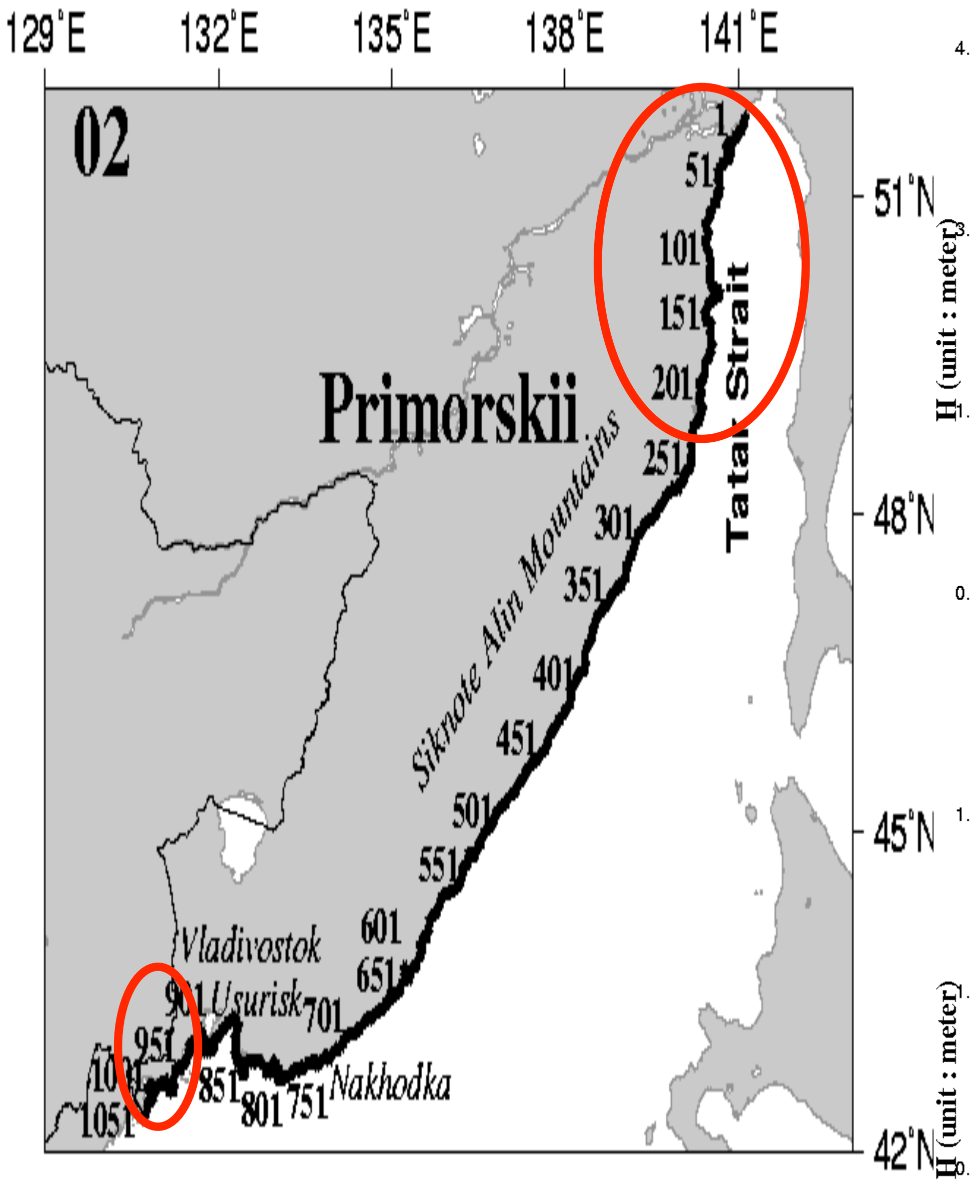


4

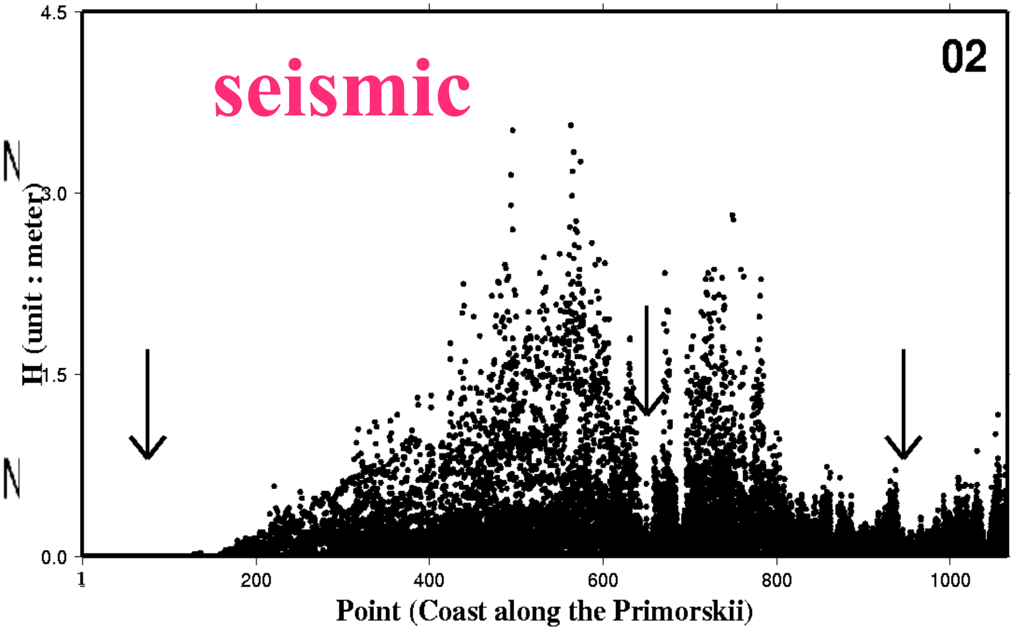
model

East Sea Zones

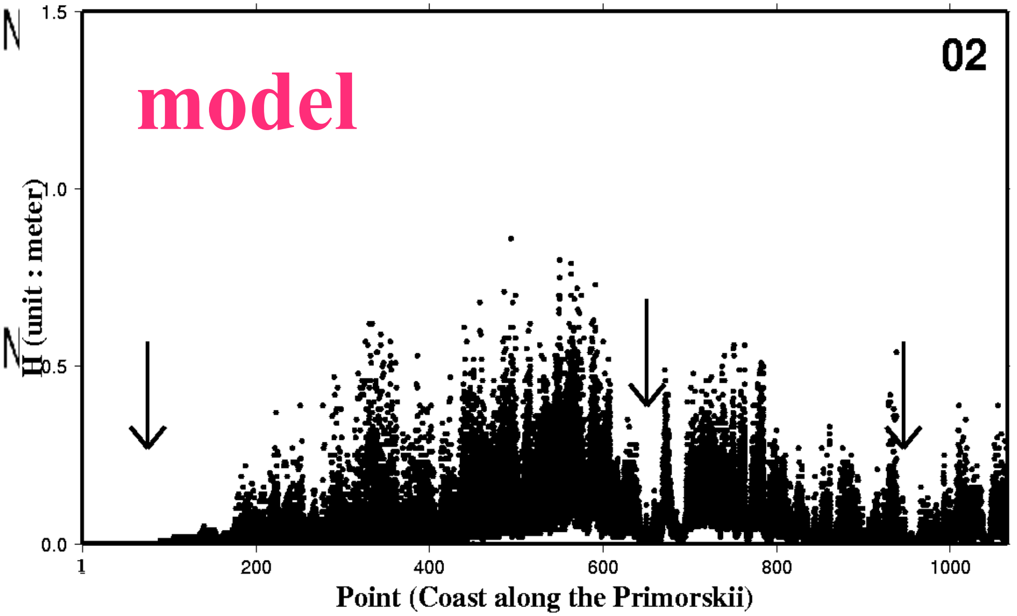




Max. Wave Height

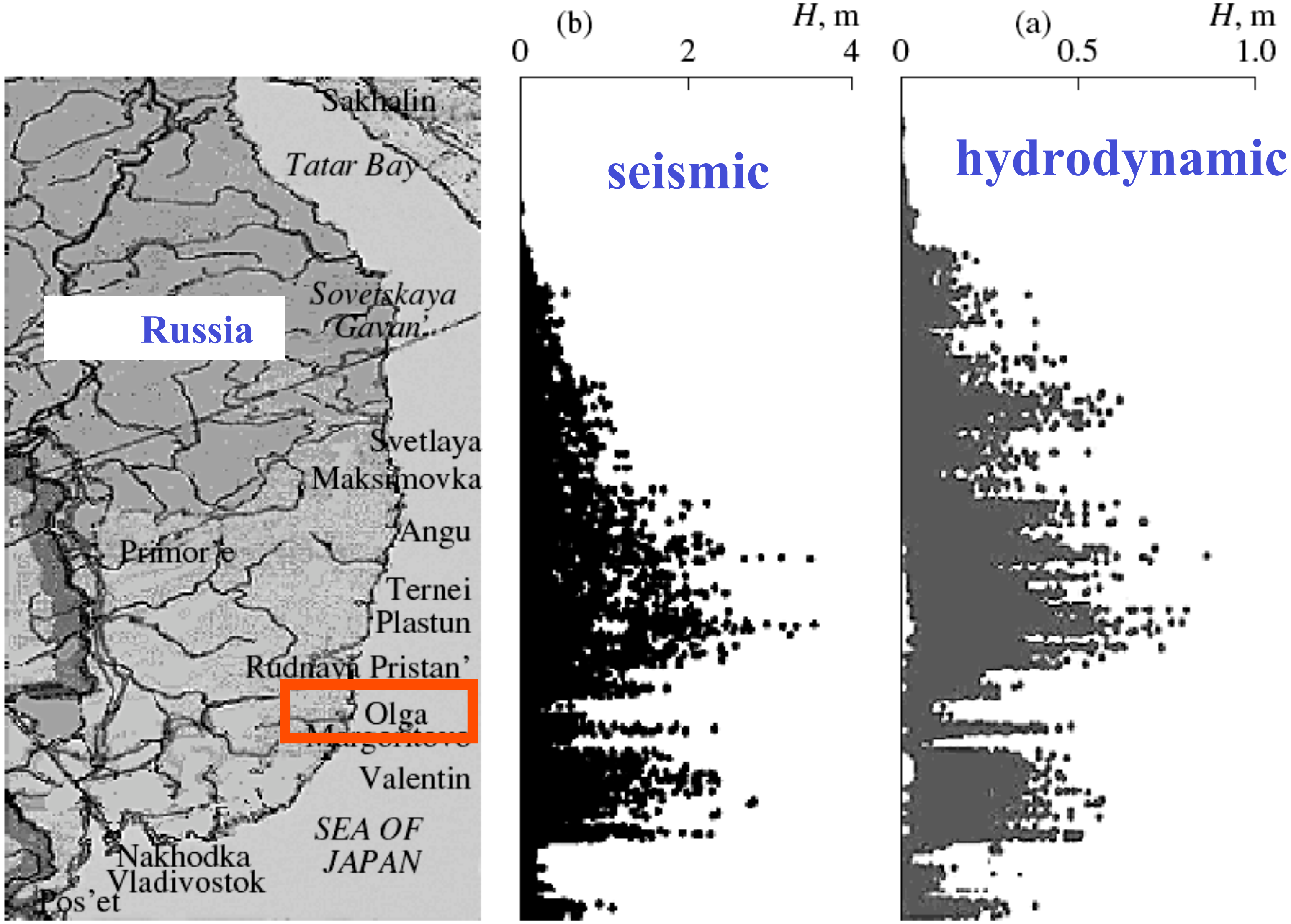


Max. Wave Height



Russia

Computations



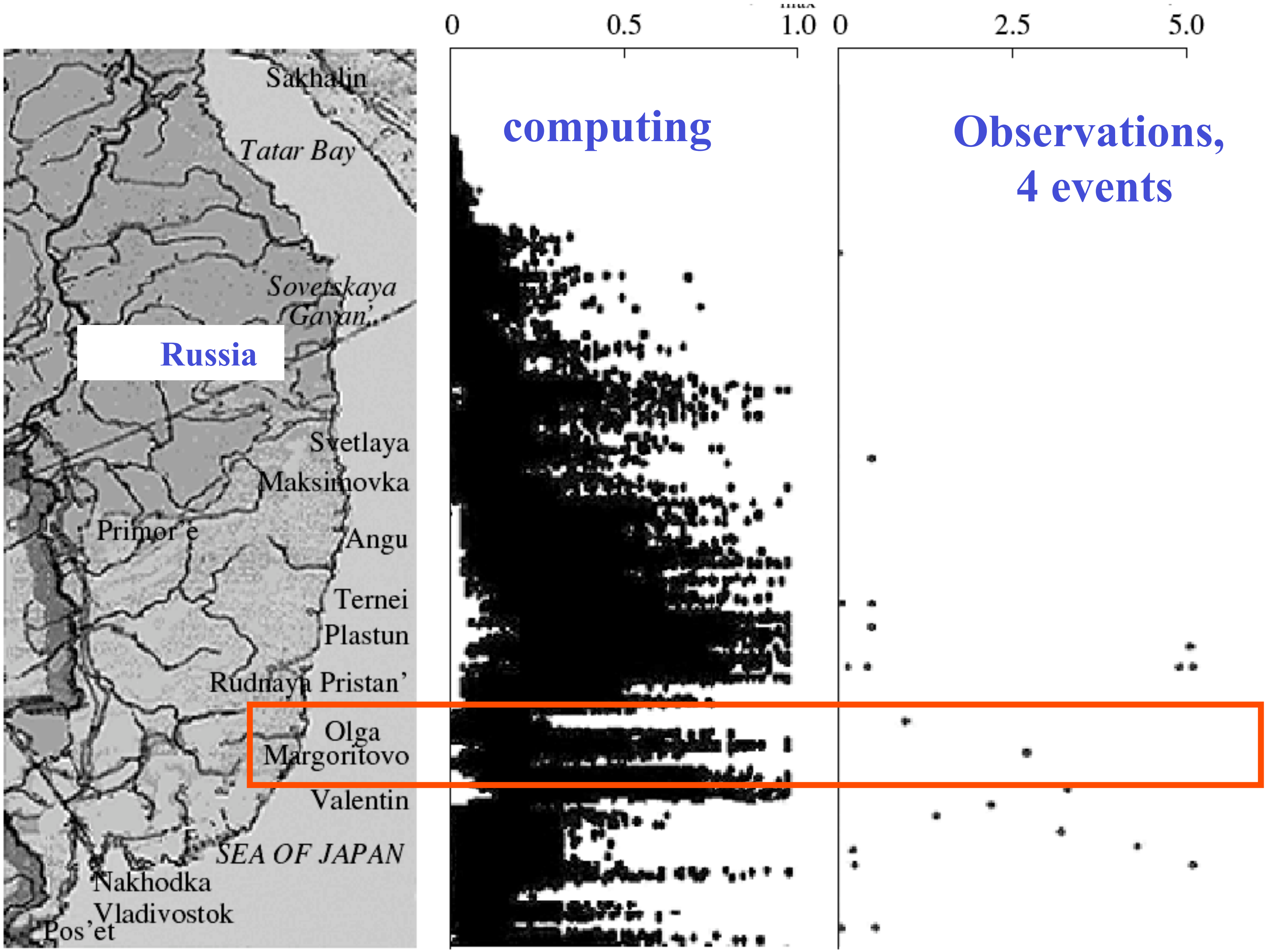
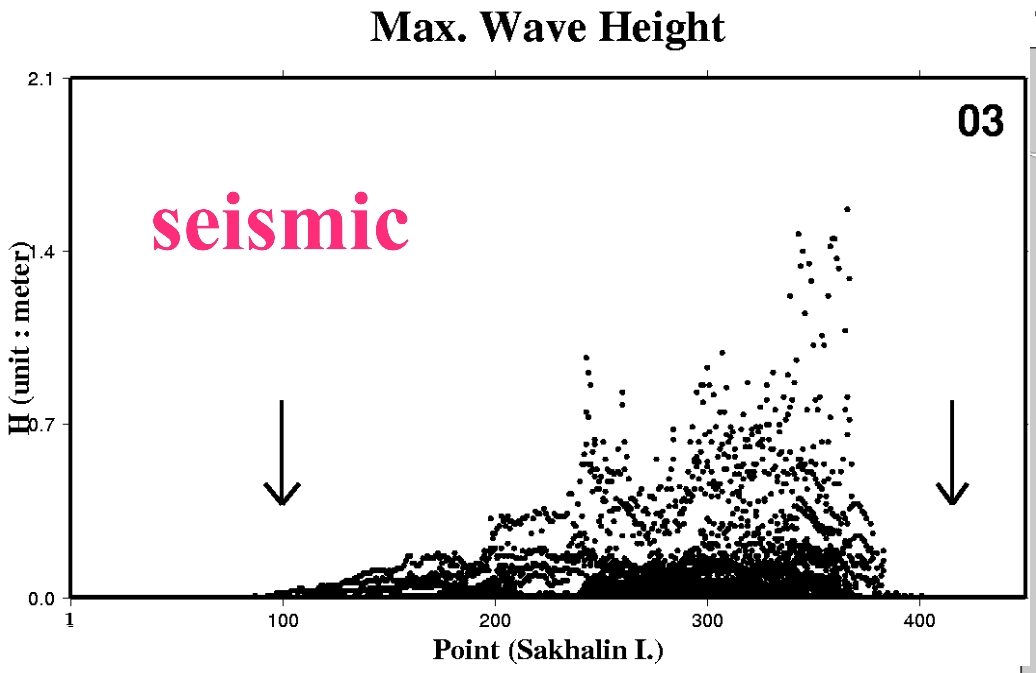
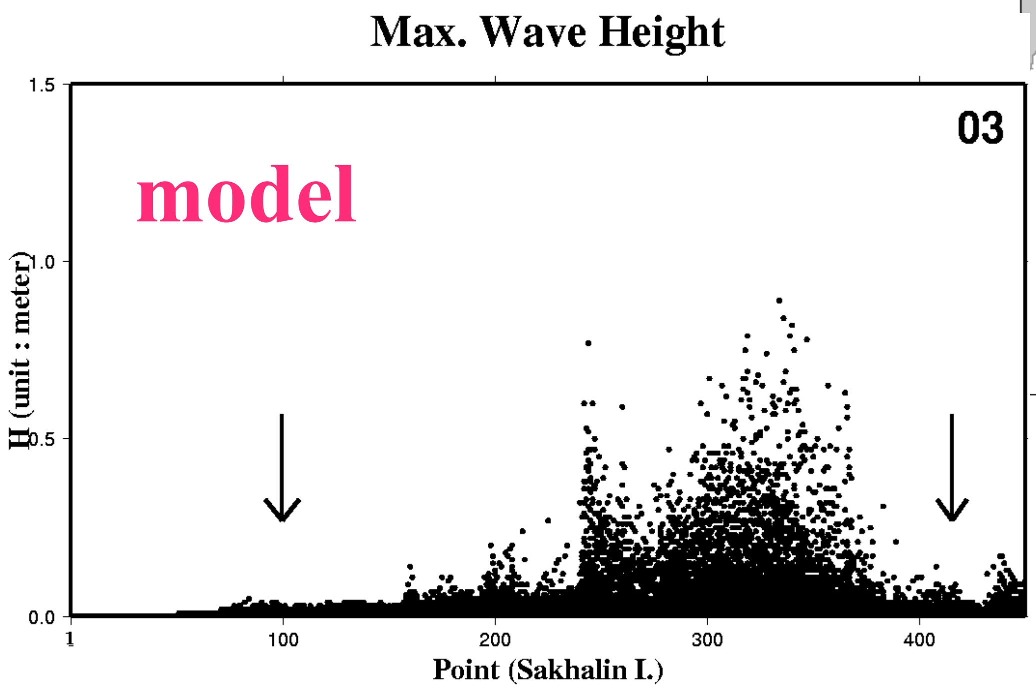
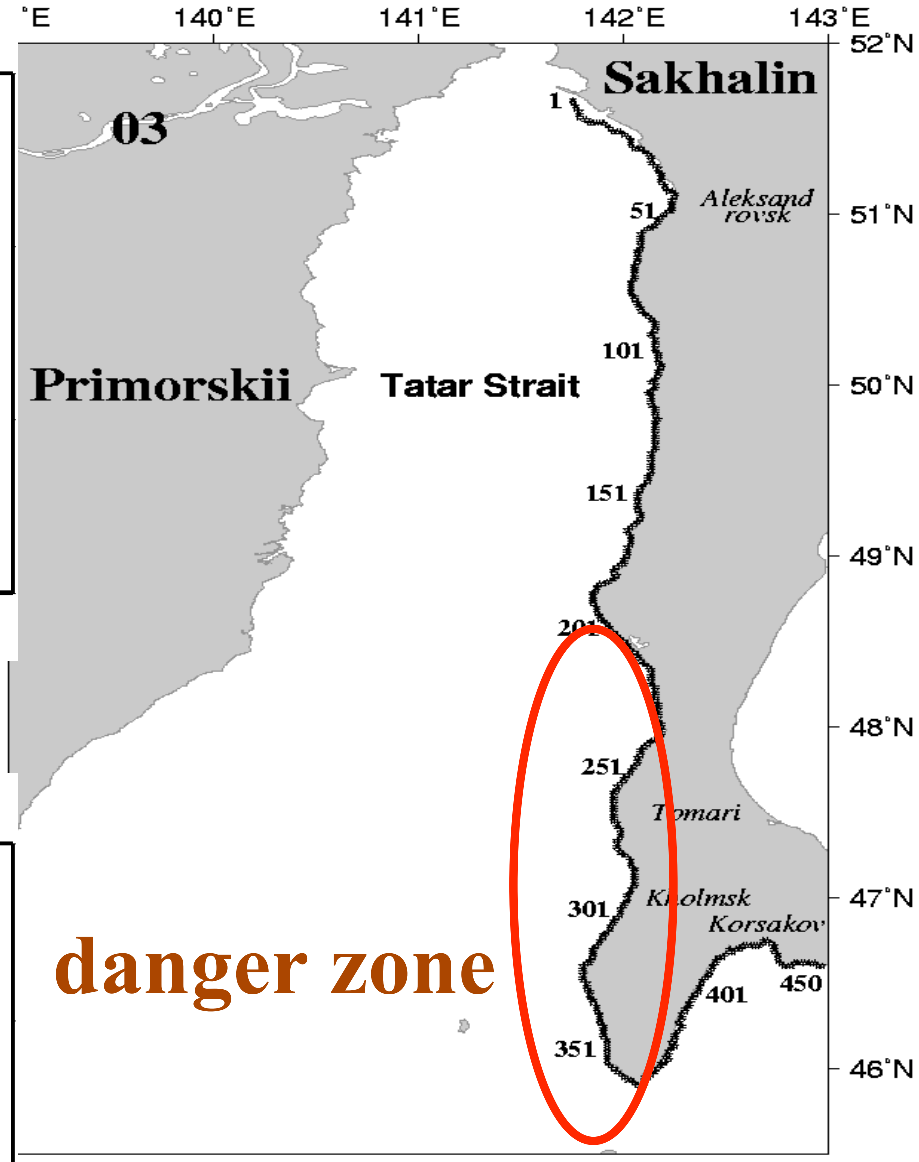


Fig. 7. Comparison of the calculated tsunami height distributions with the observed data.


Max. Wave Height
03
seismic
H (unit : meter)
2.1
1.4
0.7
0.0
1
100
200
300
400
Point (Sakhalin I.)

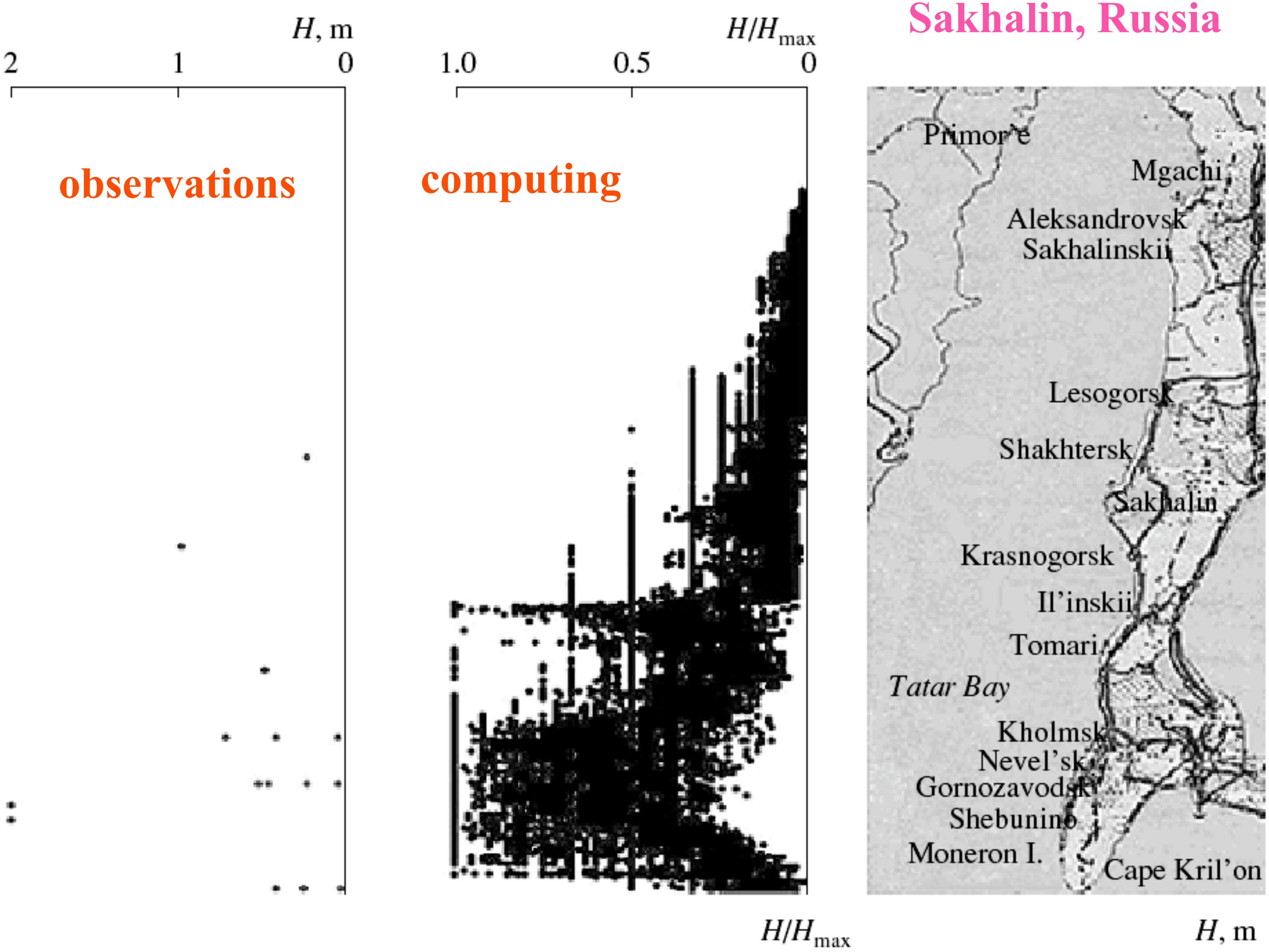

Max. Wave Height
03
model
H (unit : meter)
1.5
1.0
0.5
0.0
1
100
200
300
400
Point (Sakhalin I.)

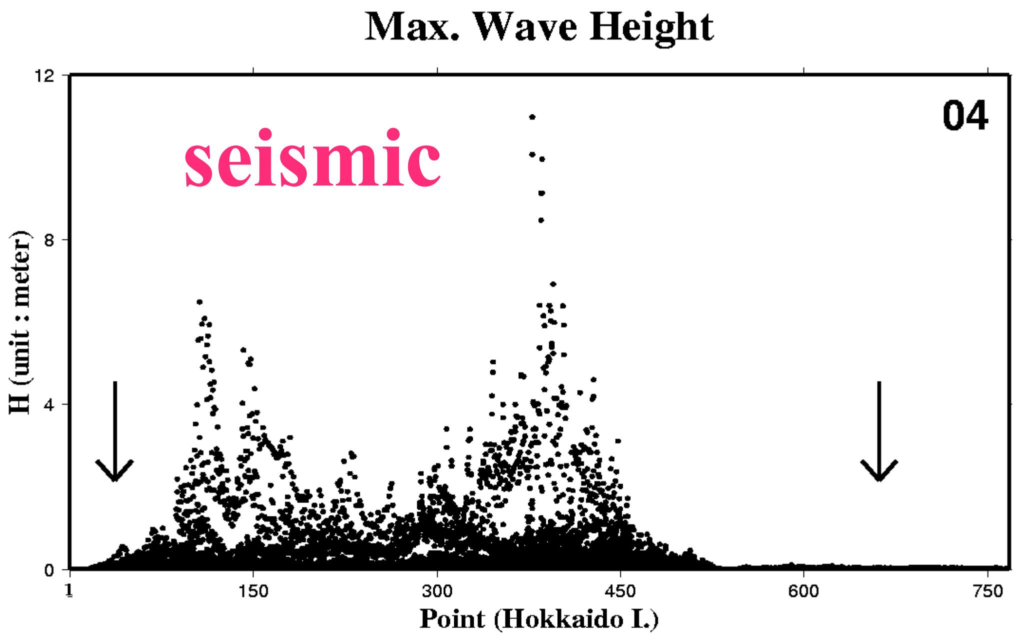

°E
140°E
141°E
142°E
143°E
52°N
51°N
50°N
49°N
48°N
47°N
46°N
Sakhalin
03
Primorskii
Tatar Strait
Aleksandrovsk
Tomari
Kholmsk
Korsakov
danger zone
1
51
101
151
201
251
301
351
401
450

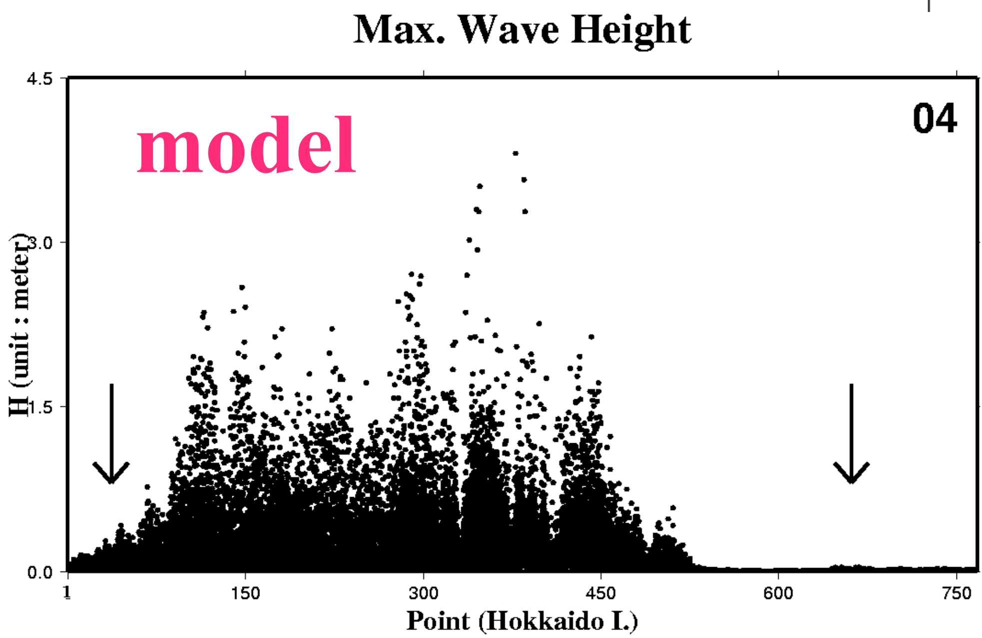
Sakhalin, Russia

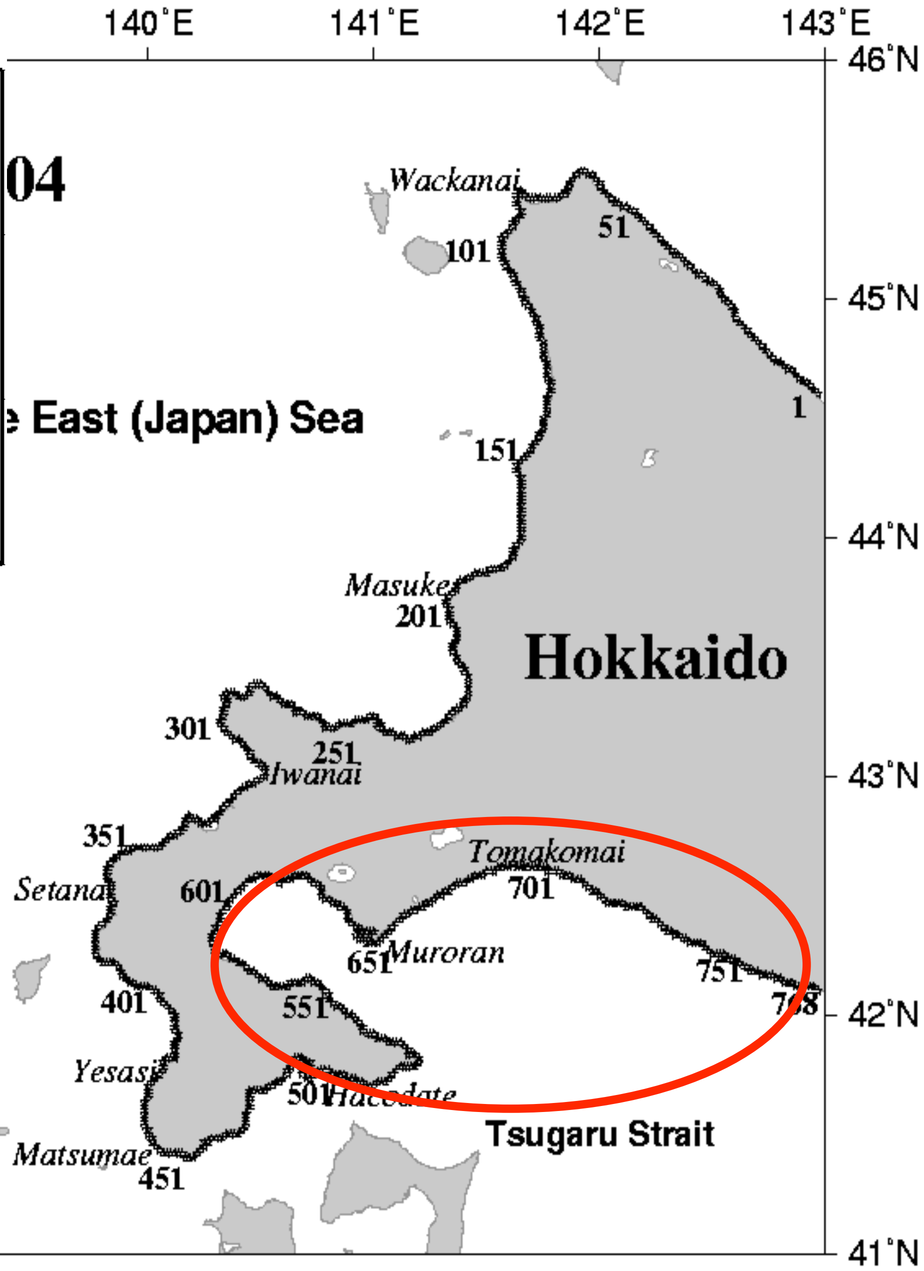
observations

computing

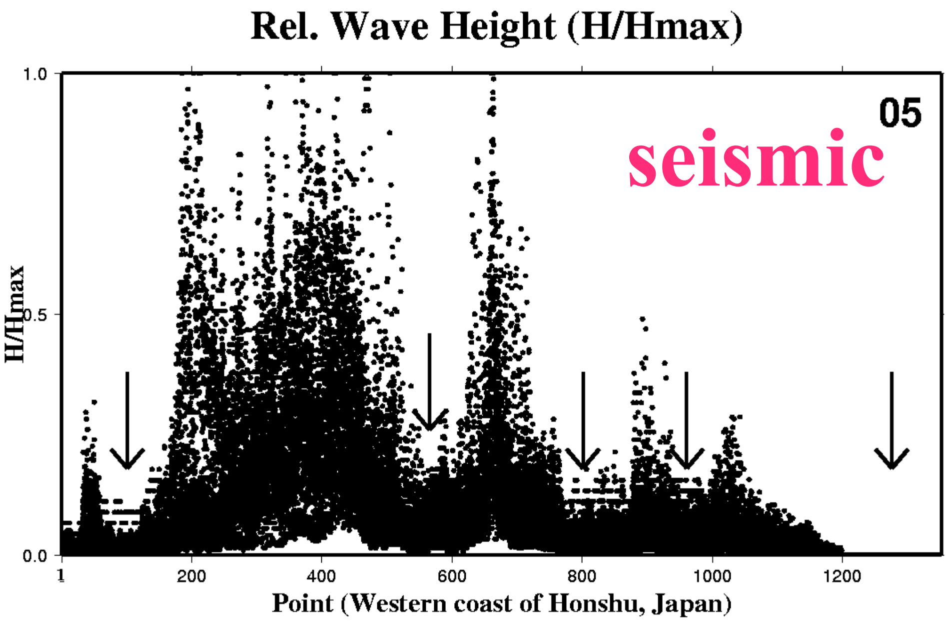




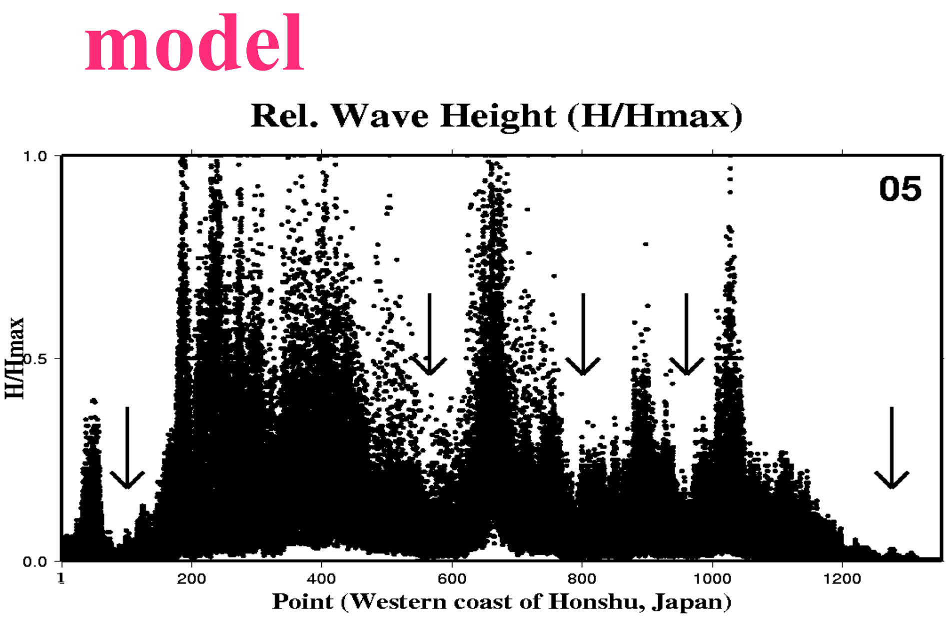


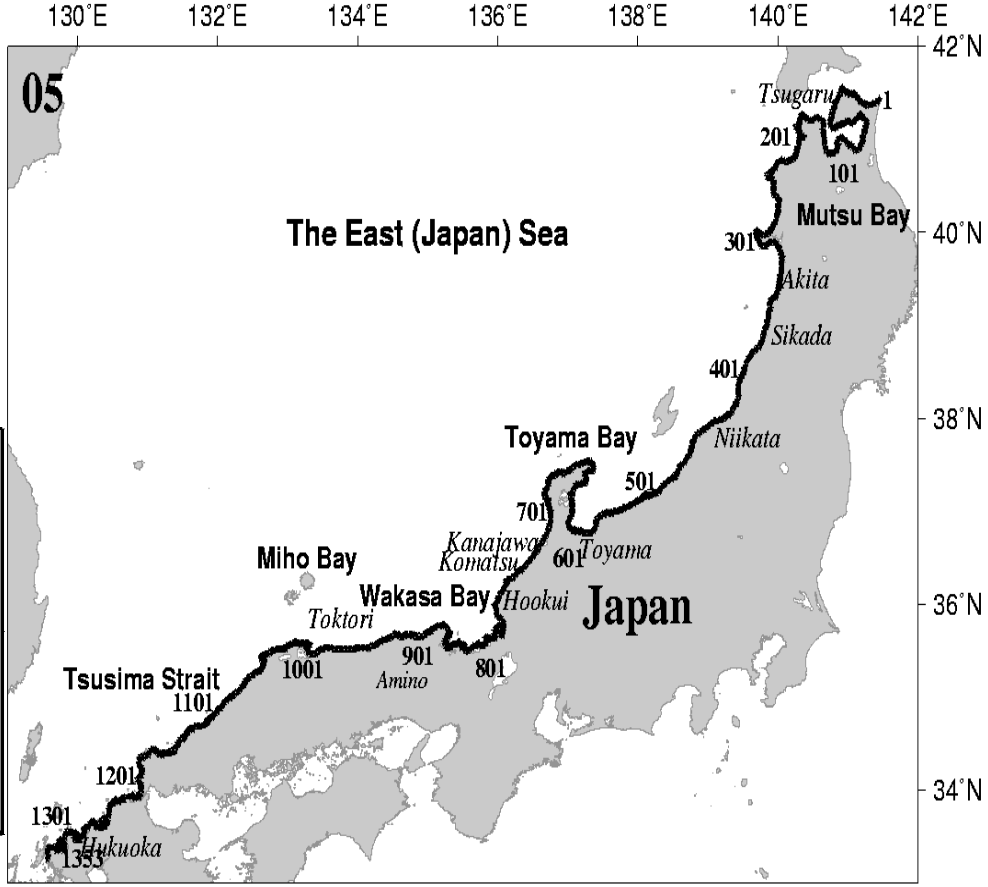


protected zone

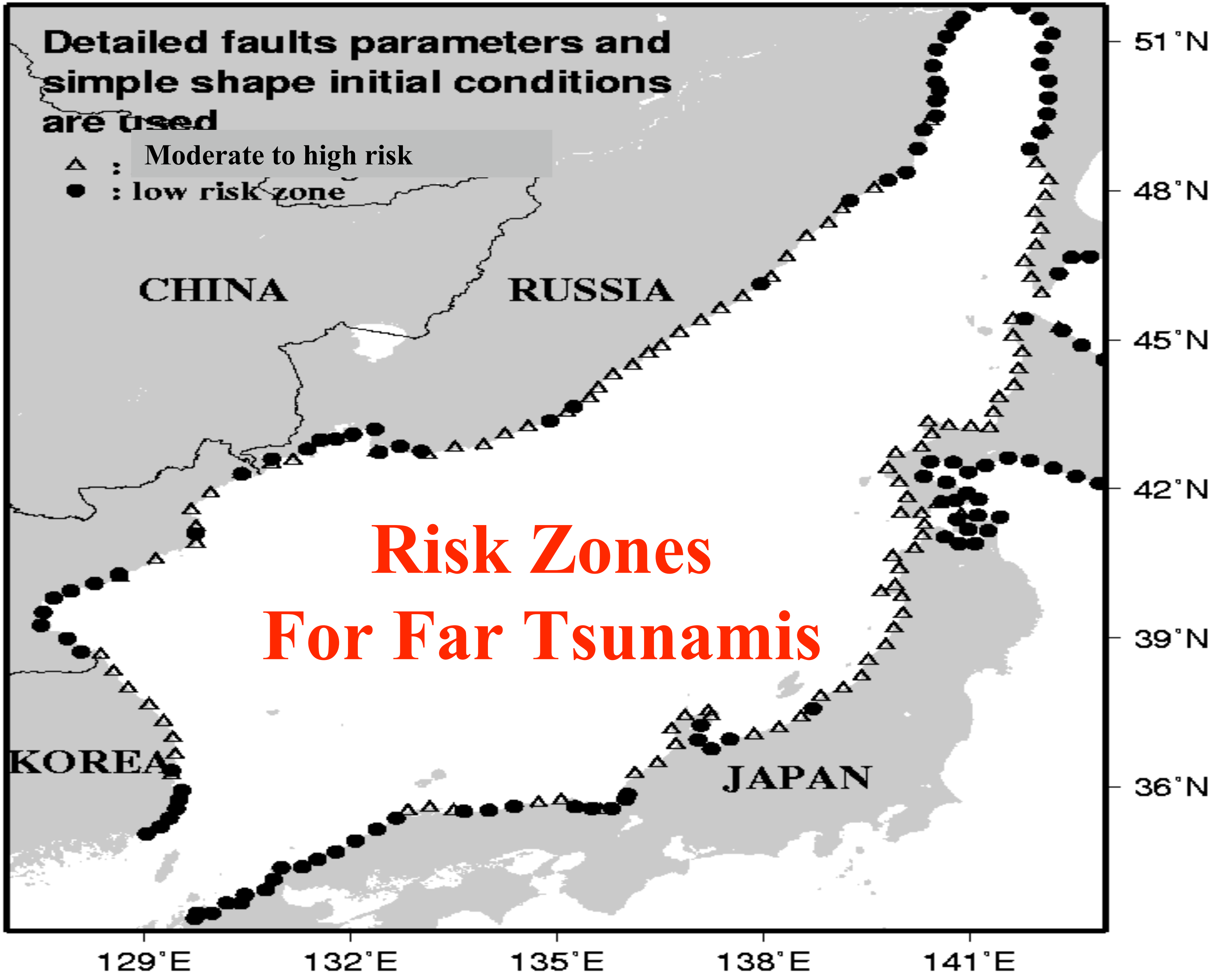


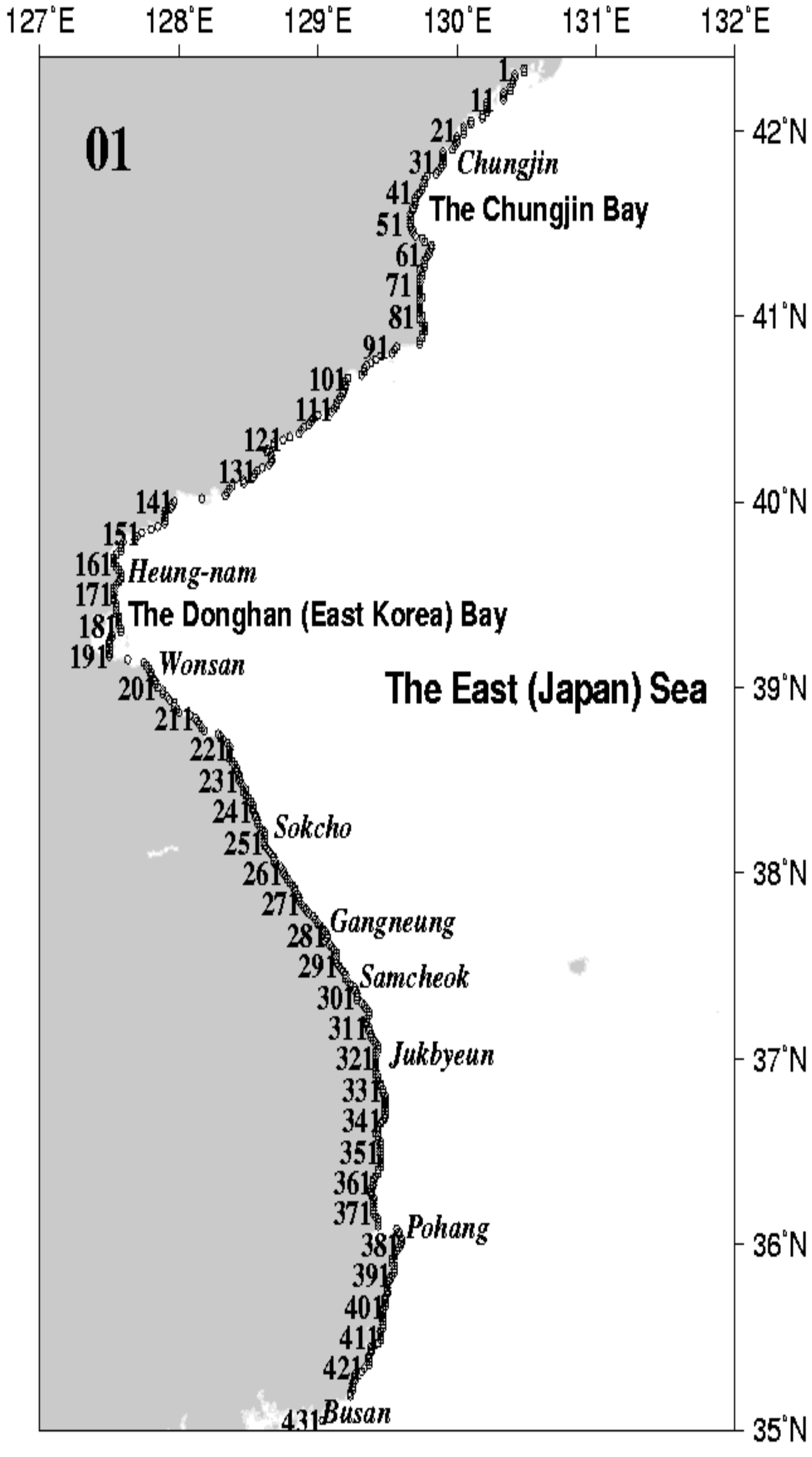
It is necessary to compare with Japanese data! (next step)



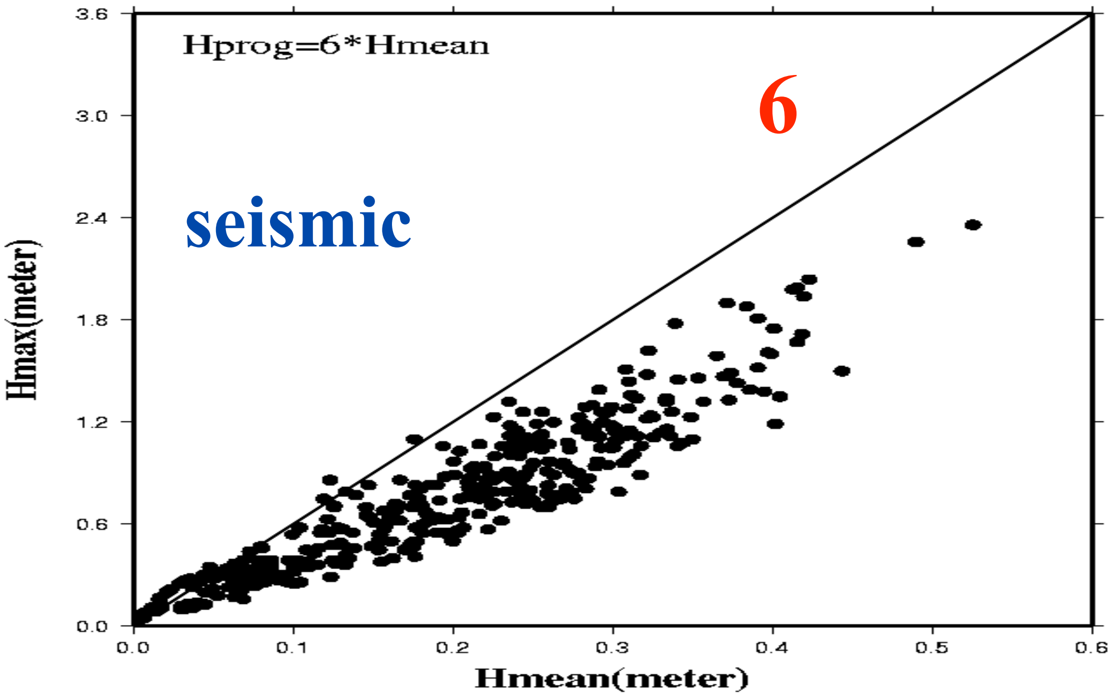


Risk Zones For Far Tsunamis

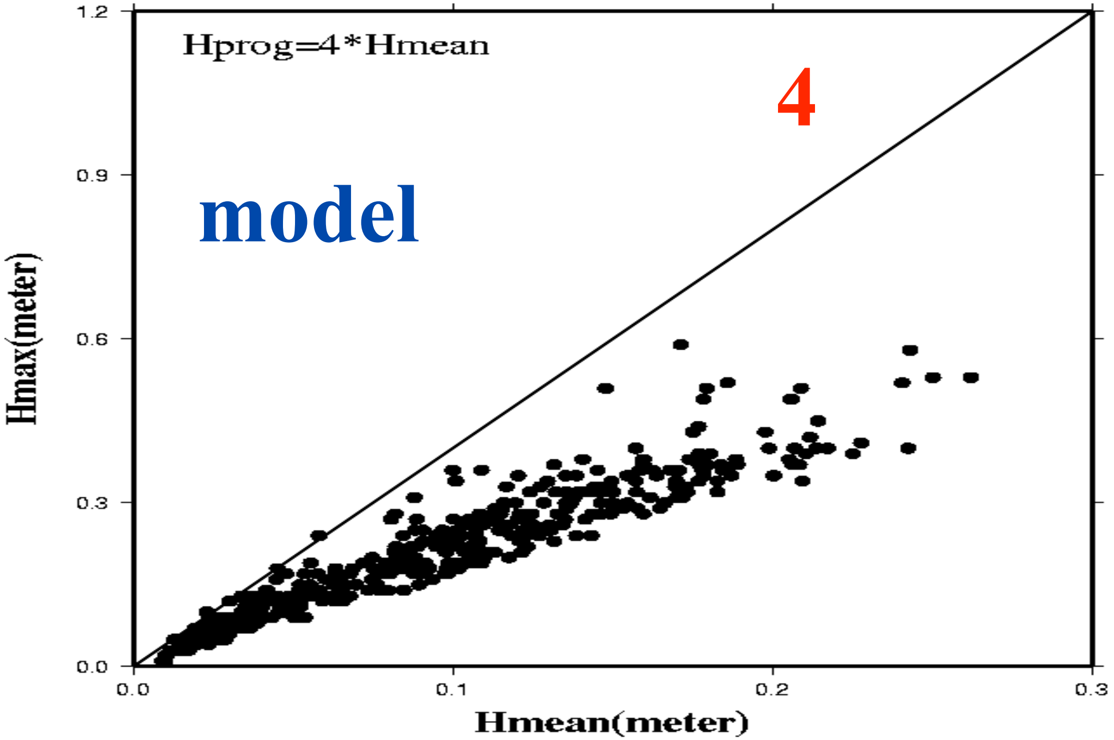




127°E
128°E
129°E
130°E
131°E
132°E
42°N
41°N
40°N
39°N
38°N
37°N
36°N
35°N
01
1
11
21
31
Chungjin
41
The Chungjin Bay
51
61
71
81
91
101
111
121
131
141
151
161
Heung-nam
171
The Donghan (East Korea) Bay
181
191
Wonsan
201
The East (Japan) Sea
211
221
231
241
Sokcho
251
261
271
Gangneung
281
291
Samcheok
301
311
321
Jukbyeun
331
341
351
361
371
Pohang
381
391
401
411
421
431
Busan

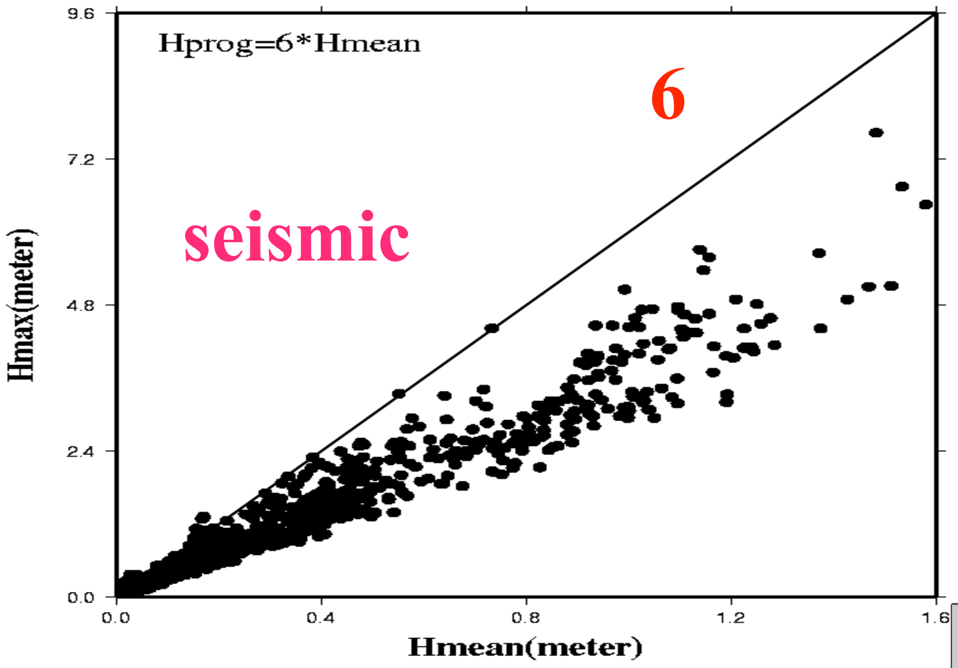


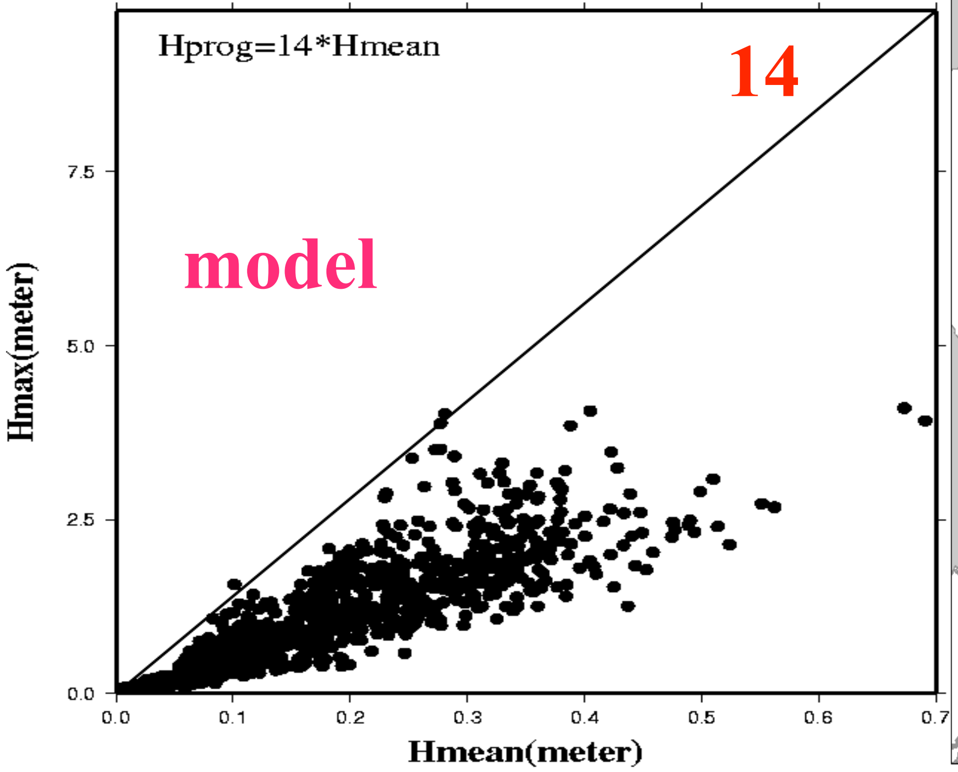
Hprog=6*Hmean
6
seismic
Hmax(meter)
Hmean(meter)
0.0
0.6
1.2
1.8
2.4
3.0
3.6
0.0
0.1
0.2
0.3
0.4
0.5
0.6

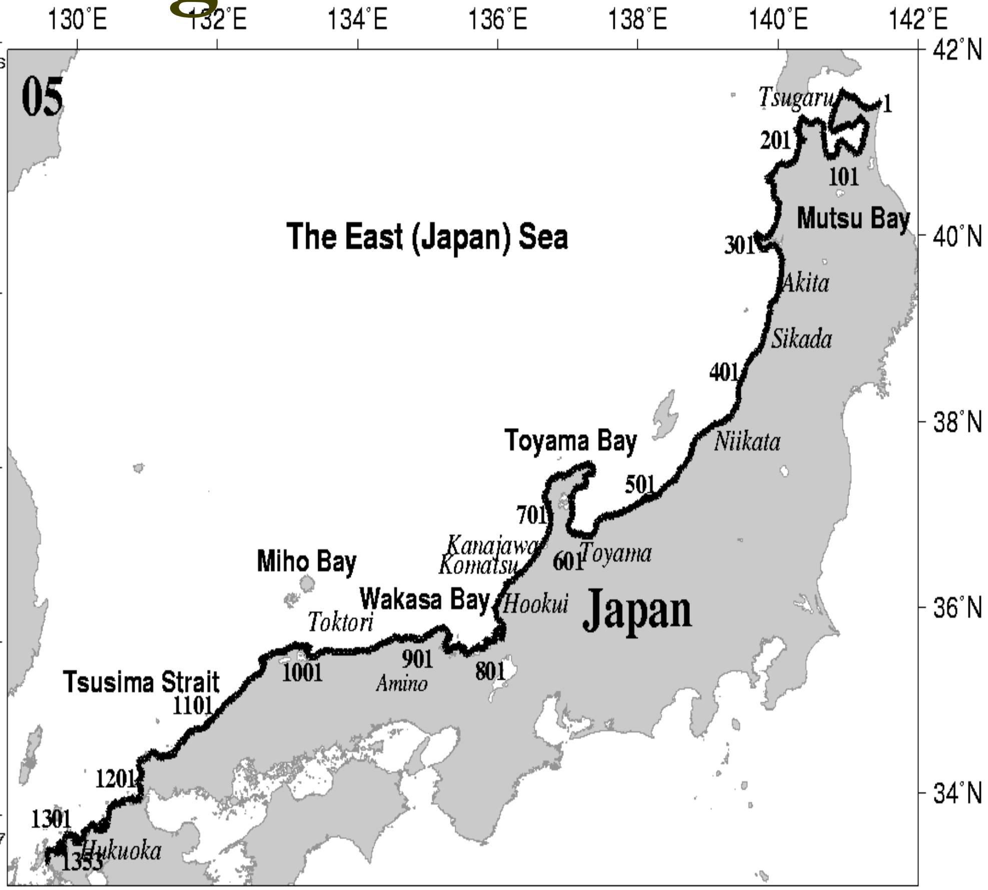


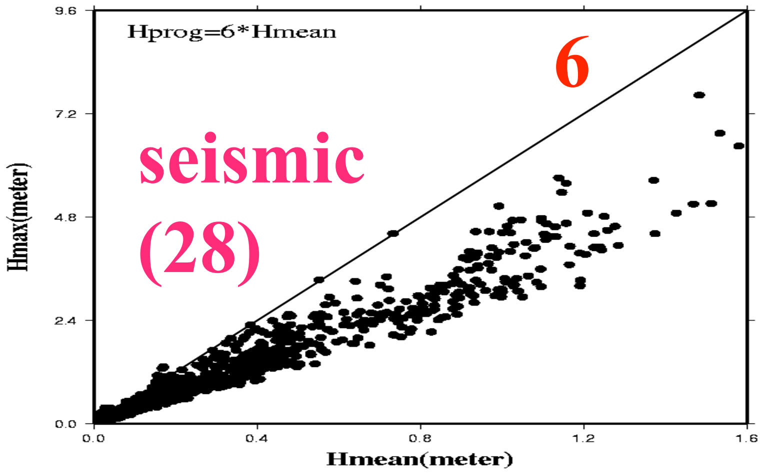
Hprog=4*Hmean
4
model
Hmax(meter)
Hmean(meter)
0.0
0.3
0.6
0.9
1.2
0.0
0.1
0.2
0.3

Large Deviation: Event Numbers? Source Features? Regional Features?

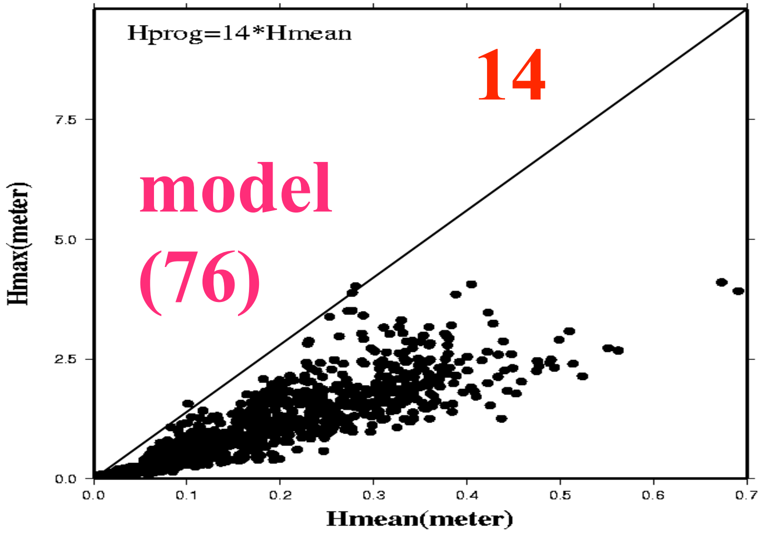








Large Deviation: Event Numbers?



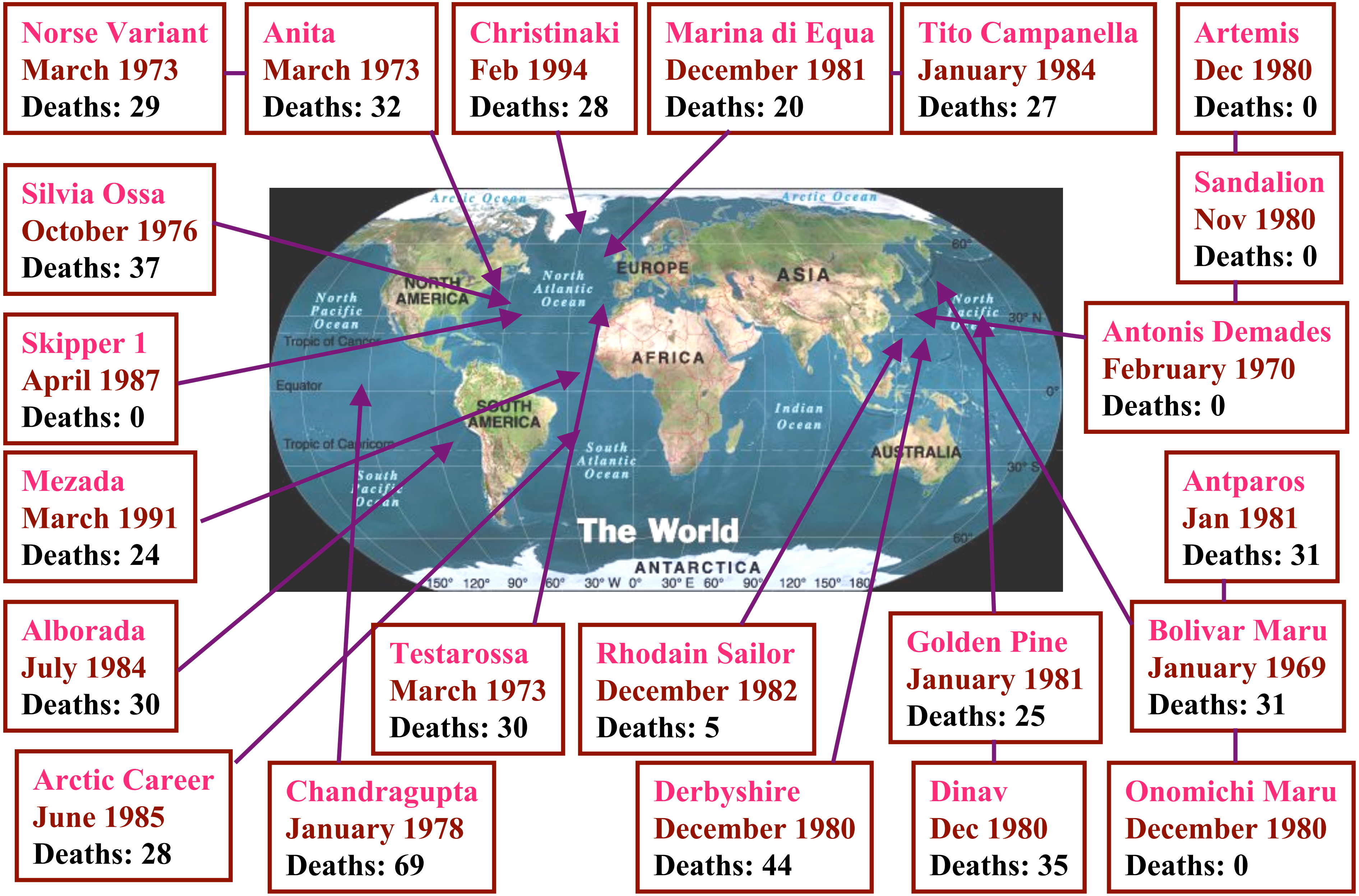
Increase of Event Number leads to increase of H_{max}

↓

Classical Problem of Freak Waves Phenomenon

But Increase of Event Number Corresponds to Long History (>1000 years?)

22 supercarriers were lost for 1968-1994 (Deaths:525)



Norse Variant
March 1973
Deaths: 29

Anita
March 1973
Deaths: 32

Christinaki
Feb 1994
Deaths: 28

Marina di Equa
December 1981
Deaths: 20

Tito Campanella
January 1984
Deaths: 27

Artemis
Dec 1980
Deaths: 0

Silvia Ossa
October 1976
Deaths: 37

Skipper 1
April 1987
Deaths: 0

Mezada
March 1991
Deaths: 24

Alborada
July 1984
Deaths: 30

Arctic Career
June 1985
Deaths: 28

Sandalion
Nov 1980
Deaths: 0

Antonis Demades
February 1970
Deaths: 0

Antparos
Jan 1981
Deaths: 31

Bolivar Maru
January 1969
Deaths: 31

Chandragupta
January 1978
Deaths: 69

Testarossa
March 1973
Deaths: 30

Rhodain Sailor
December 1982
Deaths: 5

Derbyshire
December 1980
Deaths: 44

Golden Pine
January 1981
Deaths: 25

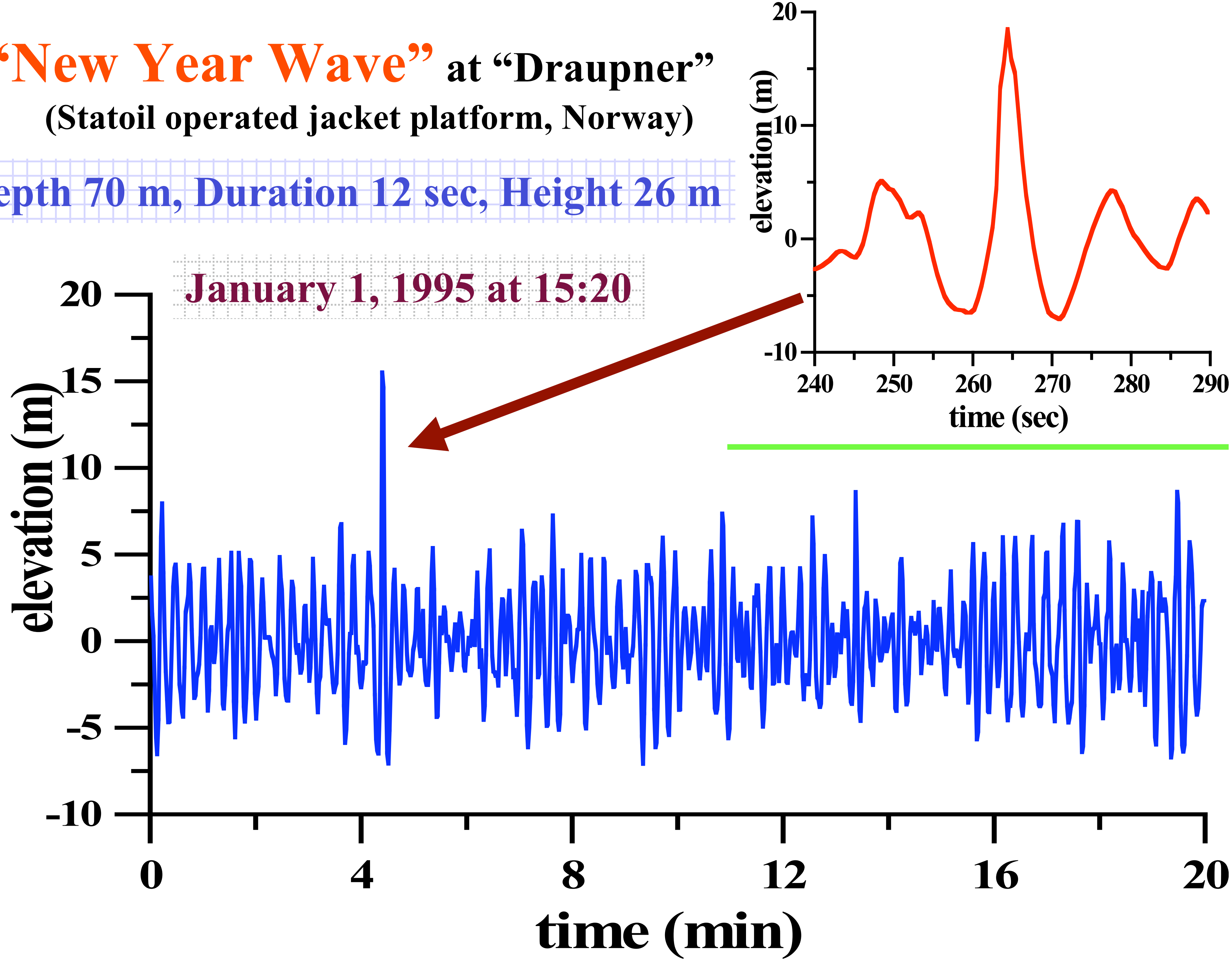
Dinav
Dec 1980
Deaths: 35

Onomichi Maru
December 1980
Deaths: 0

“New Year Wave” at “Draupner”

(Statoil operated jacket platform, Norway)

Depth 70 m, Duration 12 sec, Height 26 m

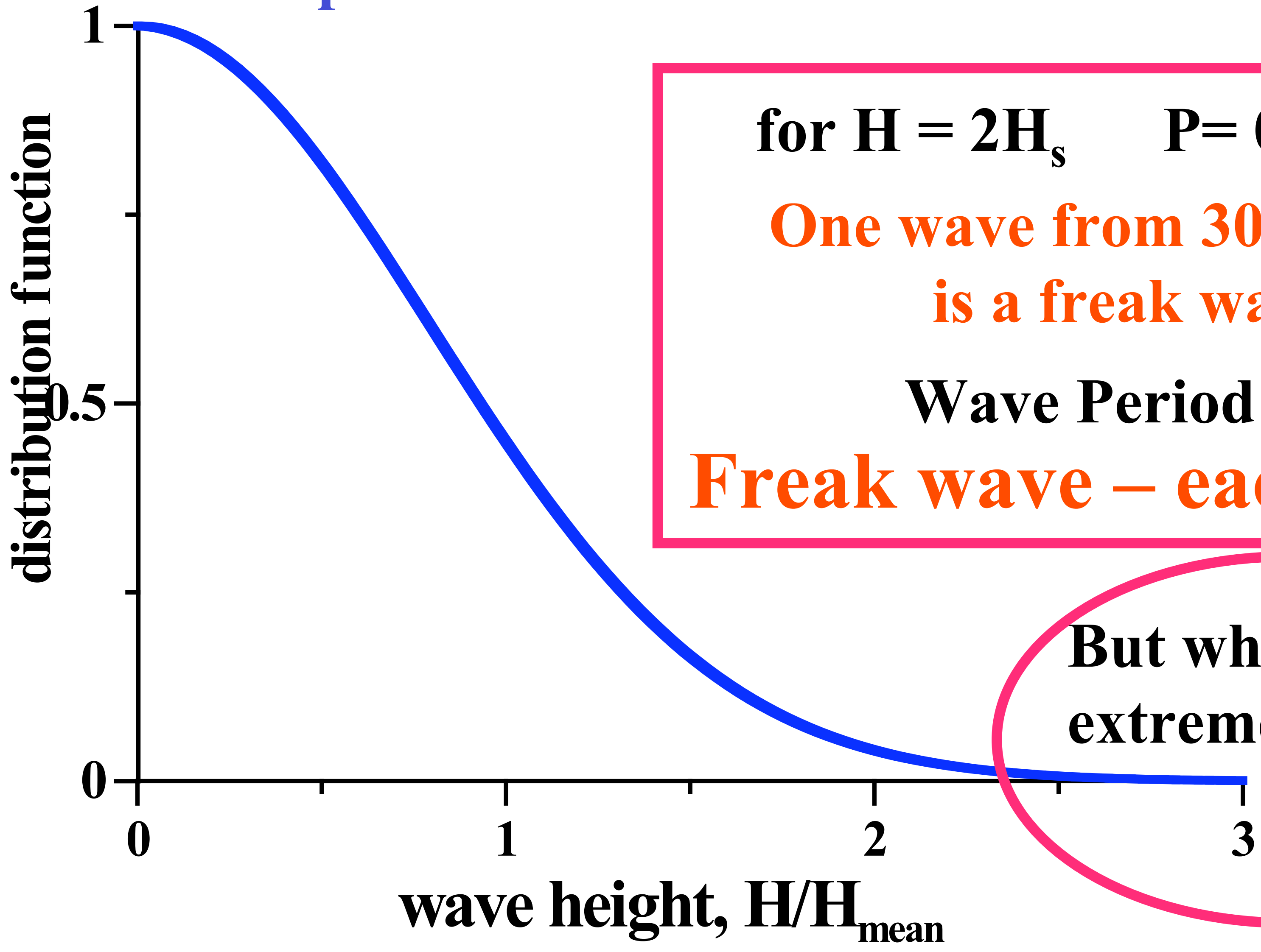


January 1, 1995 at 15:20

“Gaussian” Prediction

Wind wave field has narrow spectrum

$$P(H) = \exp\left(-\frac{2H^2}{H_s^2}\right)$$



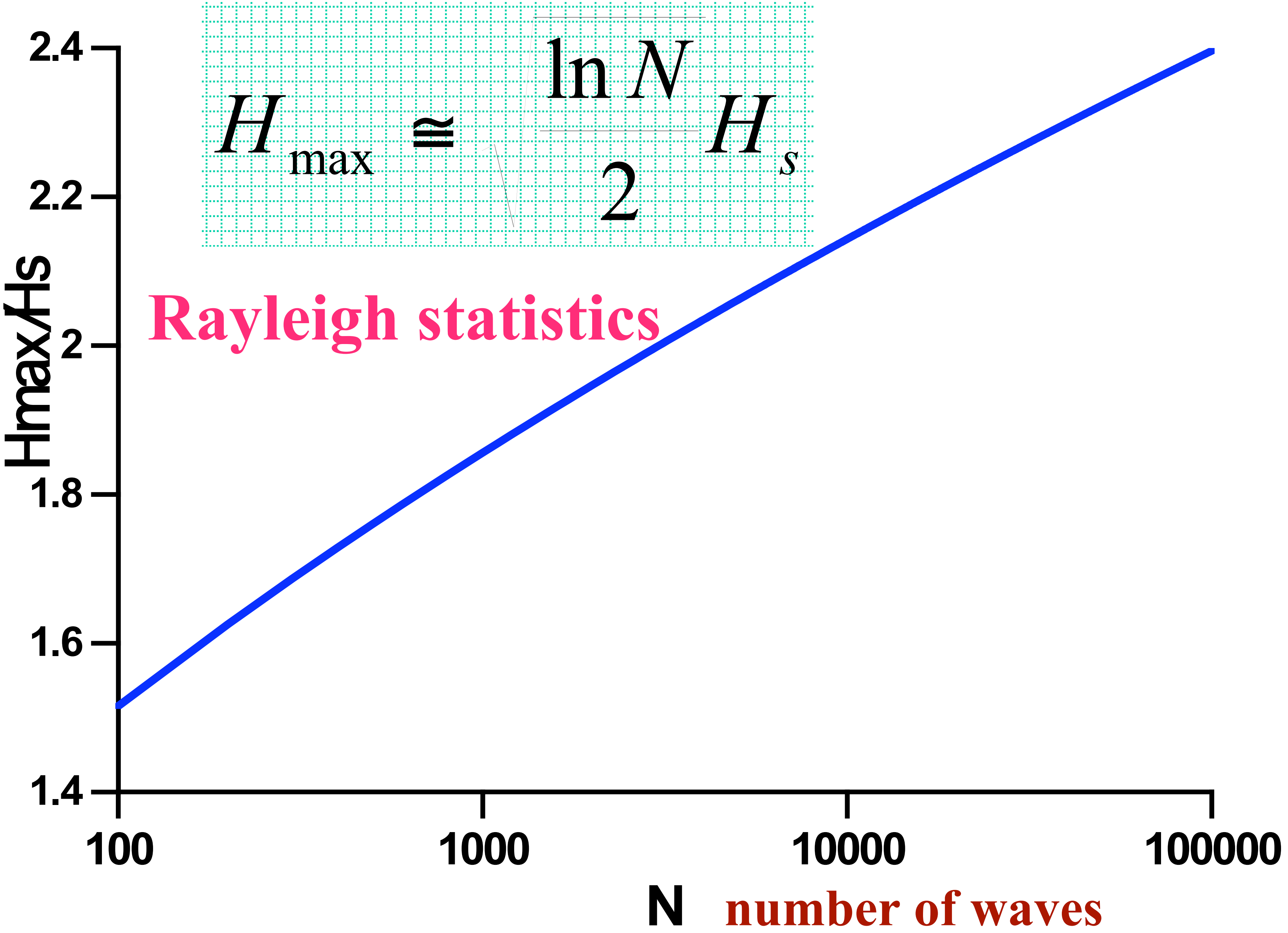
for H = 2H$_s$ P= 0.000336

One wave from 3000 waves is a freak wave!

Wave Period ~ 10 s,

Freak wave – each 10 hr!

But who knows extreme statistics?

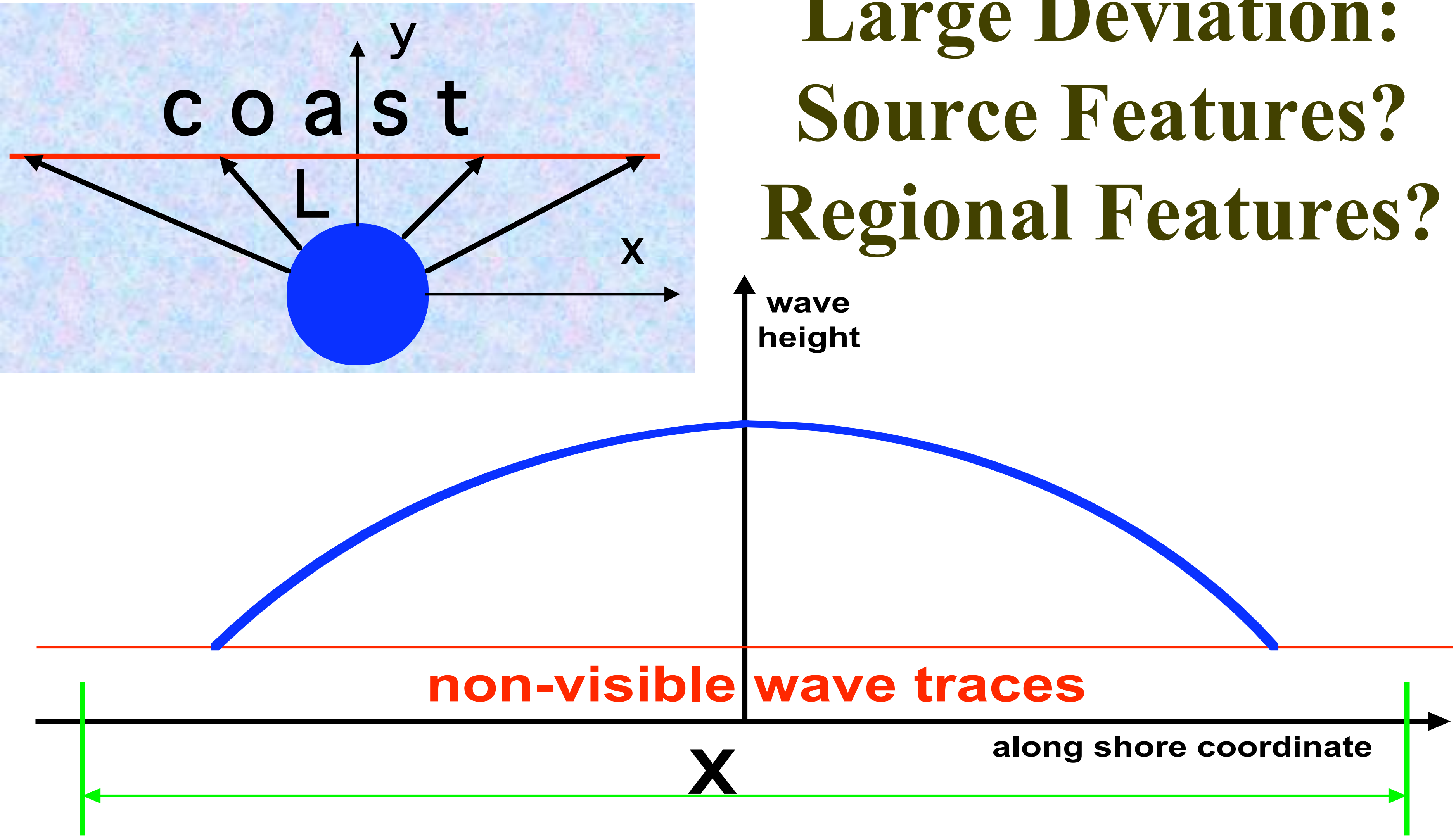


$$H_{\max} \cong \sqrt{\frac{\ln N}{2}}\, H_s$$

Rayleigh statistics

Wave Distribution

Large Deviation:
Source Features?
Regional Features?



H_{mean} decreases with increase X

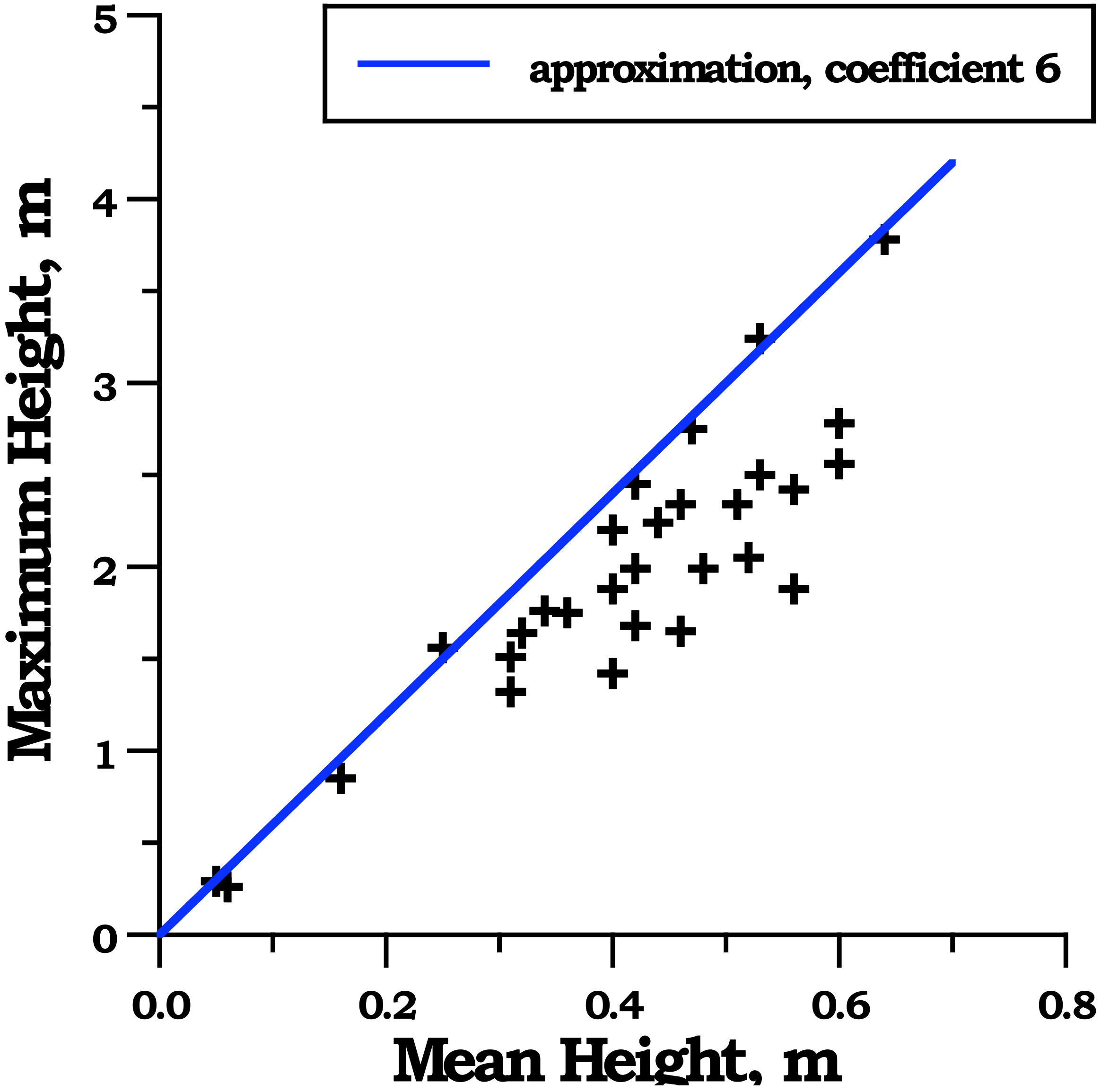
For each point – series contained wave heights

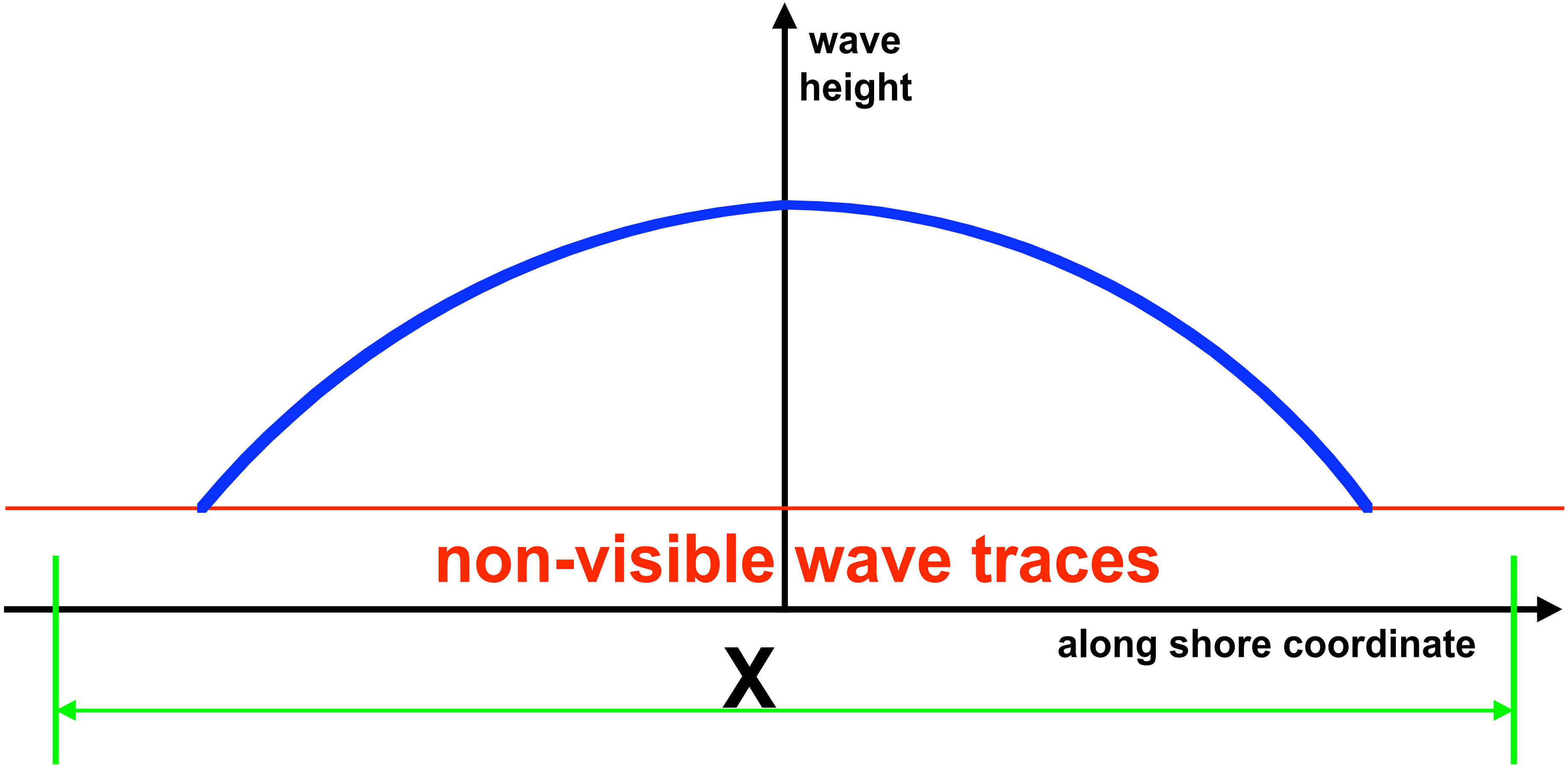
It characterizes by H_{mean} and H_{max}

H_{mean} is stable to variation of earthquake parameters

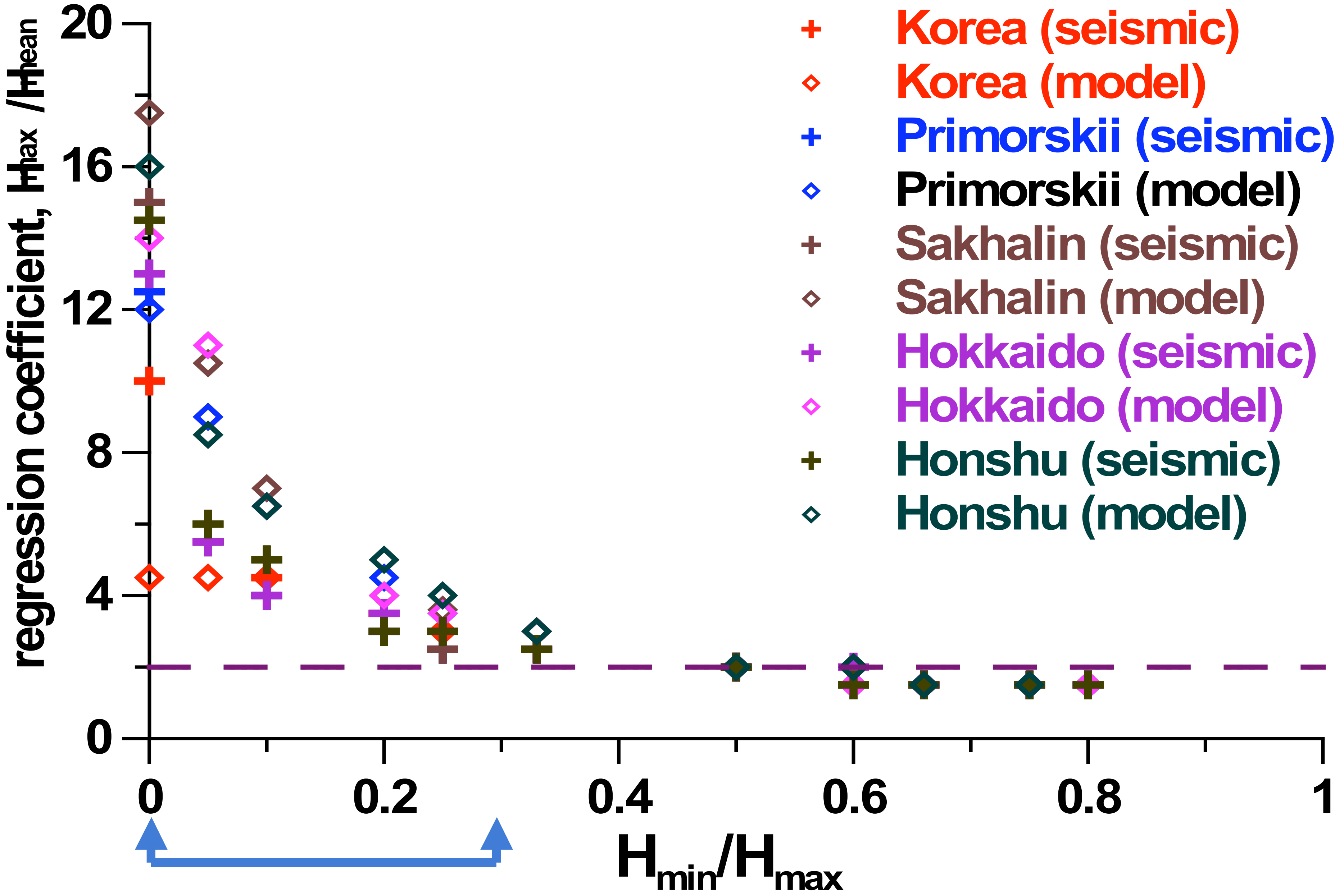
But H_{mean} unstable to length of series!

H_{max} is unstable

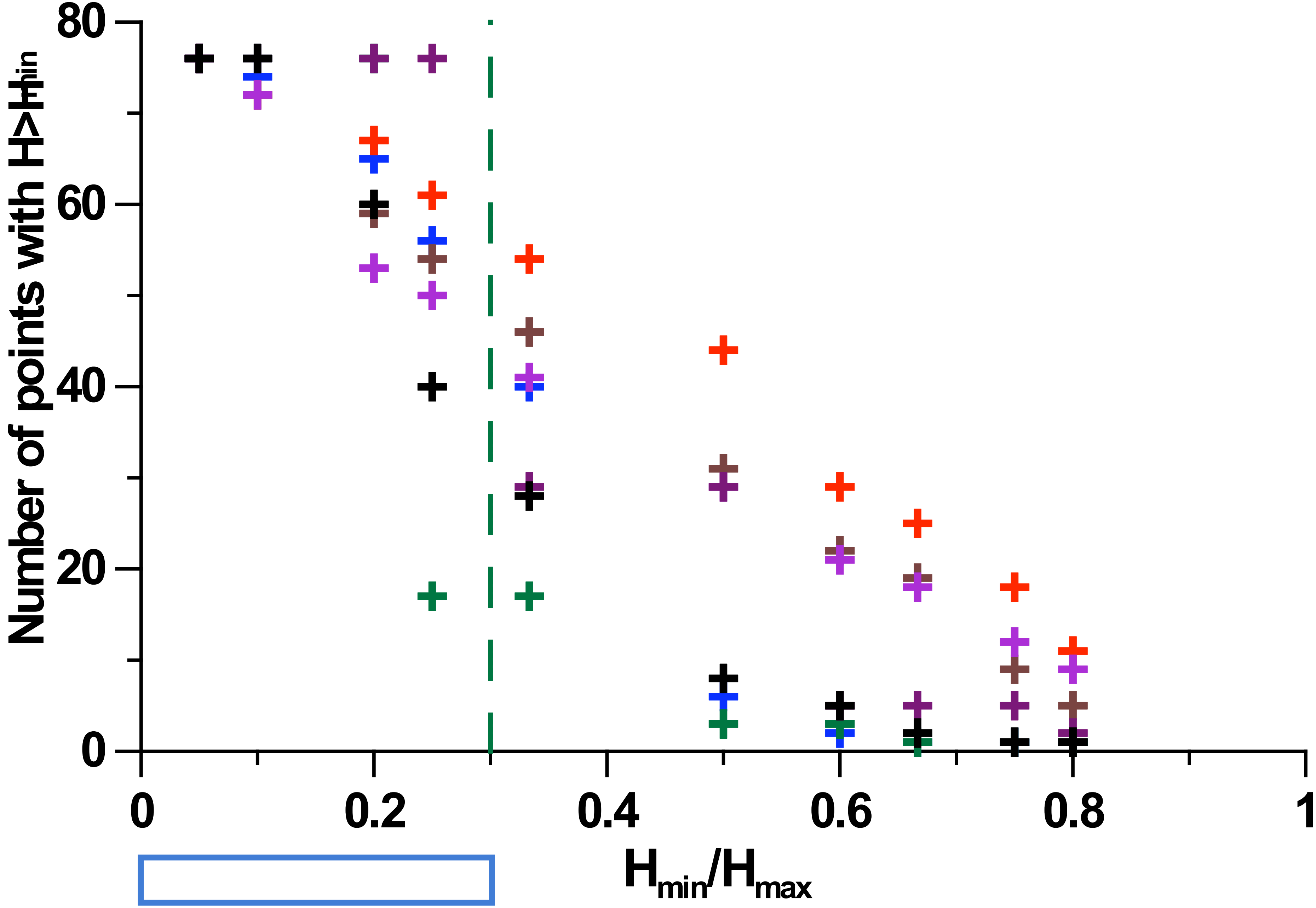




1. Coastal Length should be bounded
2. Wave Heights should exceed H_{min}



Data with H_{min} should be executed



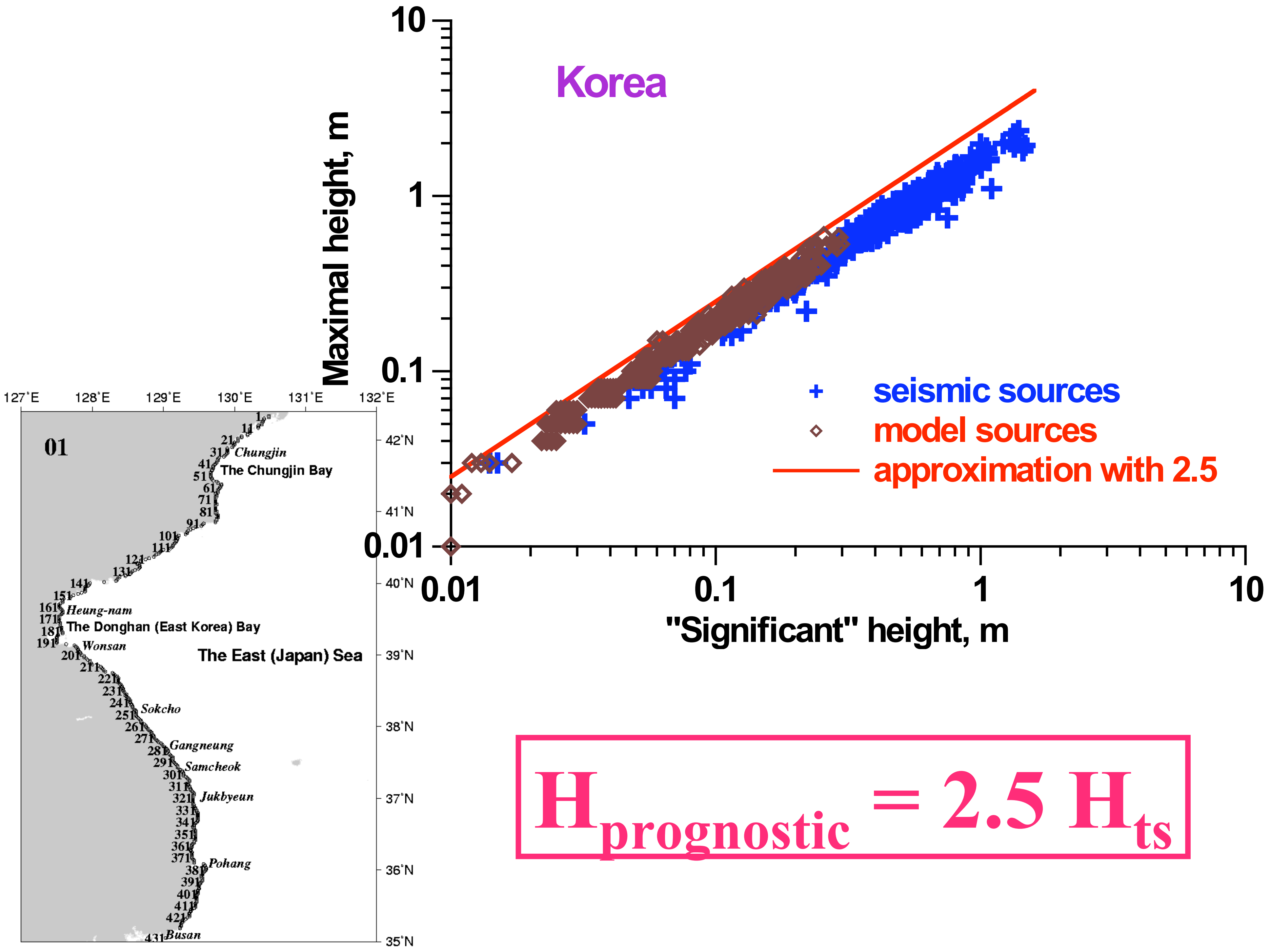
Data with H_{min} should be executed

This procedure is similar to significant wave conception in wind wave field, Hs

Hs is mean value of 1/3 highest waves

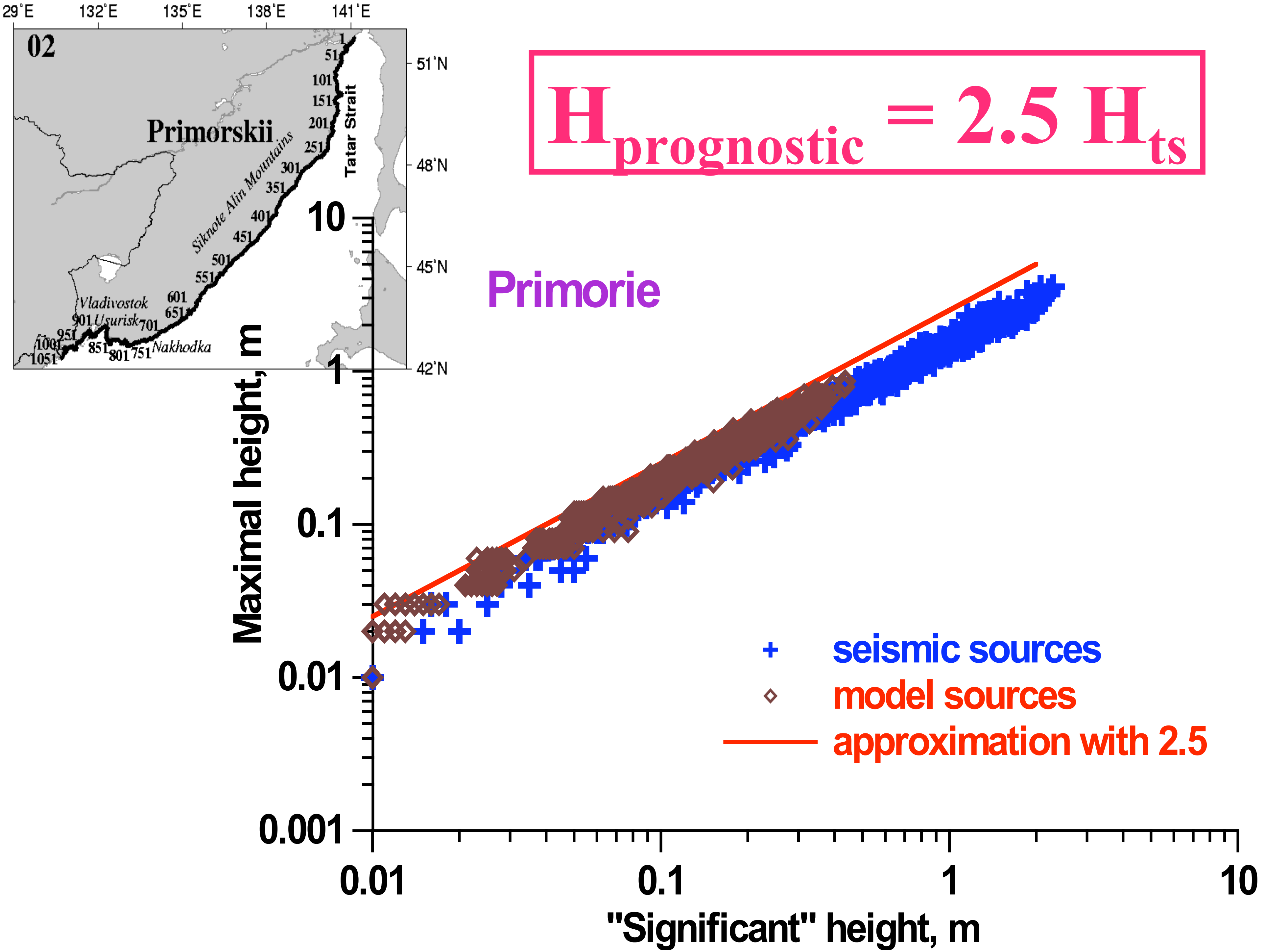
Our suggestion is to find mean value of 2/3 highest waves

$$H_{ts} = \text{Average}\ \{(1/3 - 1)H_{max}\}$$

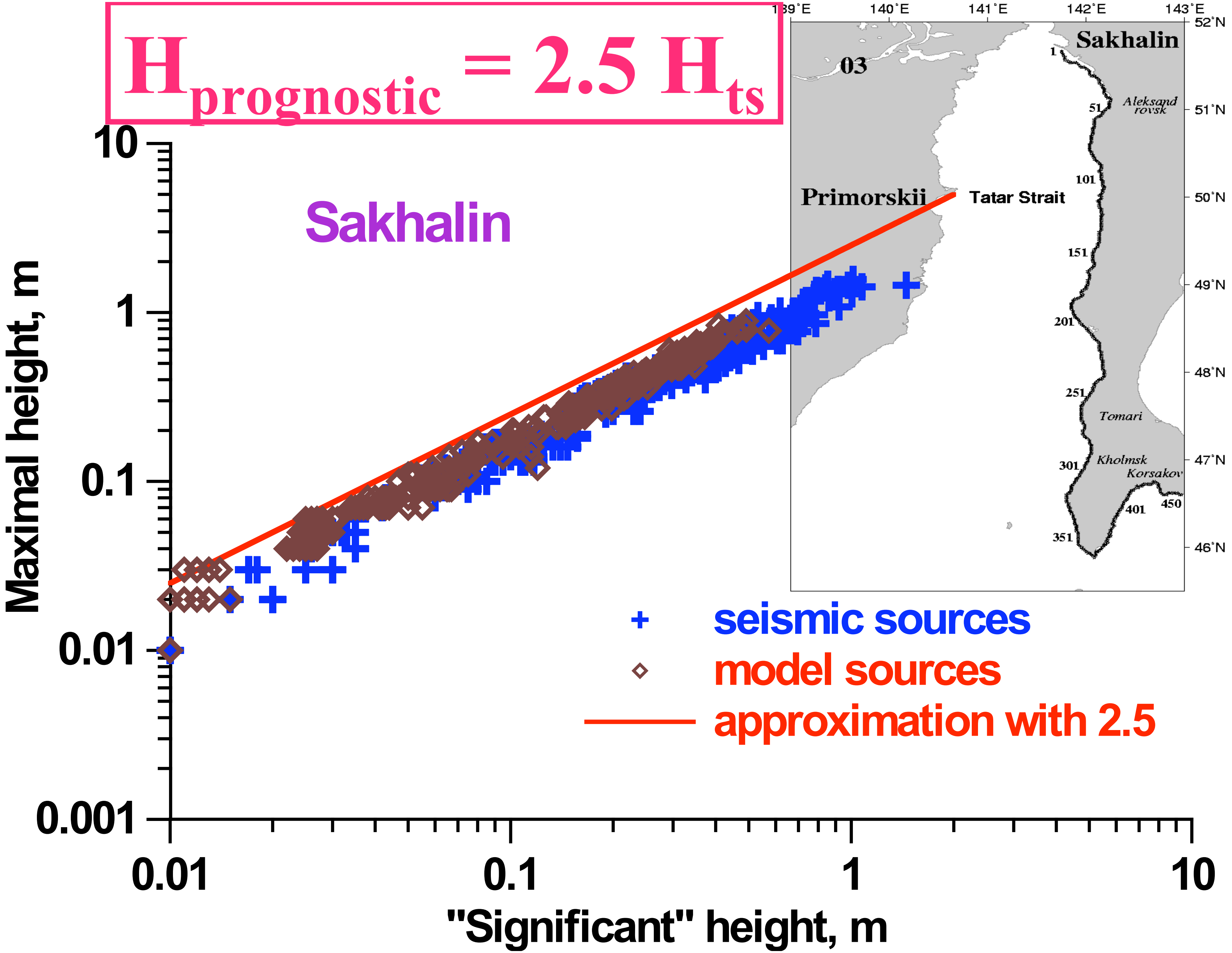


$$\boxed{H_{prognostic} = 2.5\ H_{ts}}$$

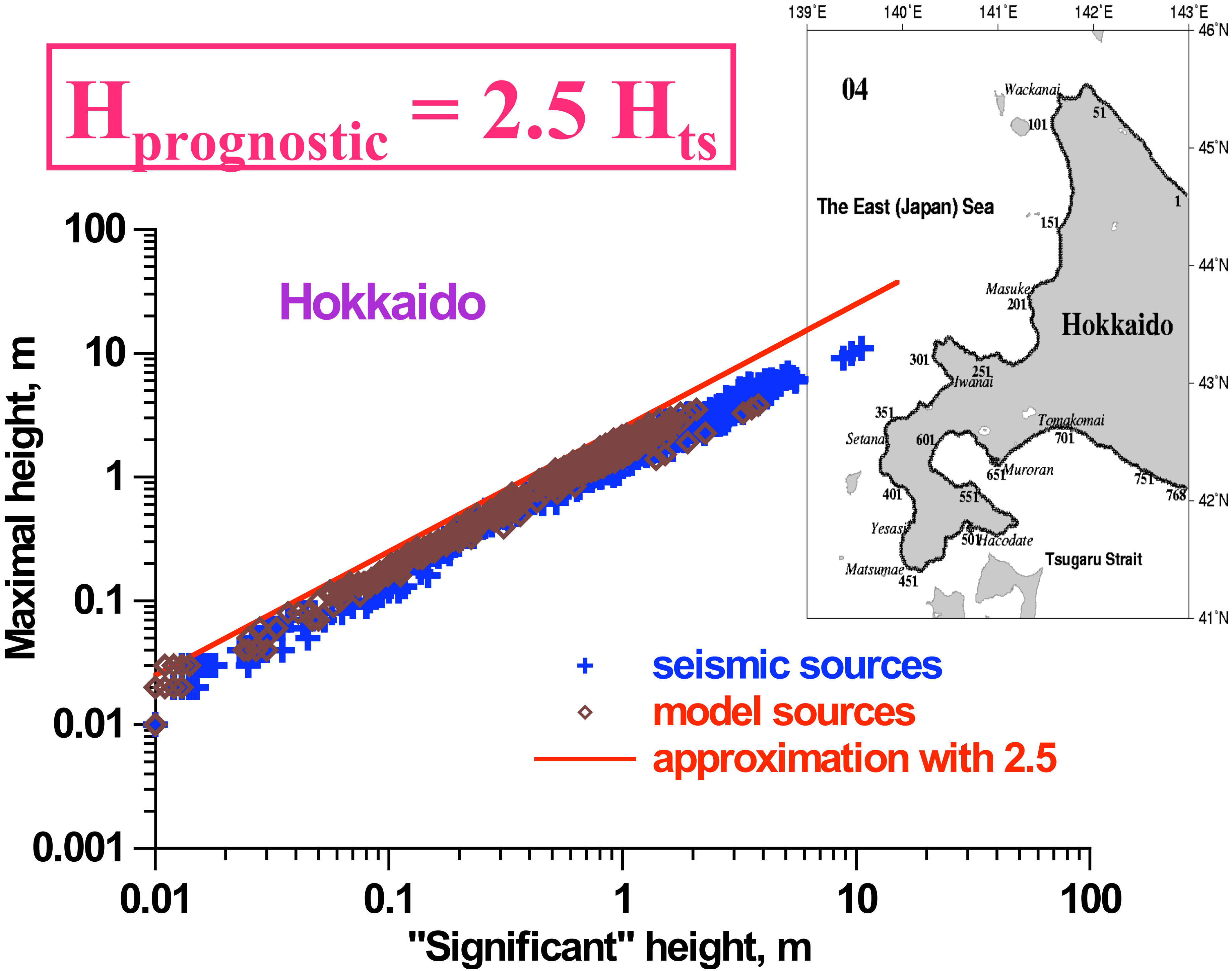
$$H_{prognostic} = 2.5\ H_{ts}$$



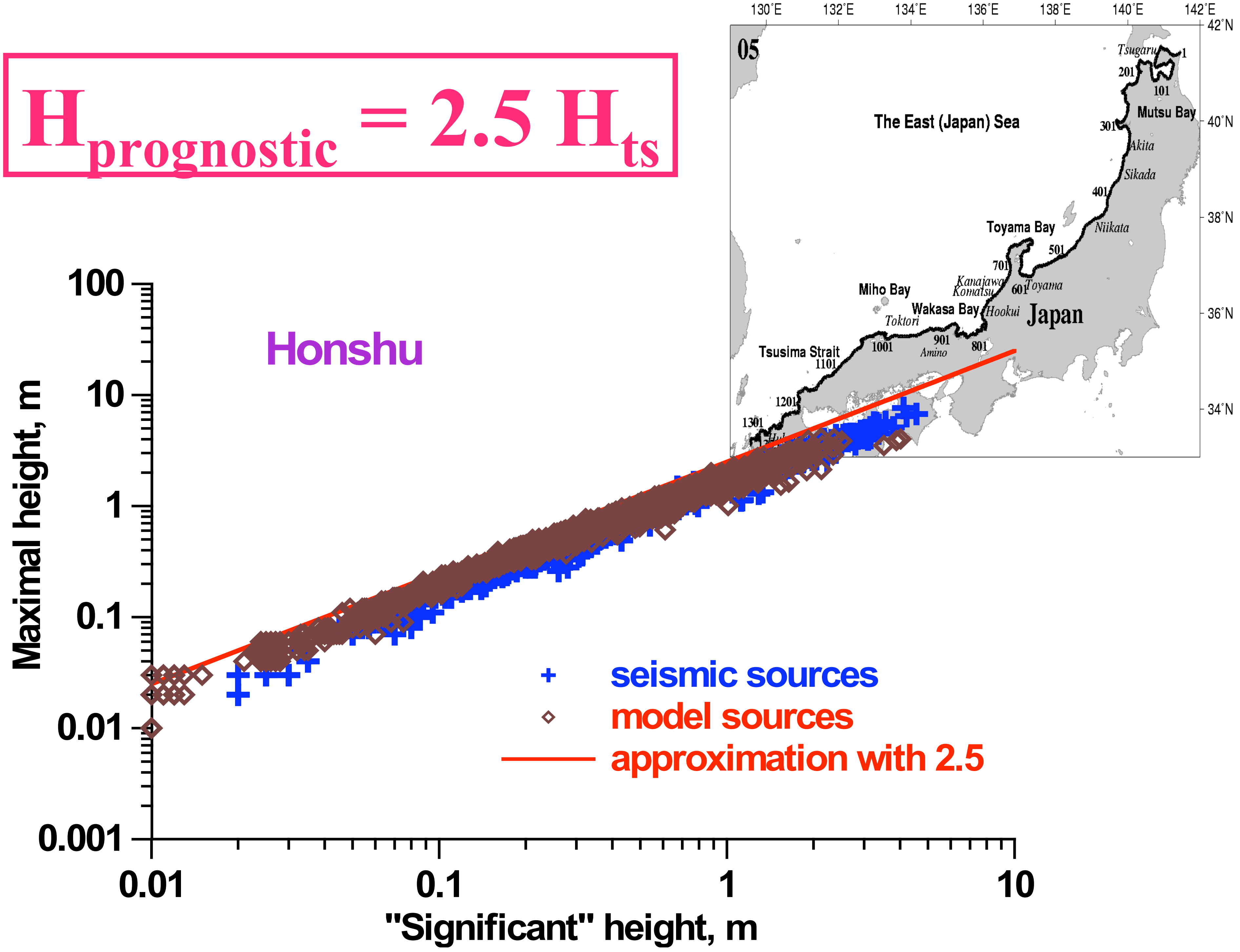
$$H_{prognostic} = 2.5\ H_{ts}$$



$$\boxed{H_{prognostic} = 2.5\ H_{ts}}$$



$$H_{prognostic} = 2.5\ H_{ts}$$



Forecasting of Tsunami for Each Location

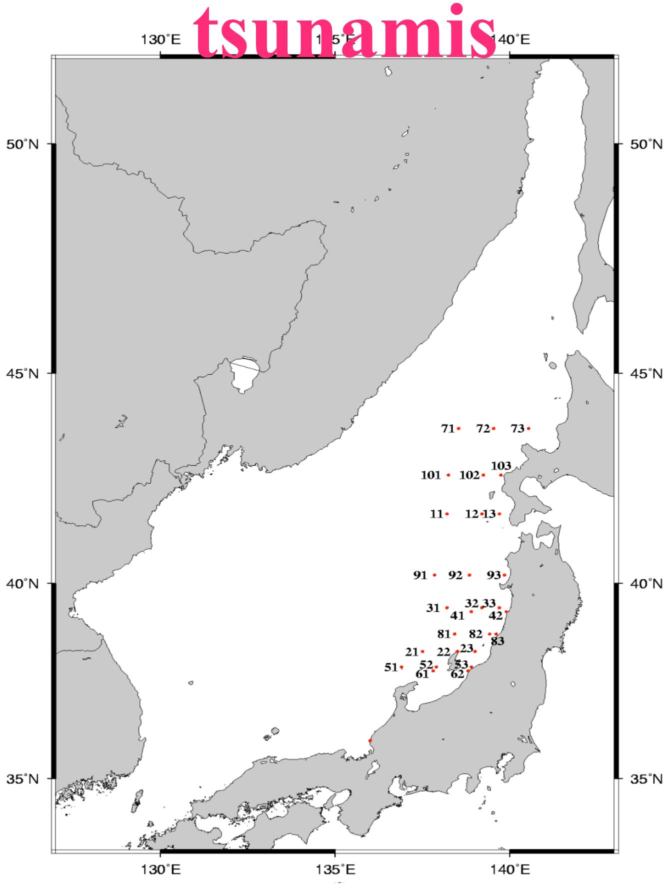
$$\boxed{H_{prognostic} = 2.5\ H_{ts}}$$

How to find H_{ts}?

From Synthetic Catalogue contained:

1. **Historical Data**
2. **Possible seismic events**
3. **Possible other (landslide?) events**

Epicenters of hypothetical tsunamis



Fault parameters for hypothetic earthquakes

N	Length (Km)	Dislocation (m)	Width (Km)	Slip angle (°)	Strike (°)	Dip angle (°)
1	45	2.3	25	100	110	45
2	140	5.0	50	90	23	35
3	100	4.1	50	90	105	45
4	70	2.0	20	75	23	45
5	70	3.2	40	90	15	20
6	60	1.9	20	90	190	55
7	100	5.35	35	90	347	40
8	80	7.81	30	90	189	56
9	40 60	7.6 3.05	30 30	90 80	22 355	40 25
10	100	3.7	50	84	1	24

28 events, including 4 real events

Synthetic Catalogue for Korea

Of course, it is not completed…

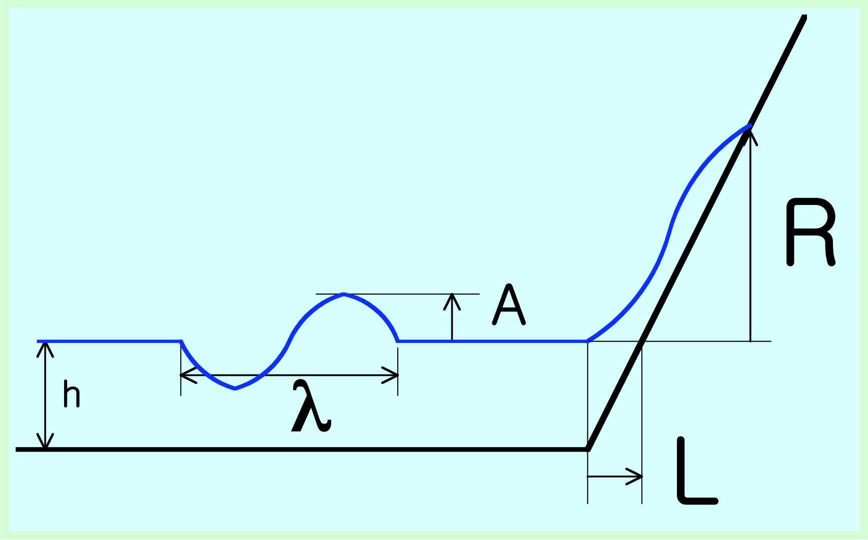
Prediction for Korea

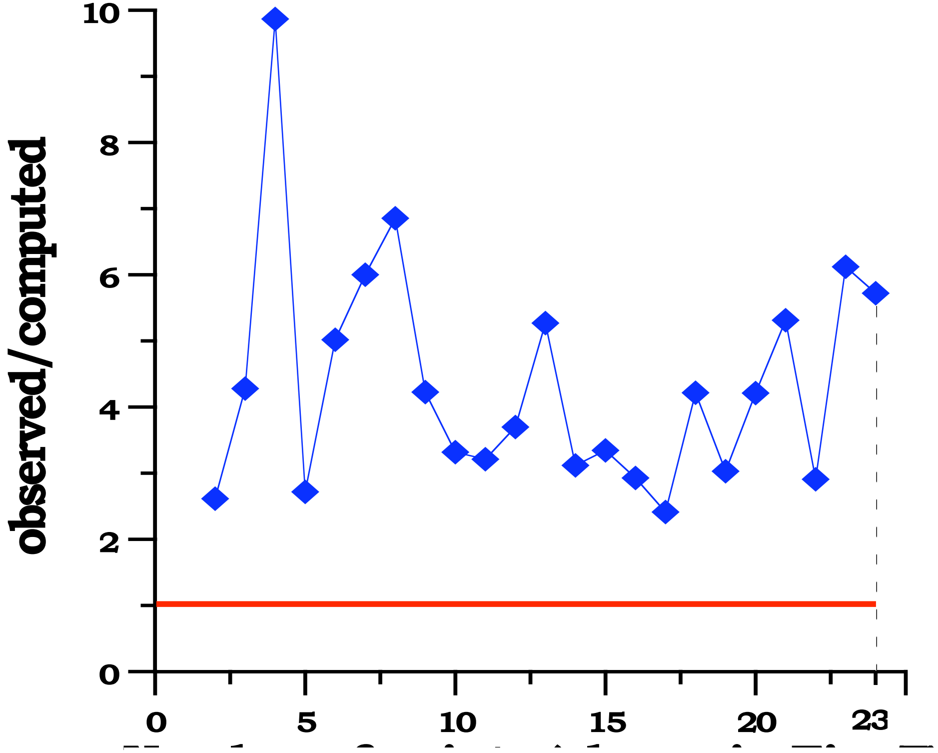
Choi, Pelinovsky, 2005

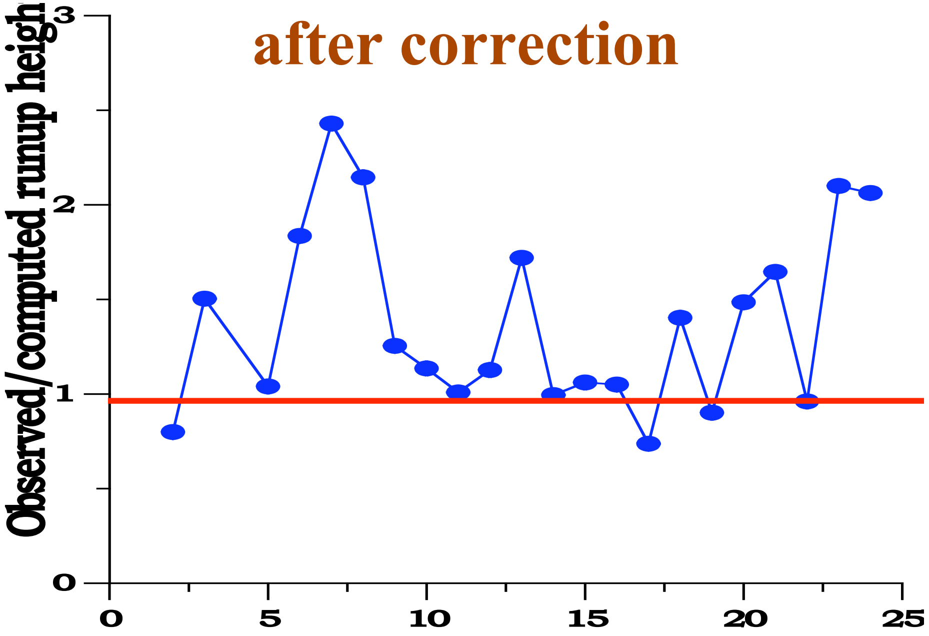
	H_{ts}, m (sea)	H_{max}, m (sea)	H_{prog}, m (sea)	1983 runup	1993 runup
Sokcho	**0.4**	**0.7**	**0.9**		**0.9**
Mukho	**0.8**	**1.5**	**2.1**		**2**
Imwon	**0.8**	**1.2**	**2**	**6.4**	**2.4**
Samchuk	**0.7**	**1.1**	**1.8**	**3.5**	**1.9**

Long Wave Runup on Plane Beach

$$\frac{R}{A} = 2\pi\sqrt{\frac{2L}{\lambda}}$$





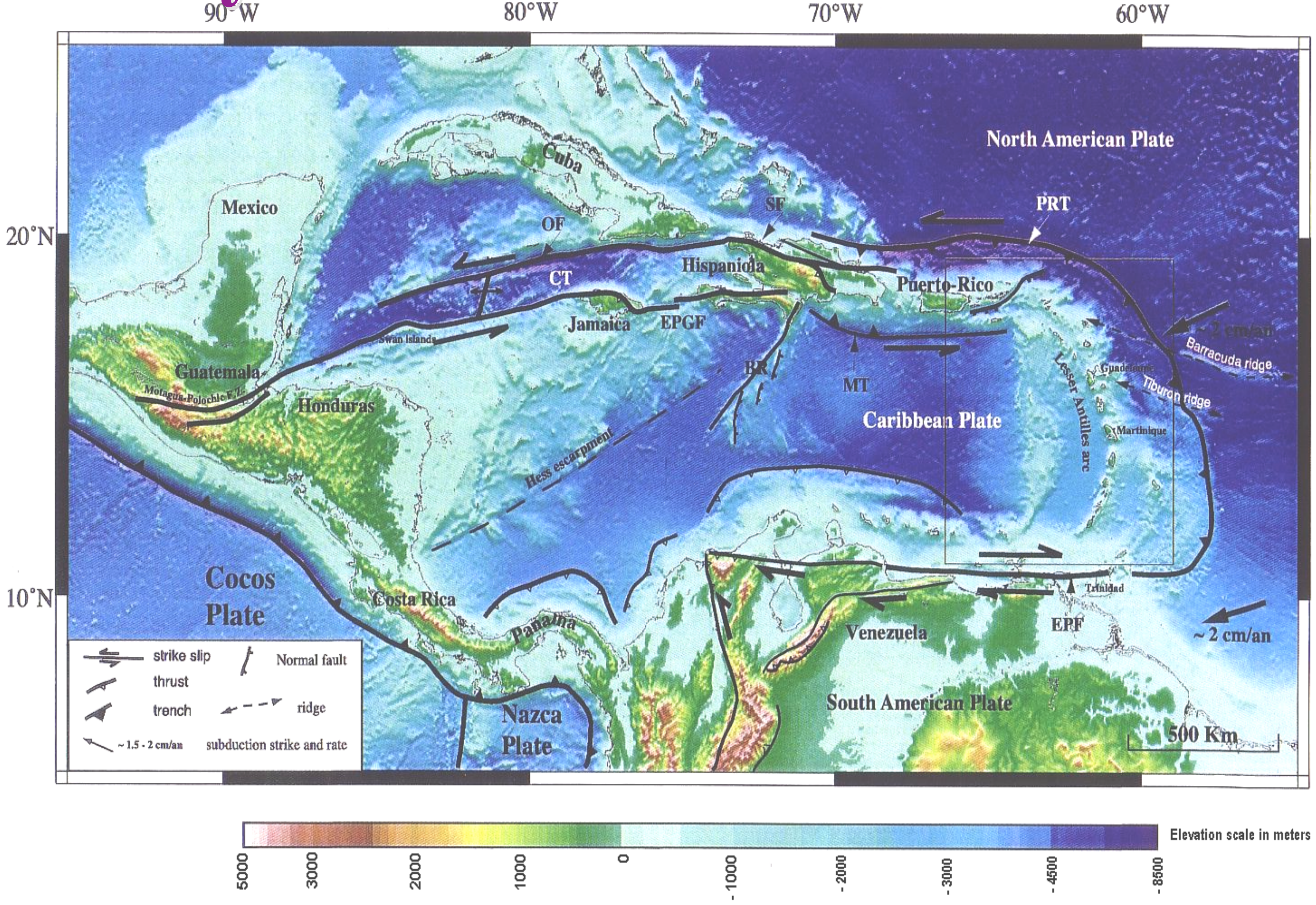


Prediction for Korea

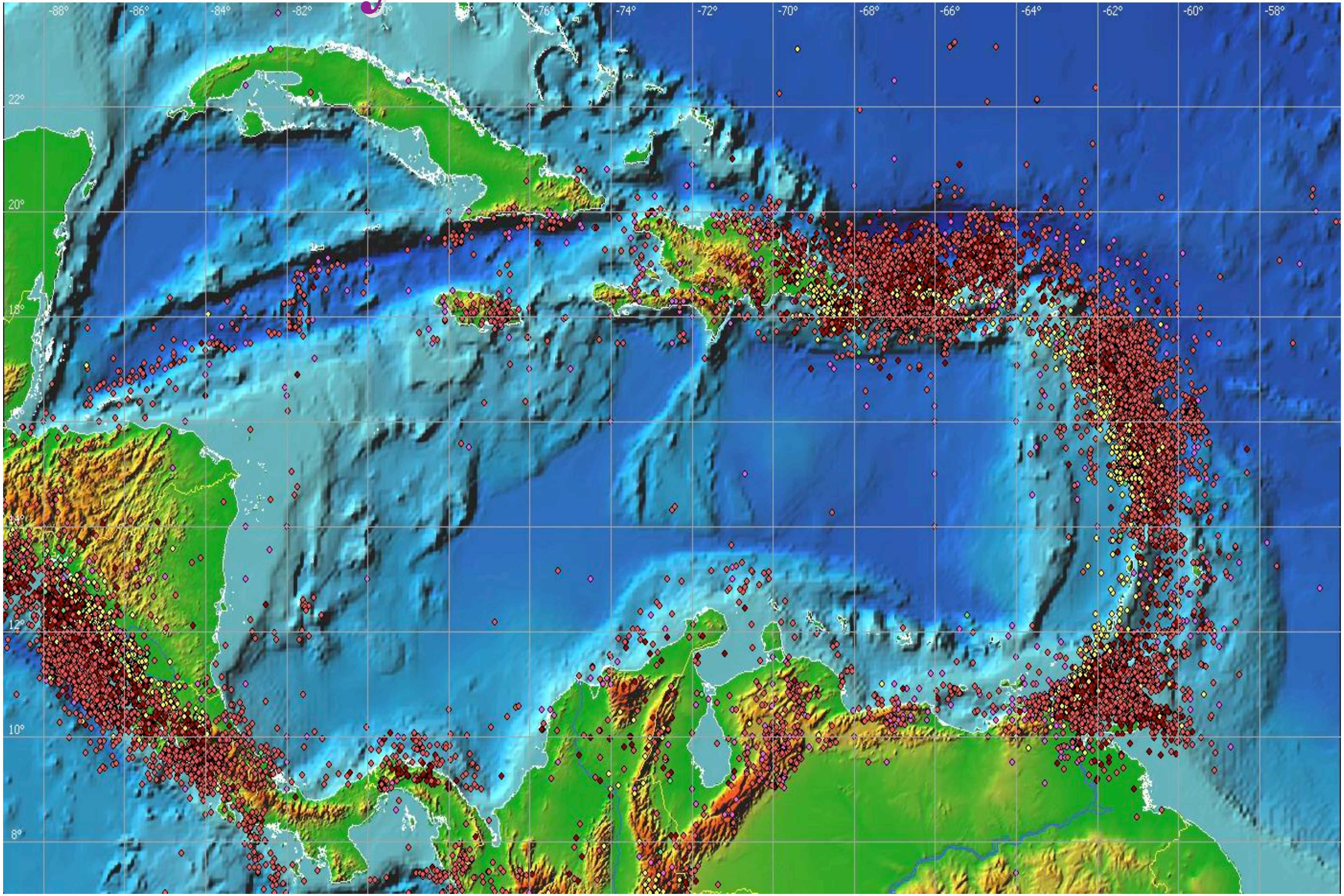
	H_{prog}, m (sea)	Runup Ratio	H_{prog}, m Runup	1983 runup	1993 runup
Sokcho	0.9	4	3.6		0.9
Mukho	2.1	4	8.4		2
Imwon	2	4	8	6.4	2.4
Samchuk	1.8	4	7.2	3.5	1.9

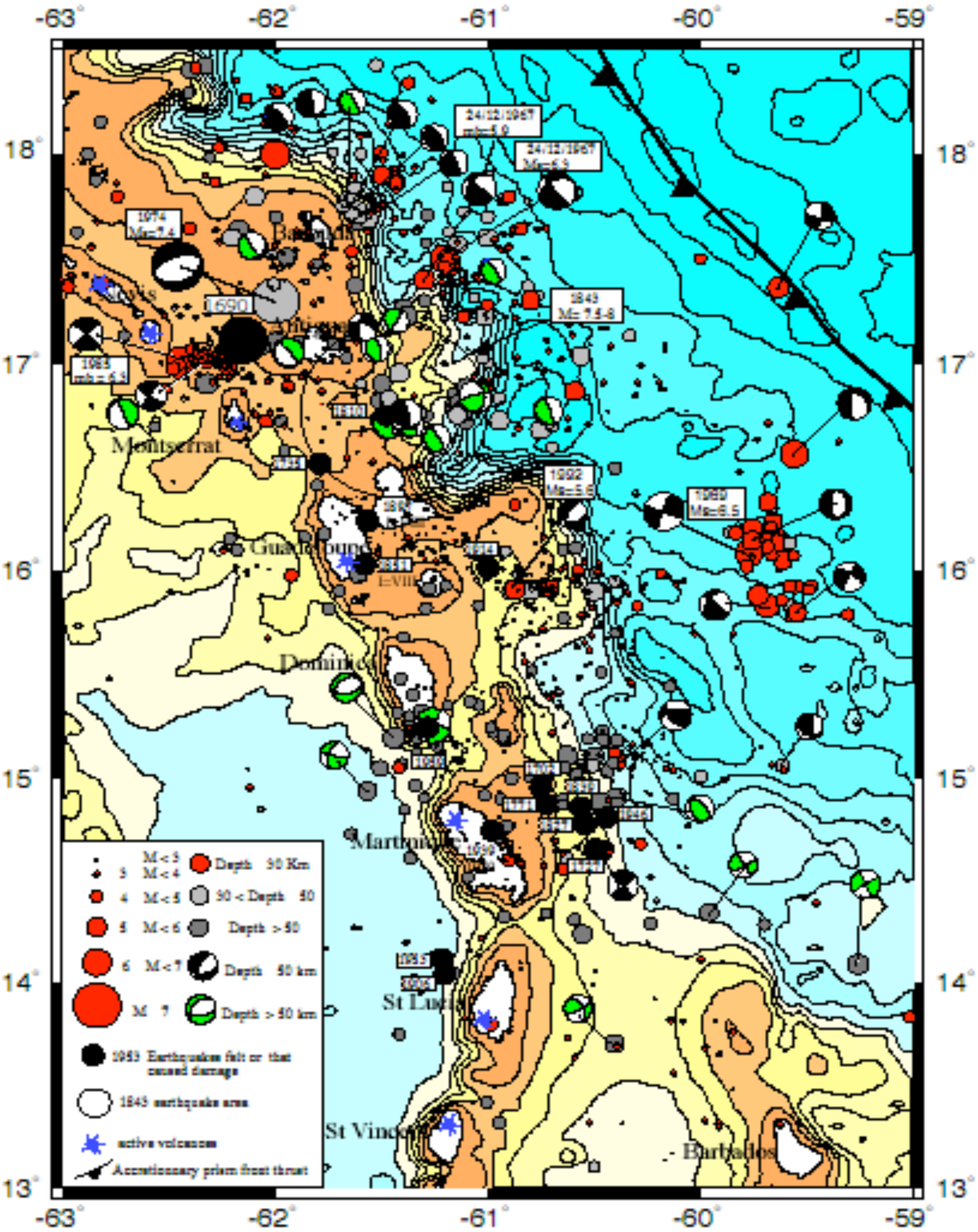
What we know about Caribbean?

Geodynamics of Caribbean



Seismicity in Caribbean

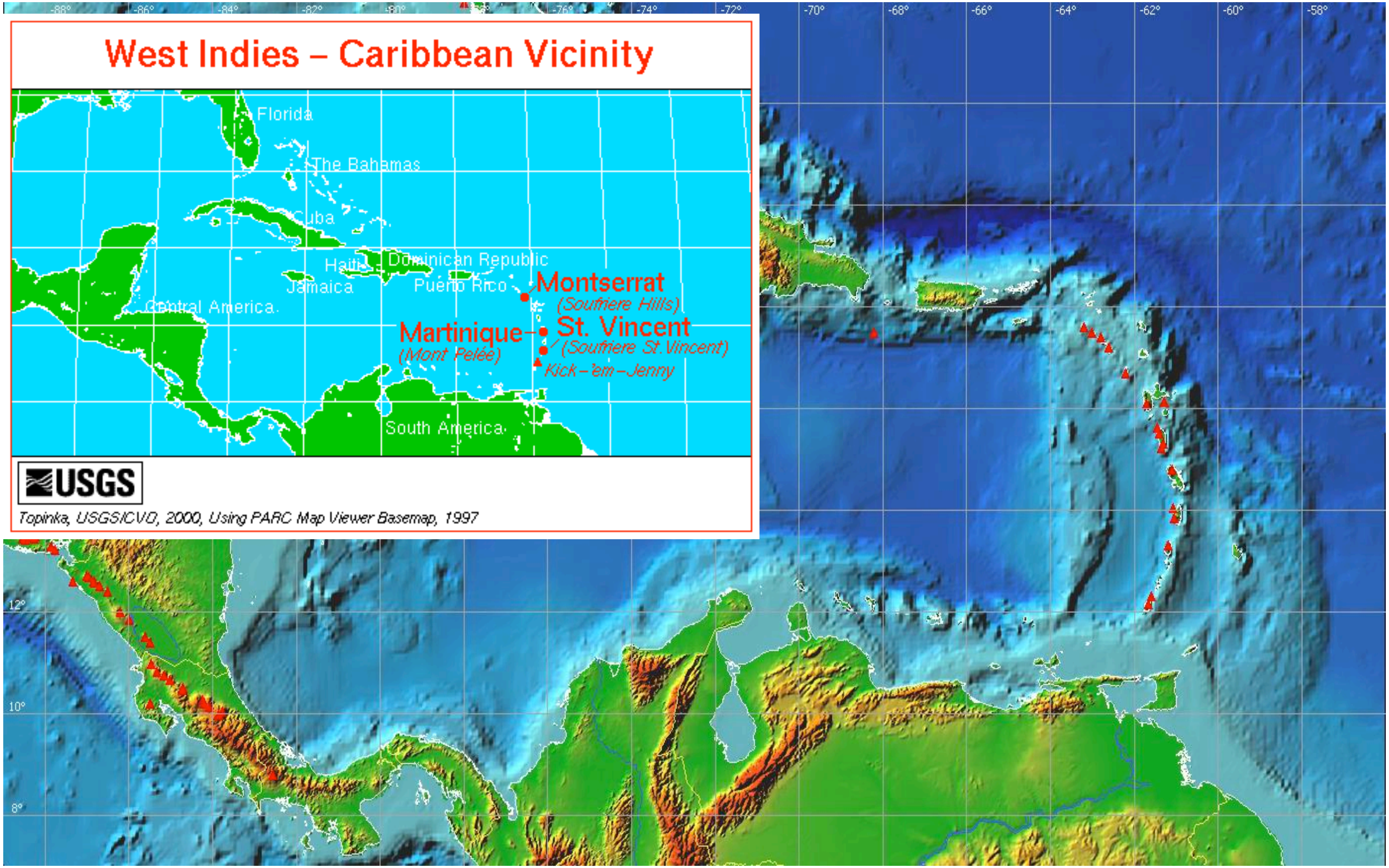




Earthquakes in Lesser Antilles

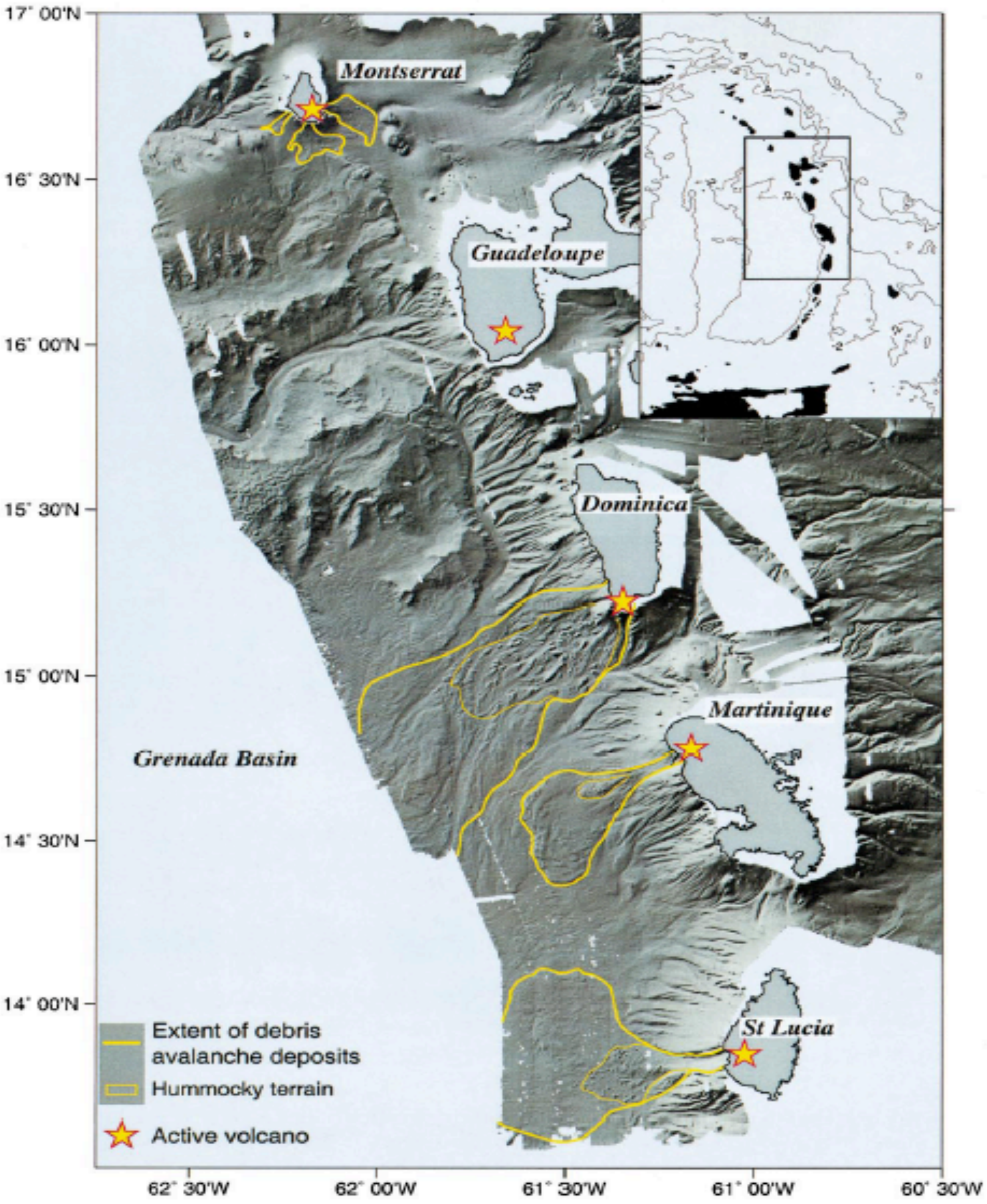
1950-1998

Volcano in Caribbean

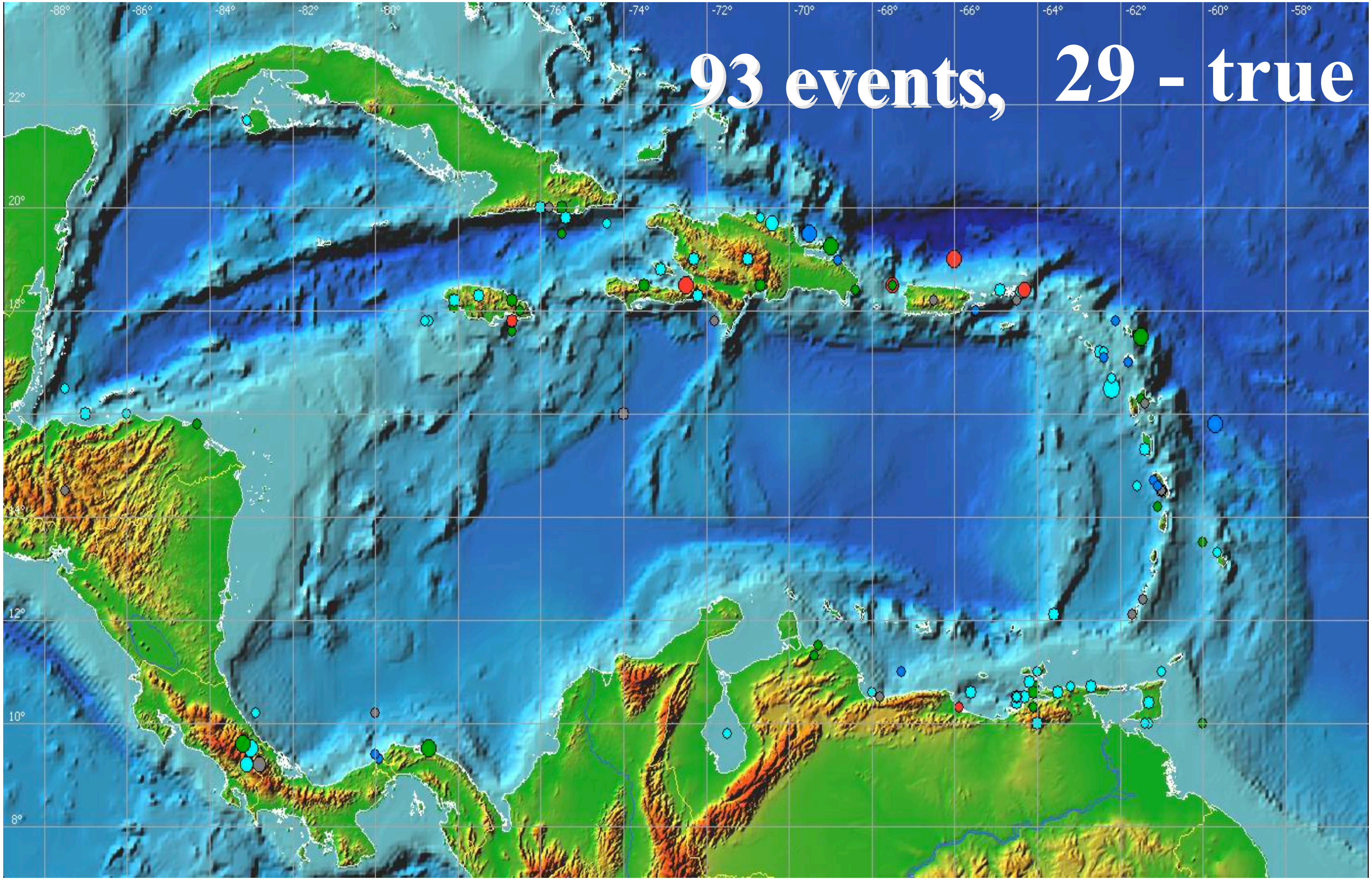


Topinka, USGS/CVO, 2000, Using PARC Map Viewer Basemap, 1997

Debris Avalanche Deposits

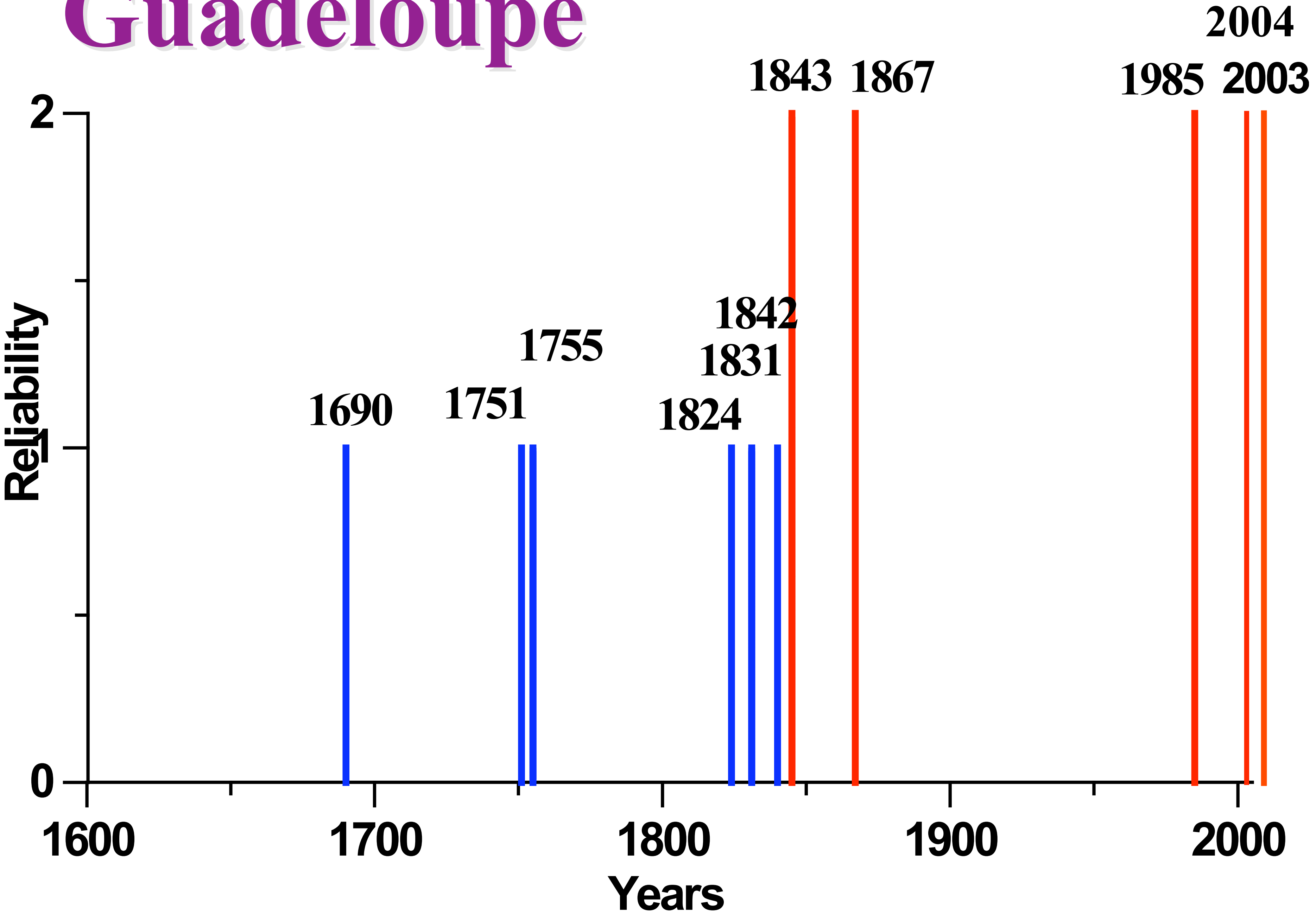


Tsunamis in Caribbean (1498-2000)

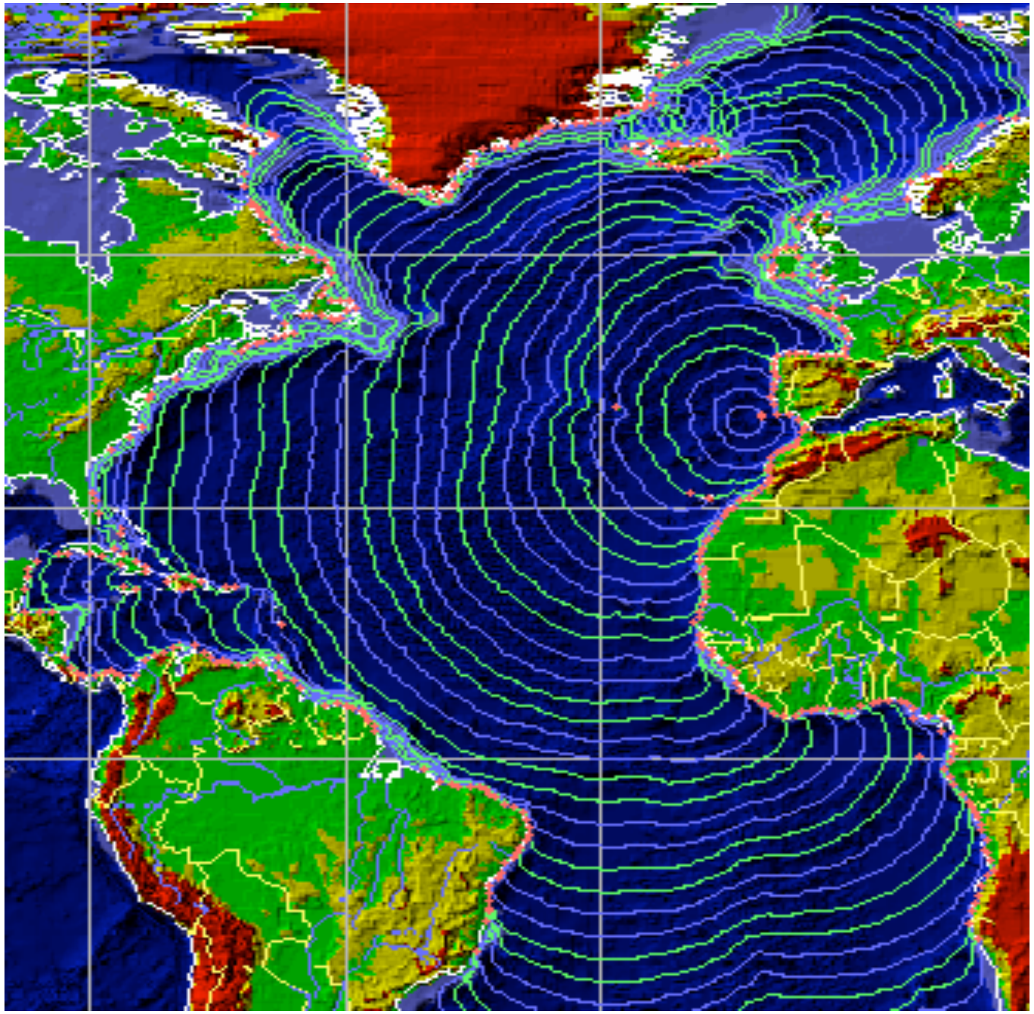


93 events, 29 - true

Guadeloupe


2004
1843
1867
1985
2003
2
1842
1755
1831
1690
1751
1824
1
0
Reliability
1600
1700
1800
1900
2000
Years

Transatlantic Tsunami, November 1, 1755



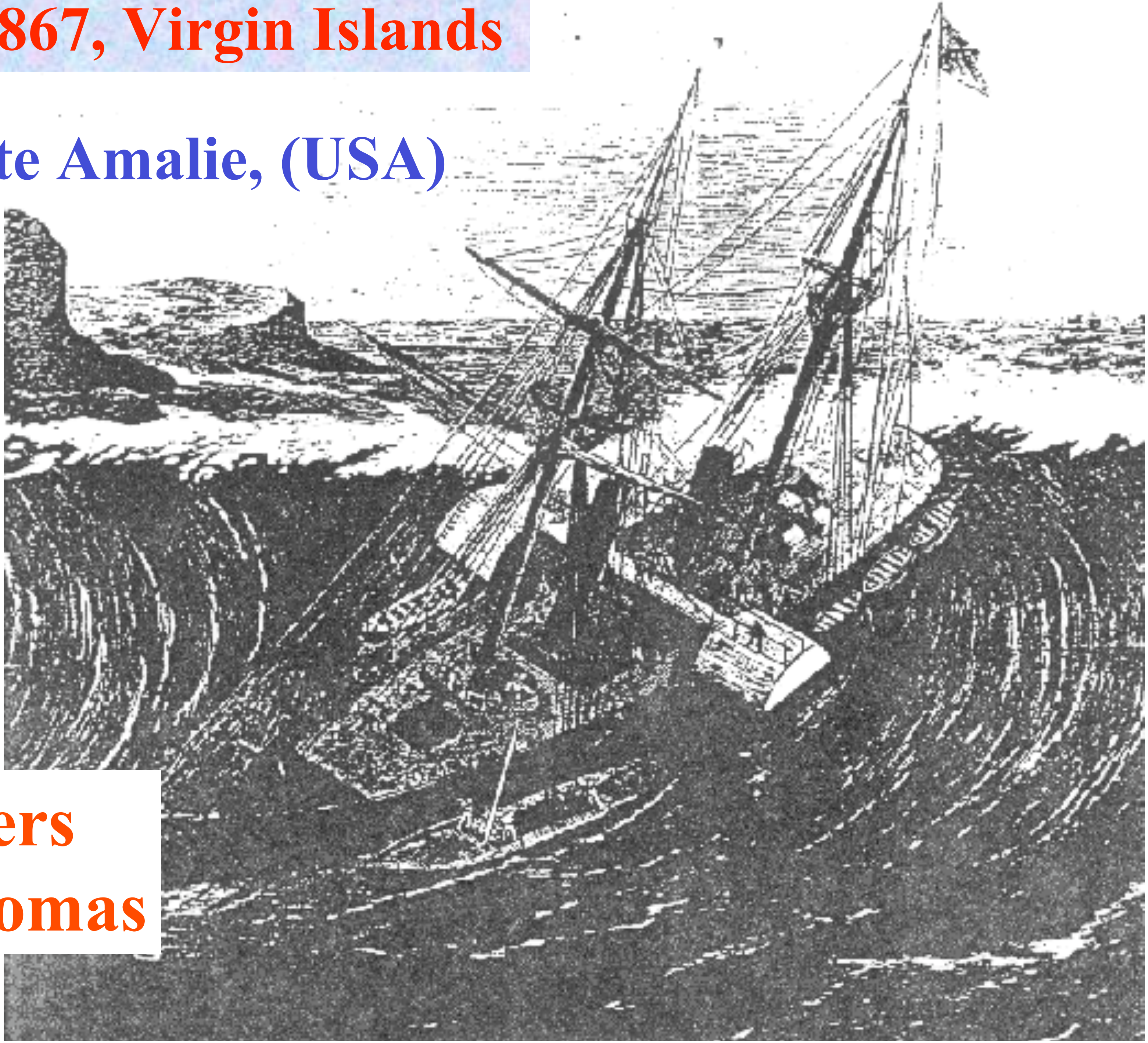
Country	Height, m
Barbados	0.8-1.5
Dominica	3.7
Antigua	3.7
Netherlands, Saba	7.0
France, St. Martin	4.5

"the lowlands on most of the other French Islands were inundated"

Lisbon earthquake

Nov 18, 1867, Virgin Islands

Charlotte Amalie, (USA)



M=7.5

6 meters at St.Thomas

1902, May 8

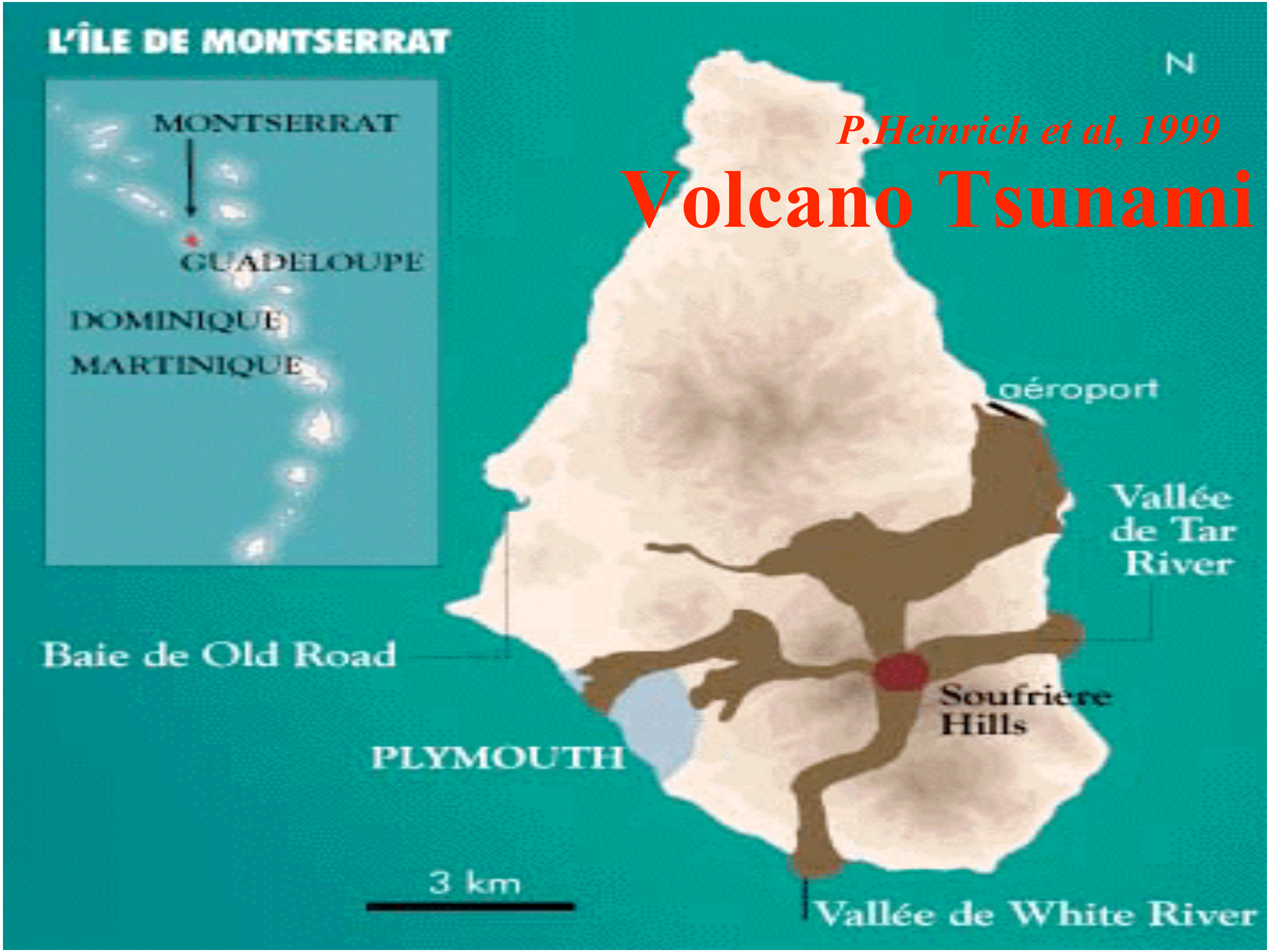
Mont Pele

There was a devastating eruption of Mont Pele, Martinique, which sent a nuée Ardente into St. Pierre, killing about 30,000 inhabitants.

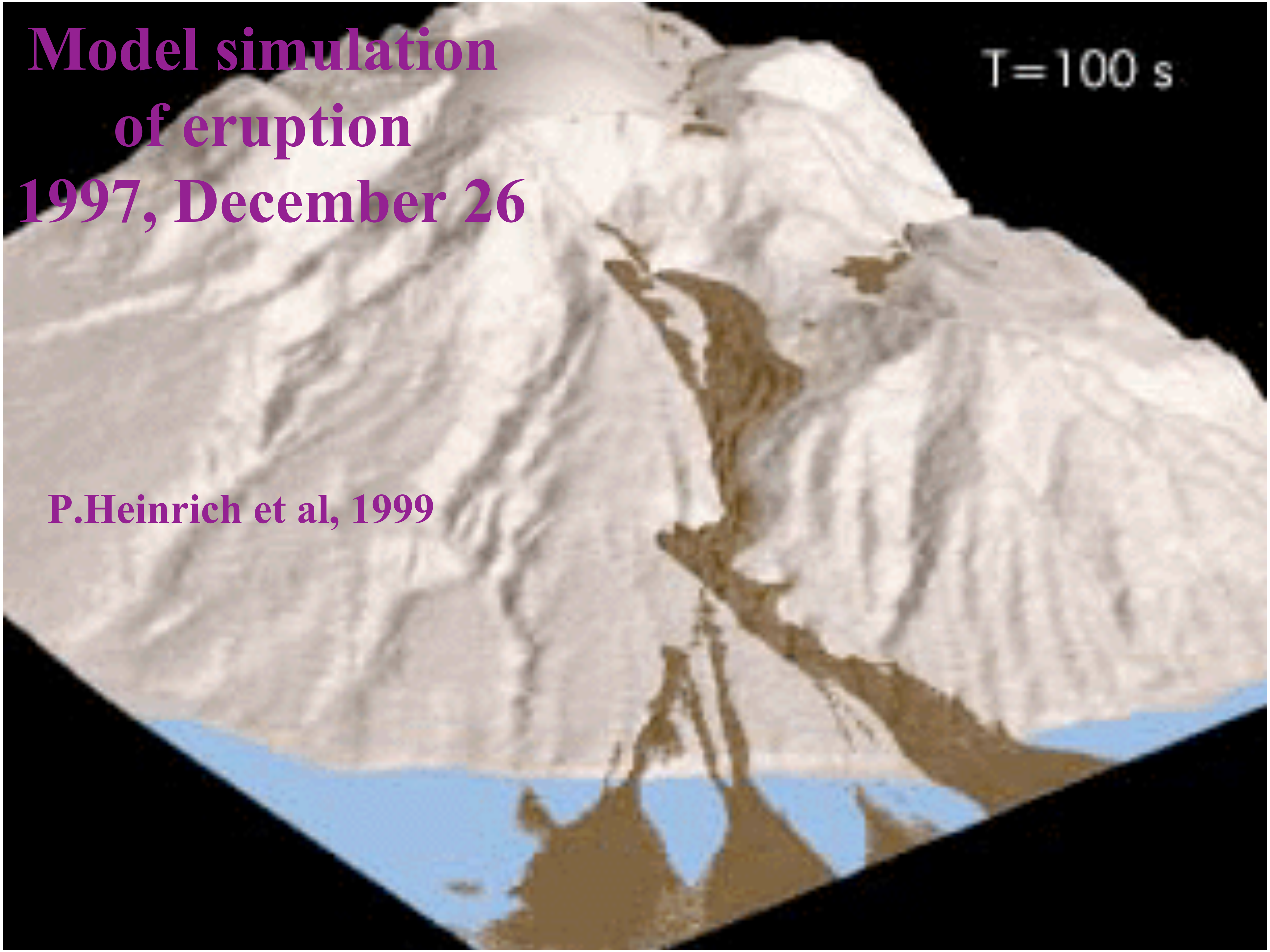
The fall of lava into the sea had pushed all the water out to the open ocean, as if trying to topple the harbour into the Atlantic a league away.

Volcano Tsunami

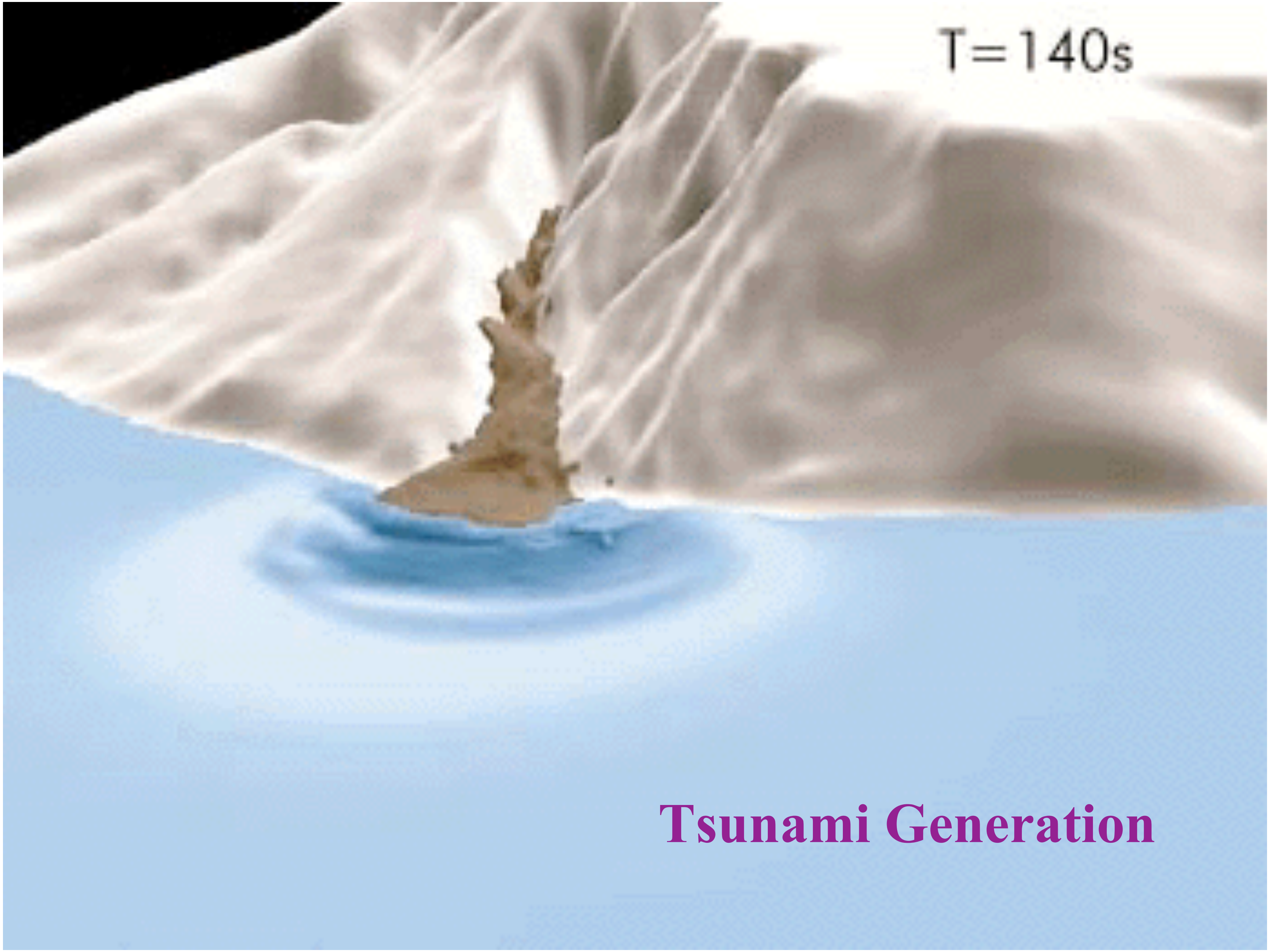
P.Heinrich et al, 1999



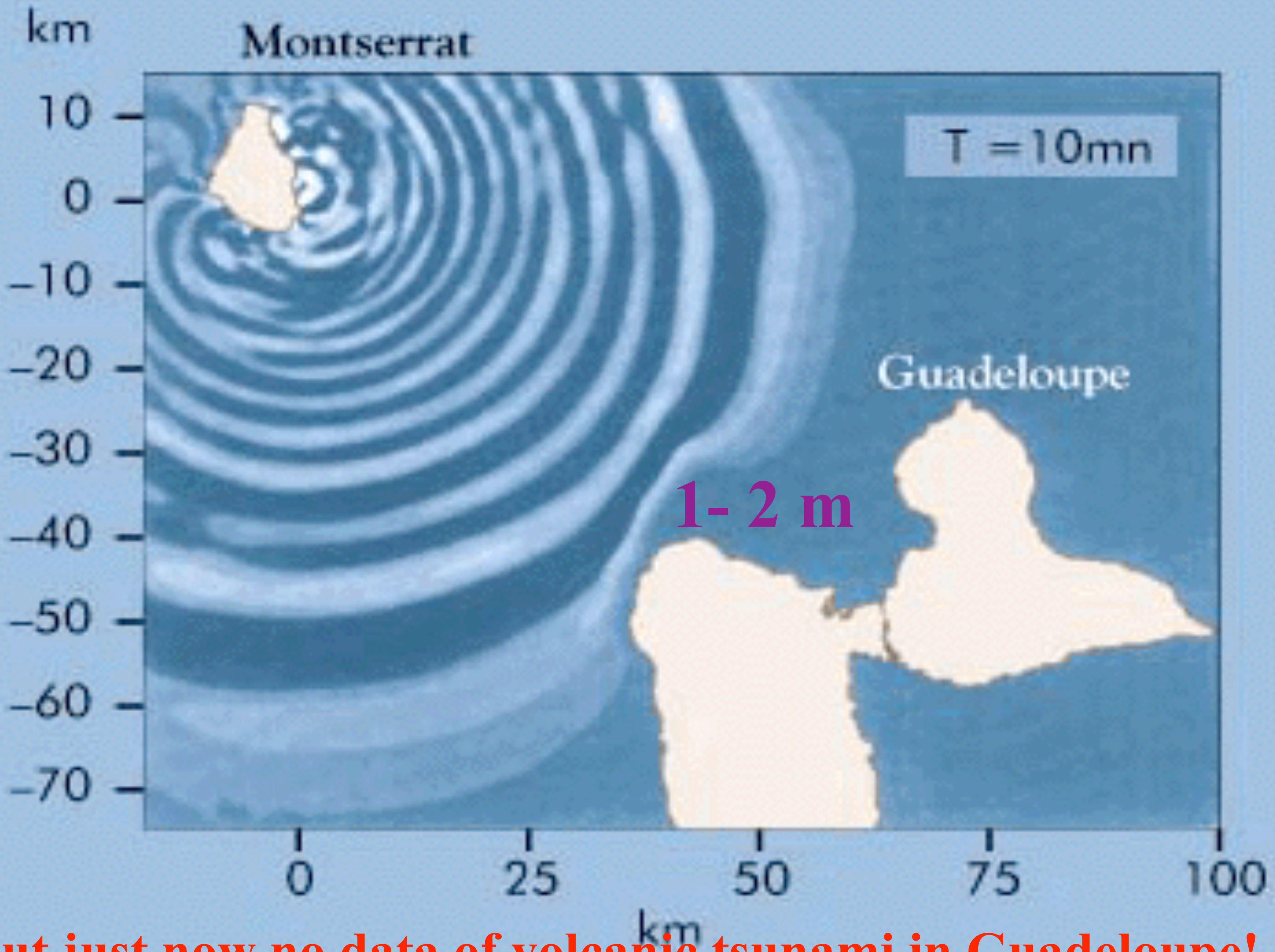
Model simulation of eruption 1997, December 26



P.Heinrich et al, 1999



Tsunami Generation



But just now no data of volcanic tsunami in Guadeloupe!

May 31, 2003

before dome collapse

July 12, 2003

120,000,000 m^3

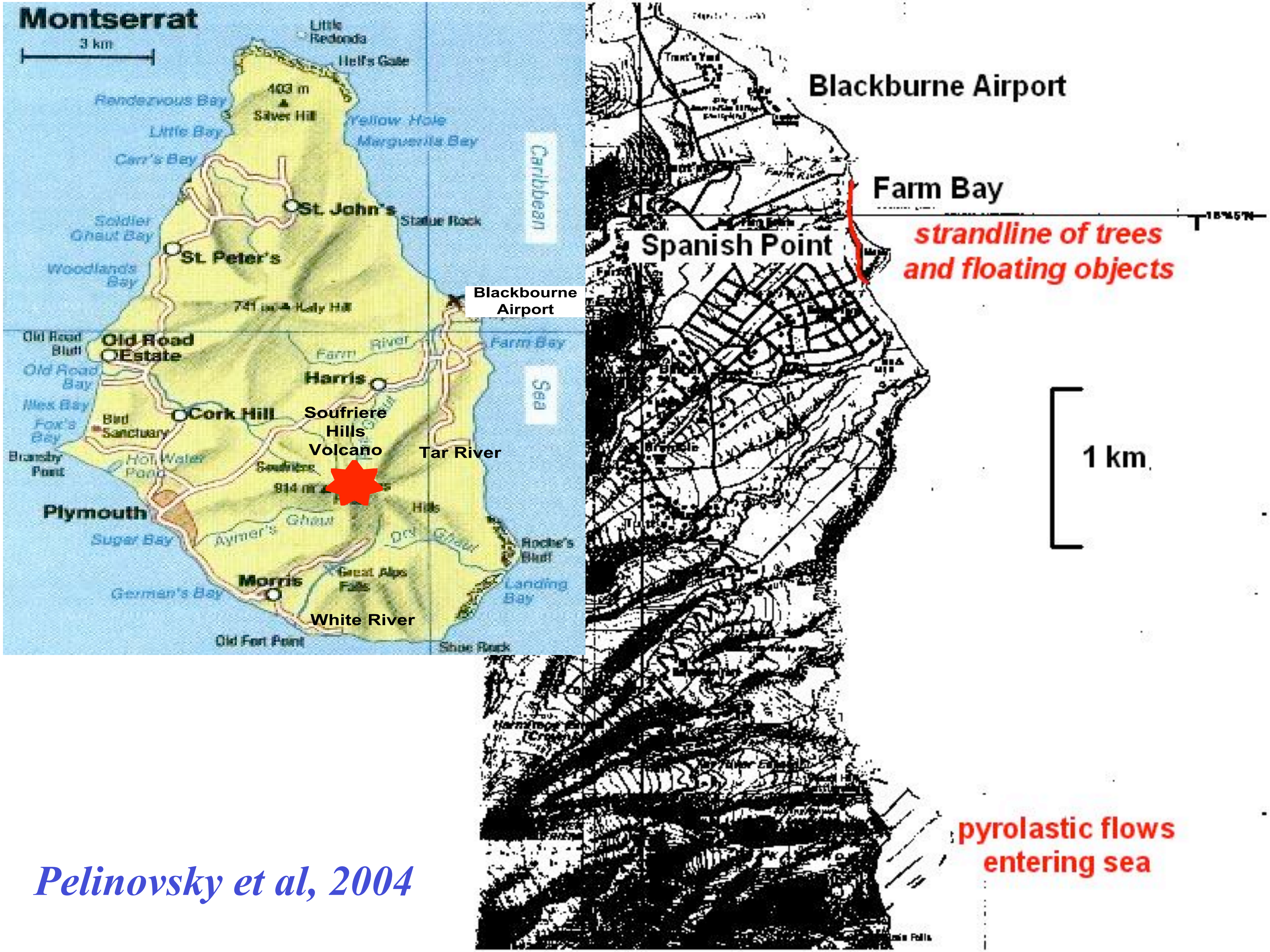
July 12-13, 2003

Tar River Valley

Pyroclastic Flow
12-13 July 2003
Tar River Valley

Tsunami generation

Tar River Valley after July 12, 2003



Pelinovsky et al, 2004

Tsunami Traces

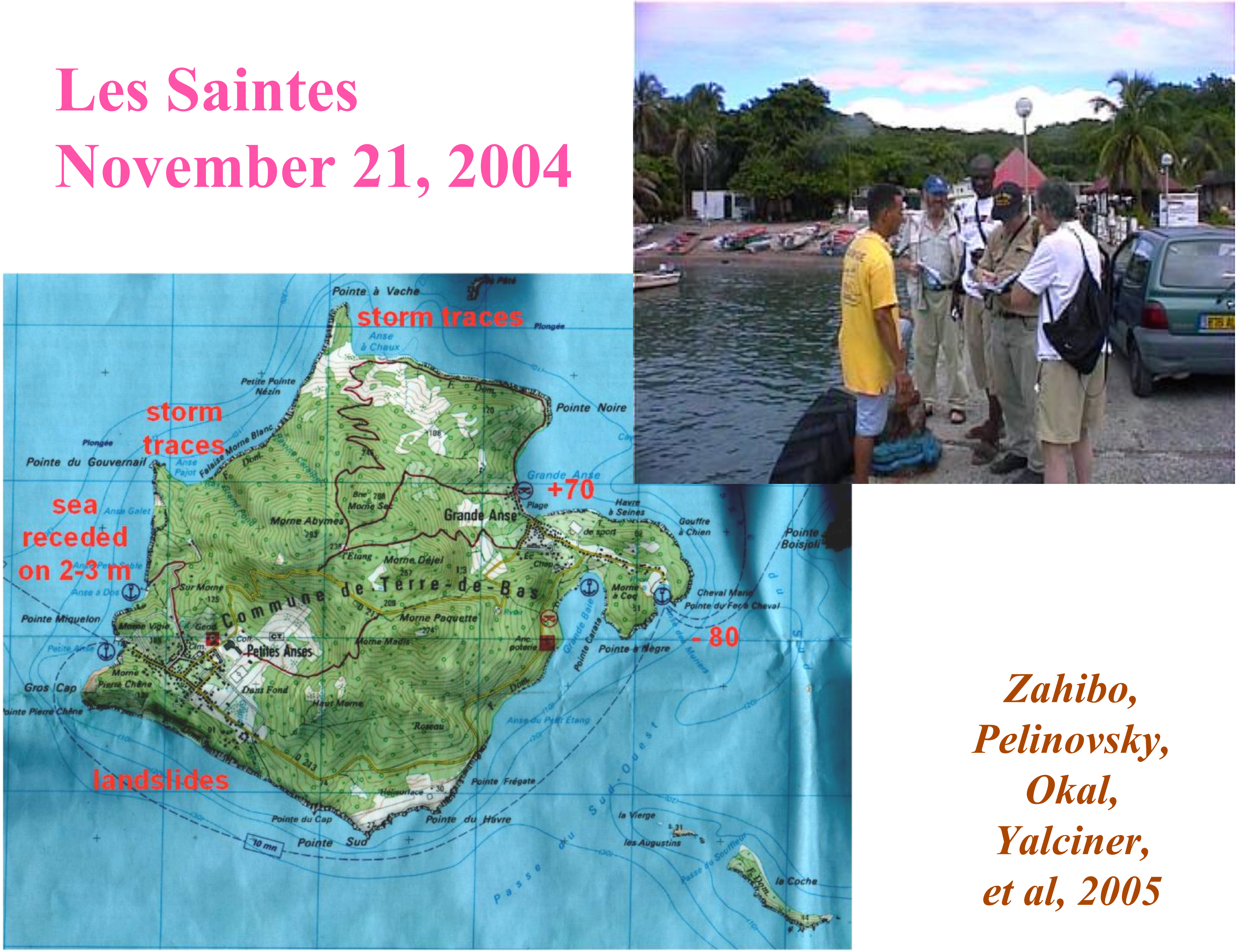
4 m high,
100-200 m inland

November 21, 2004. M = 6.3, depth 14 km

Les Saintes, 19 km from epicenter

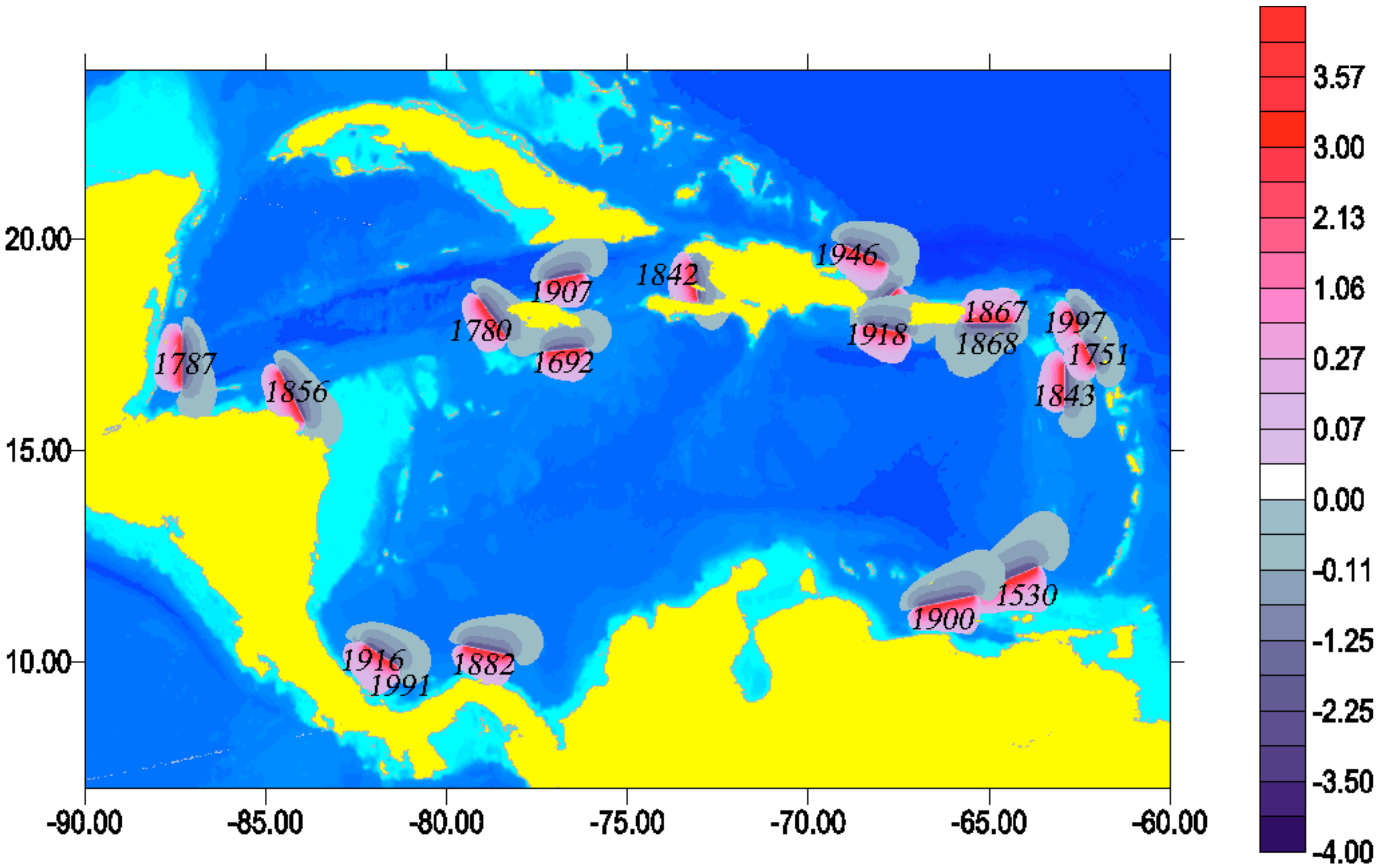
Guadeloupe, 37 km from epicenter

Les Saintes
November 21, 2004

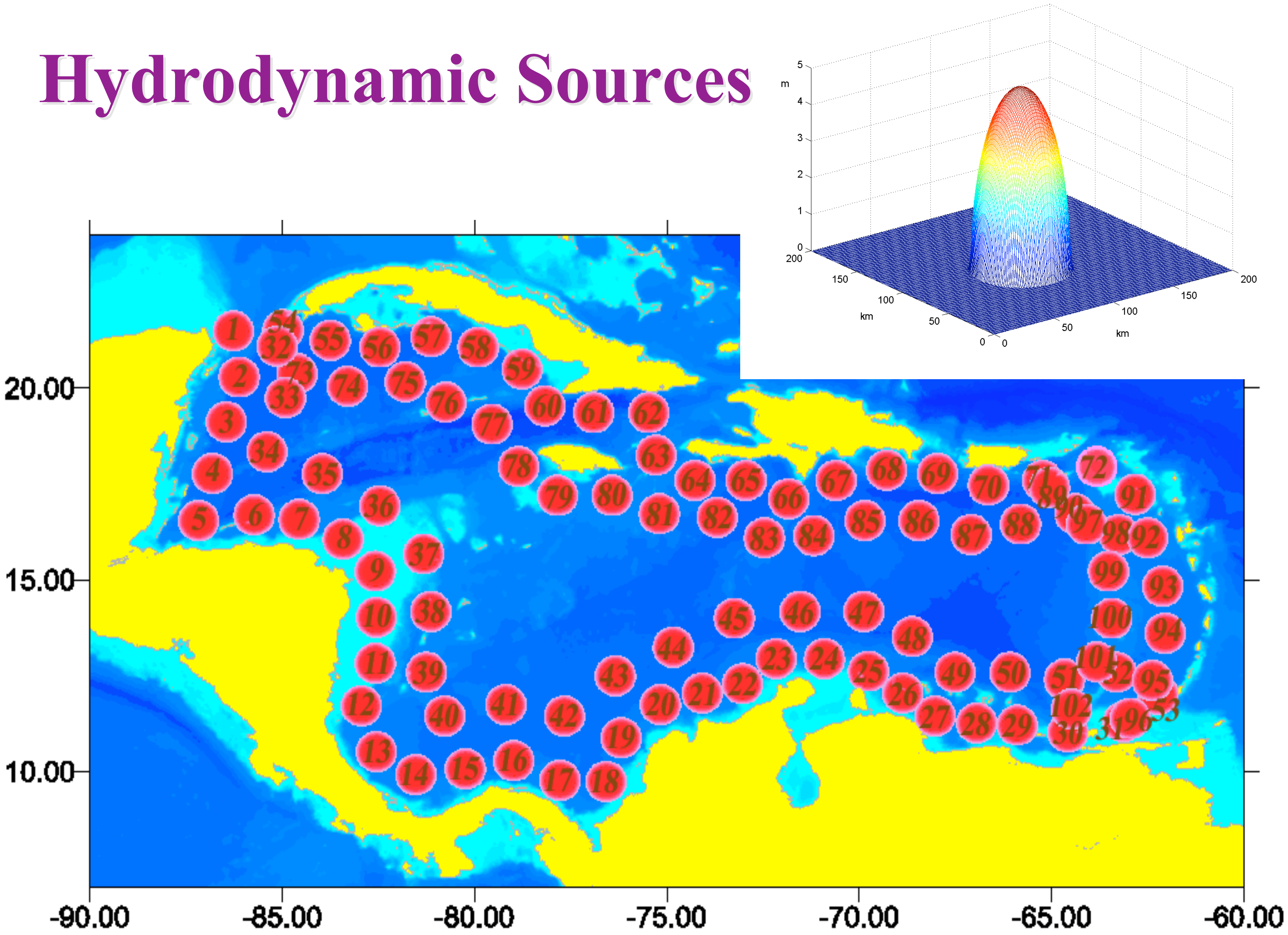


Zahibo,
Pelinovsky,
Okal,
Yalciner,
et al, 2005

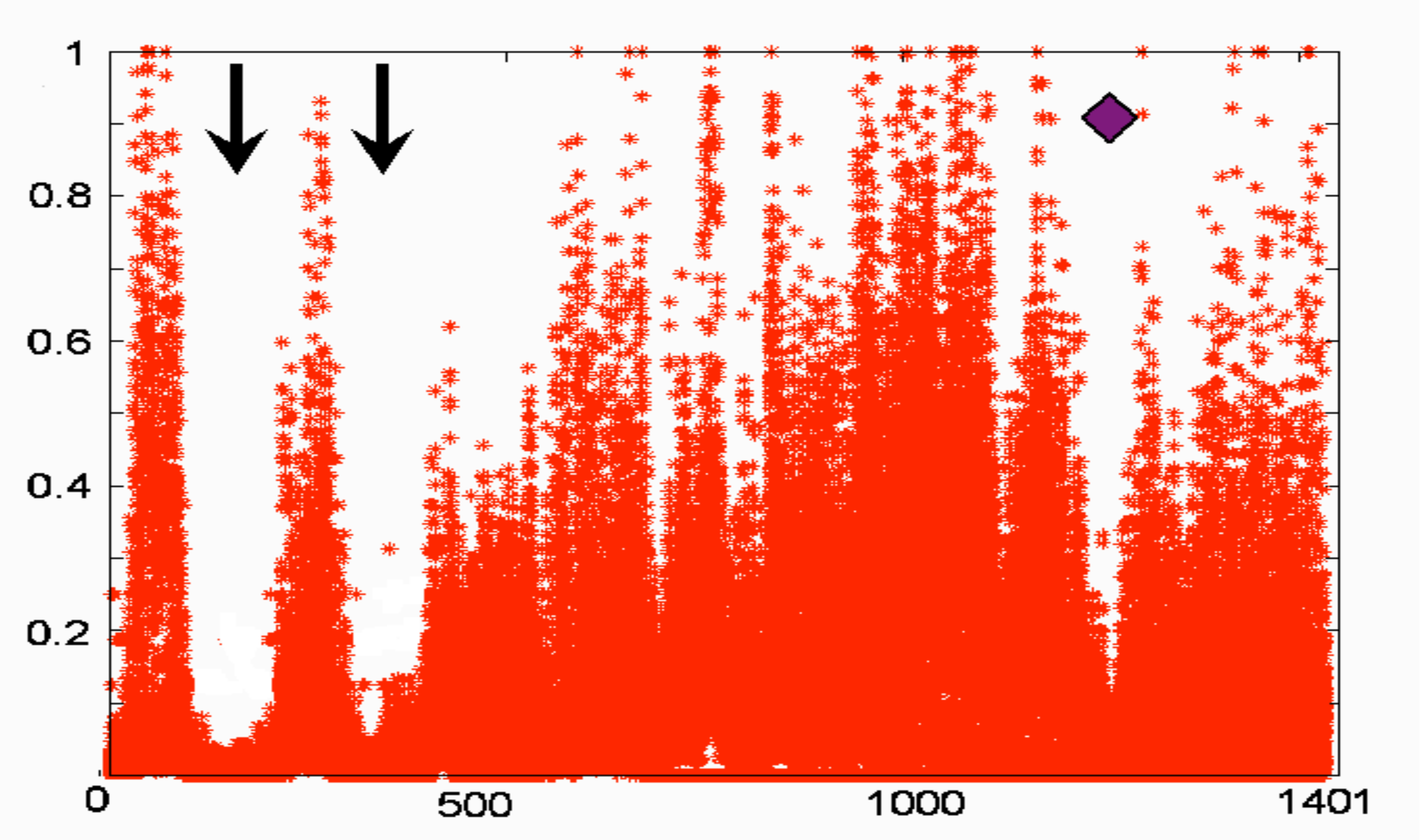
Prognostic simulation for Caribbean



Hydrodynamic Sources



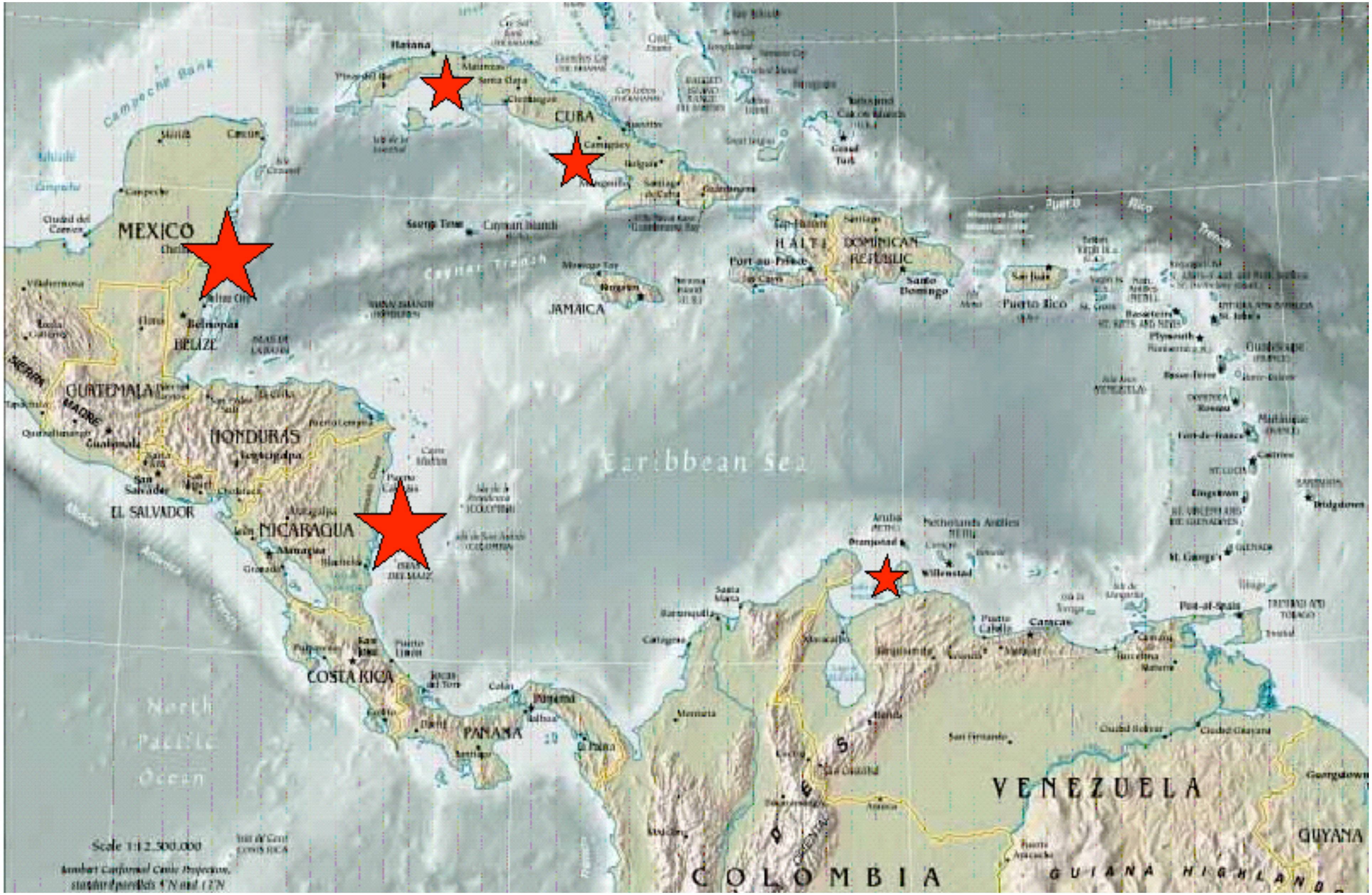
Distributions from various sources



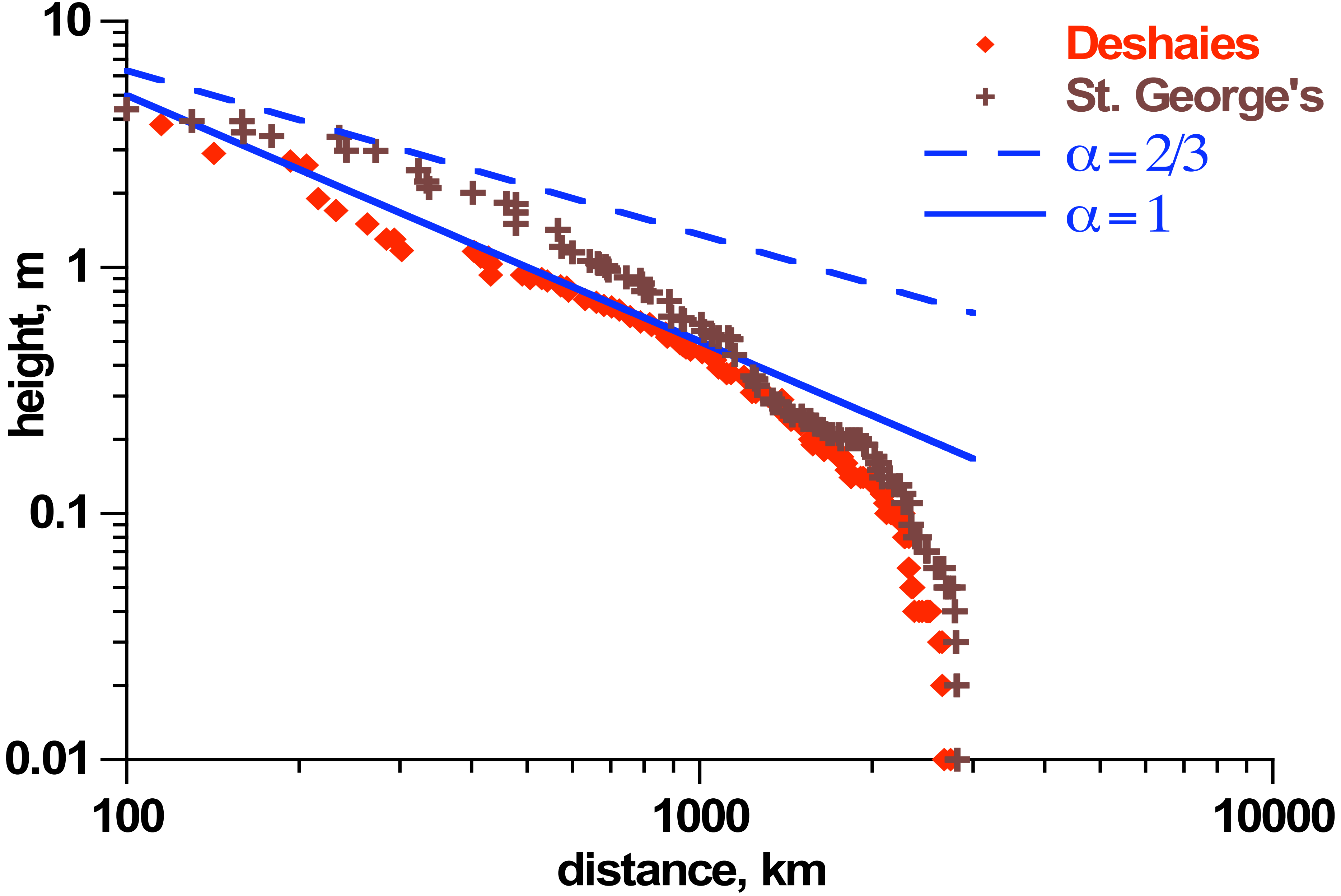
Cuba

Haiti

Low Risk Zones



3,000 km and more – dangerless tsunamis



Synthetic Catalogue leads to:

1. Tsunami Risk Zoning
2. Rough Prognostic Heights
3. Occurrence Frequency (not always)

Positive Examples:

Korea, Russia, Caribbean Sea

Tsunami Potential is evaluated also
for USA and Japan

Tsunami Risk Evaluation:

1. Analysis of historic tsunamis
2. Analysis of possible tsunami sources
3. Simulation of past and prognostic events

Final Product:

Water level and velocity with occurrence probability,
or “maximal” maximum of water level and velocity,
or probable water level and velocity

Mitigation:
evacuation maps and tsunami protection