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Probabilistic Tsunami Hazard Assessment (PTHA) for Interplate Earthquakes along the Ryukyu Trench: Long-term Mean Hazard

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1. Introduction

- Past earthquake tsunamis along the Ryukyu Trench have caused tsunami damages.
  e.g., the 1771 Yaeyama earthquake (MJ7.4, Mt8.5)[1]
  the 1911 Kikai-jima earthquake (MJ8.0, Mt7.9)[1]

- Headquarters for Earthquake Research Promotion (HERP) of the Japanese Government reported the long-term evaluation of seismic activities along the Ryukyu Trench[1, 2].

- Due to the lack of seismic observation data and historical data, they did not evaluated the probability of occurrence of these earthquakes, with the exception of M7-class earthquakes occurring in several areas (e.g., around Yonaguni Island).

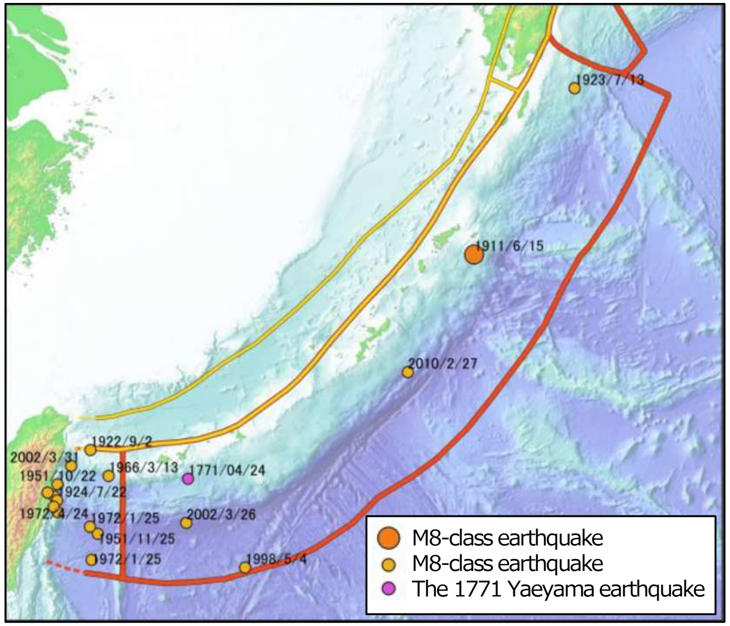


Fig. Epicenters of earthquakes along the Ryukyu Trench evaluated by HERP[1]

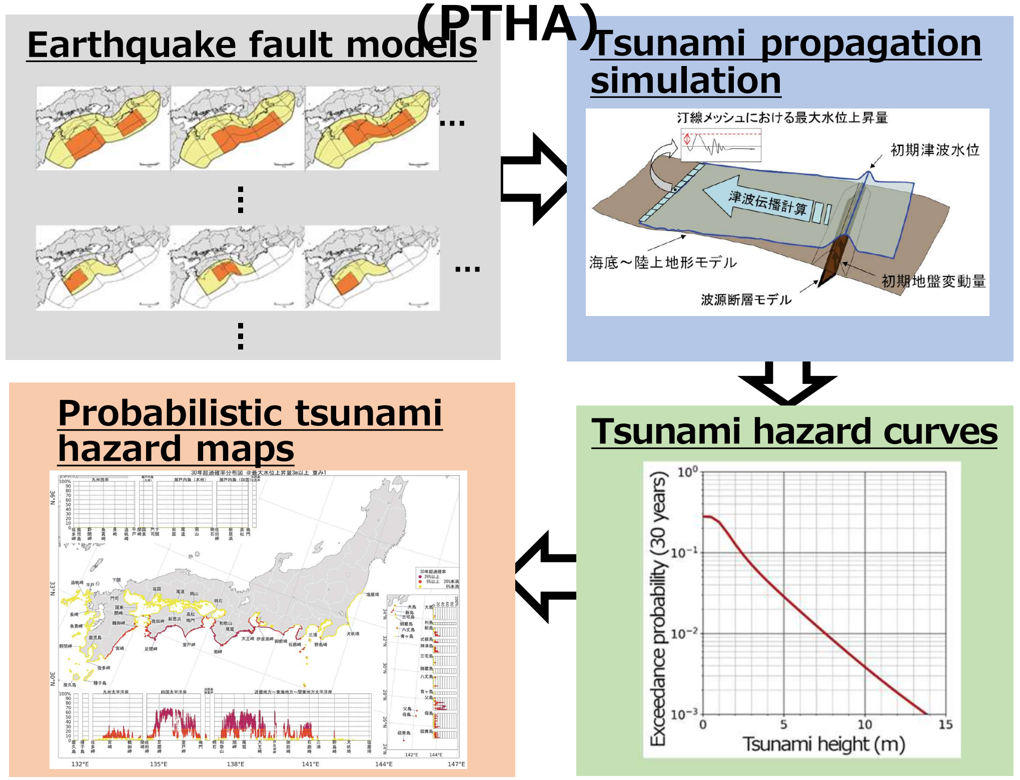
1. HERP (2022): Long-term evaluation of seismic activities at Hyuga-nada and along the Ryukyu Trench (2nd Edition) (in Japanese). https://www.jishin.go.jp/main/chousa/kaikou_pdf/hyuganada_2.pdf
2. HERP (2004): Long-term evaluation of seismic activities at Hyuga-nada and along the Ryukyu Trench (in Japanese). https://www.jishin.go.jp/main/chousa/kaikou_pdf/hyuganada.pdf

1. Introduction

- In order to evaluate future possible earthquake tsunamis, we assessed a probabilistic tsunami hazard for interplate earthquakes along the Ryukyu Trench in the view point of long-term mean hazard.

- We introduce followings:
  - earthquake fault models,
  - tsunami propagation simulation,
  - tsunami hazard curves,
  - probabilistic tsunami hazard maps.

Outline of Probabilistic Tsunami Hazard Assessment (PTHA)



2. Earthquake fault models

- We modeled interplate earthquakes as basically square-shaped “characterized earthquake fault models” (CEFMs) and placed a set of the CEFMs on the 3D upper surface of the subducting Philippine Sea plate, based on MEXT and NIED (2012)[1].

MEXT: Ministry of Education, Culture, Sports, Science and Technology
NIED: Research Institute for Earth Science and Disaster Prevention

- Target area (along-trench):
  From the southwest edge of Hyuga-nada Sea to 122° east longitude (considering the seismic activity around Yonaguni Is.)

- Target area (trench-normal):
  The depth of 0–60 km

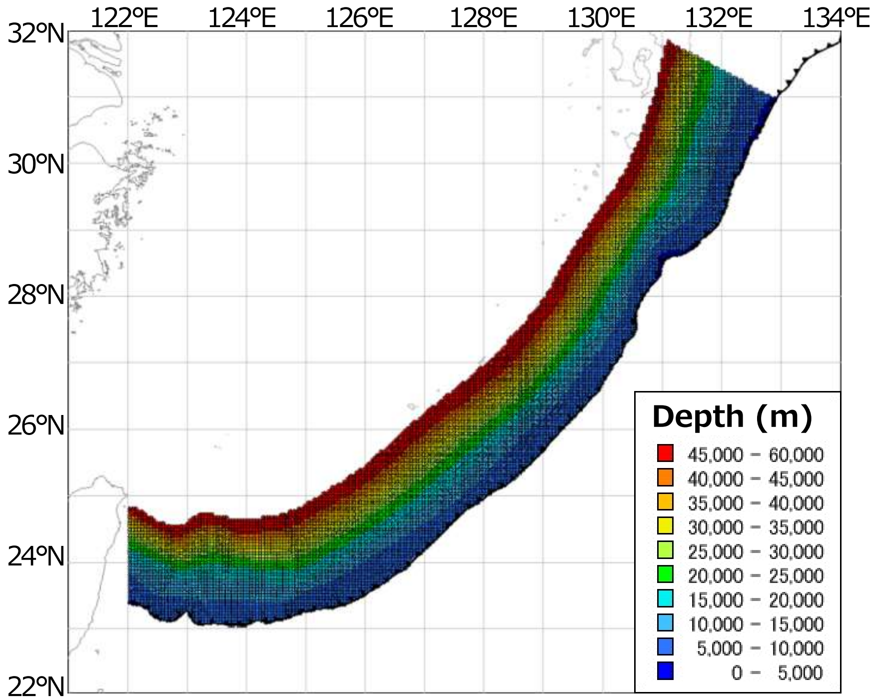


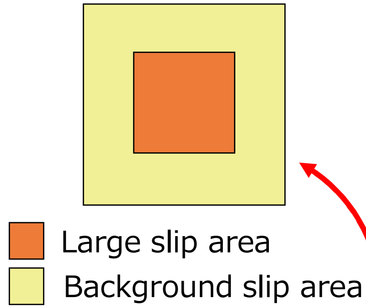
Fig. 3D upper surface of the subducting Philippine Sea plate (depth 0-60km)

1. Ministry of Education, Culture, Sports, Science and Technology and National Research Institute for Earth Science and Disaster Resilience (2012): Report of Long-period seismic hazard maps (in Japanese).

2. Earthquake fault models

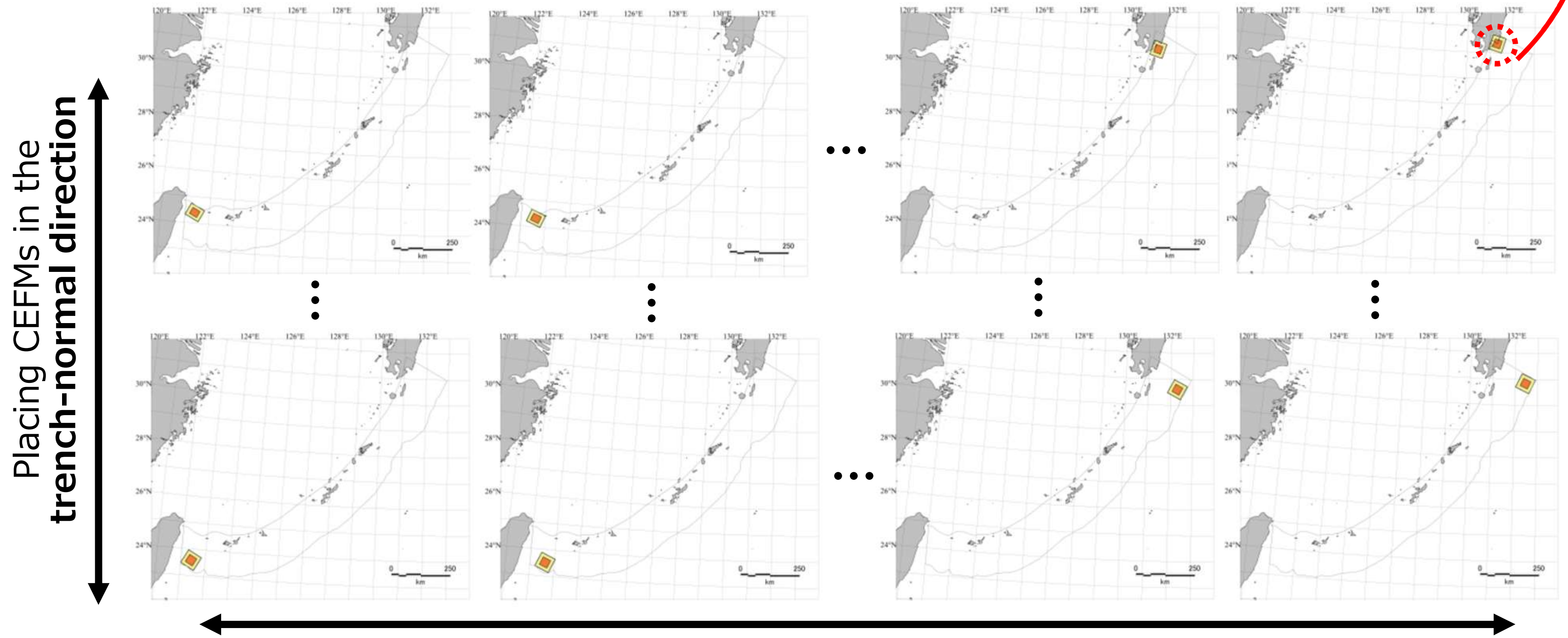
- We expressed heterogeneity in slip distribution on CEFMs by introducing a large slip area on a fault.
- Total of 3,693 CEFMs were constructed for earthquakes with magnitudes from Mw 7.0 to 9.4, using M0-S scaling law.

Image of a CEFM
(heterogeneous slip distribution)



CEFMs of Mw 7.6 (N=245)

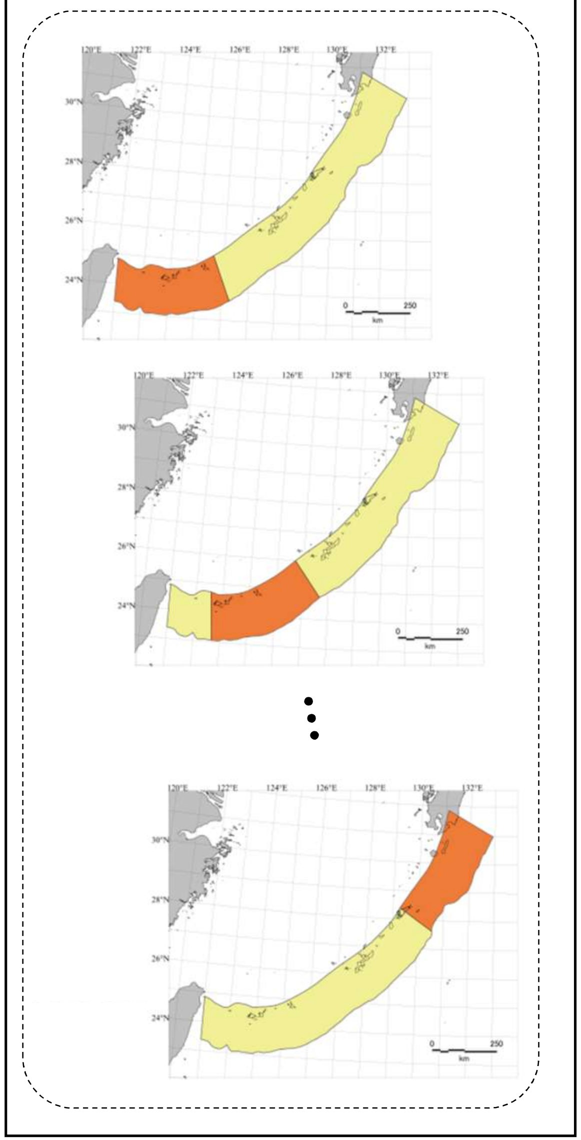
※Placing CEFMs to fill them with the target area



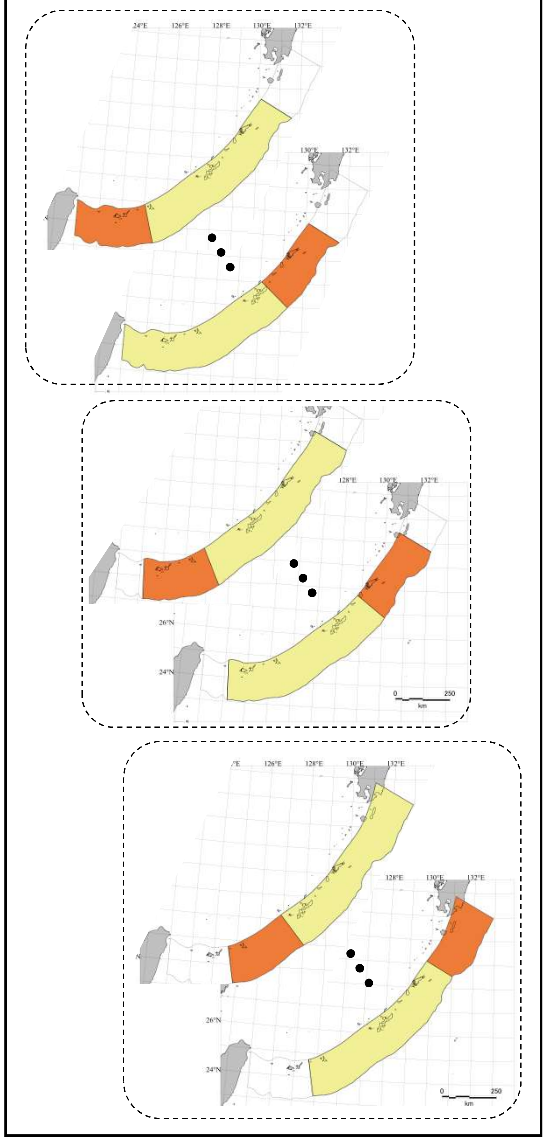
2. Earthquake fault models

Large slip area   Background slip area

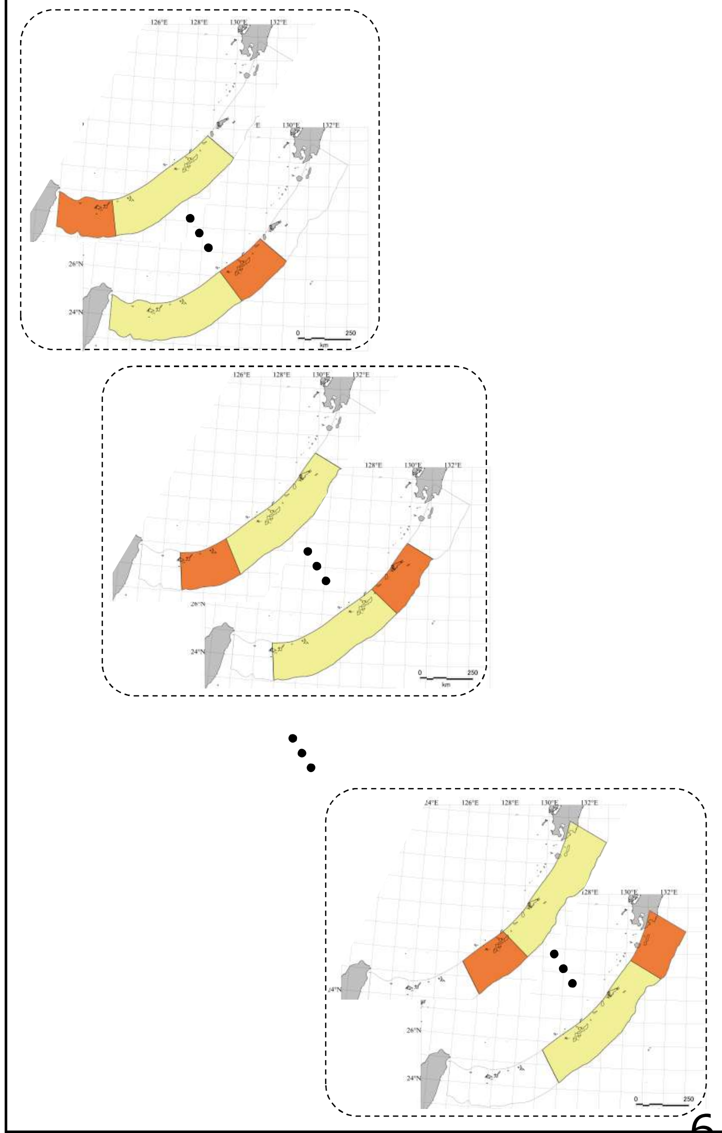
Mw9.4 (N=7)



Mw9.3 (N=21)



Mw9.2 (N=35)

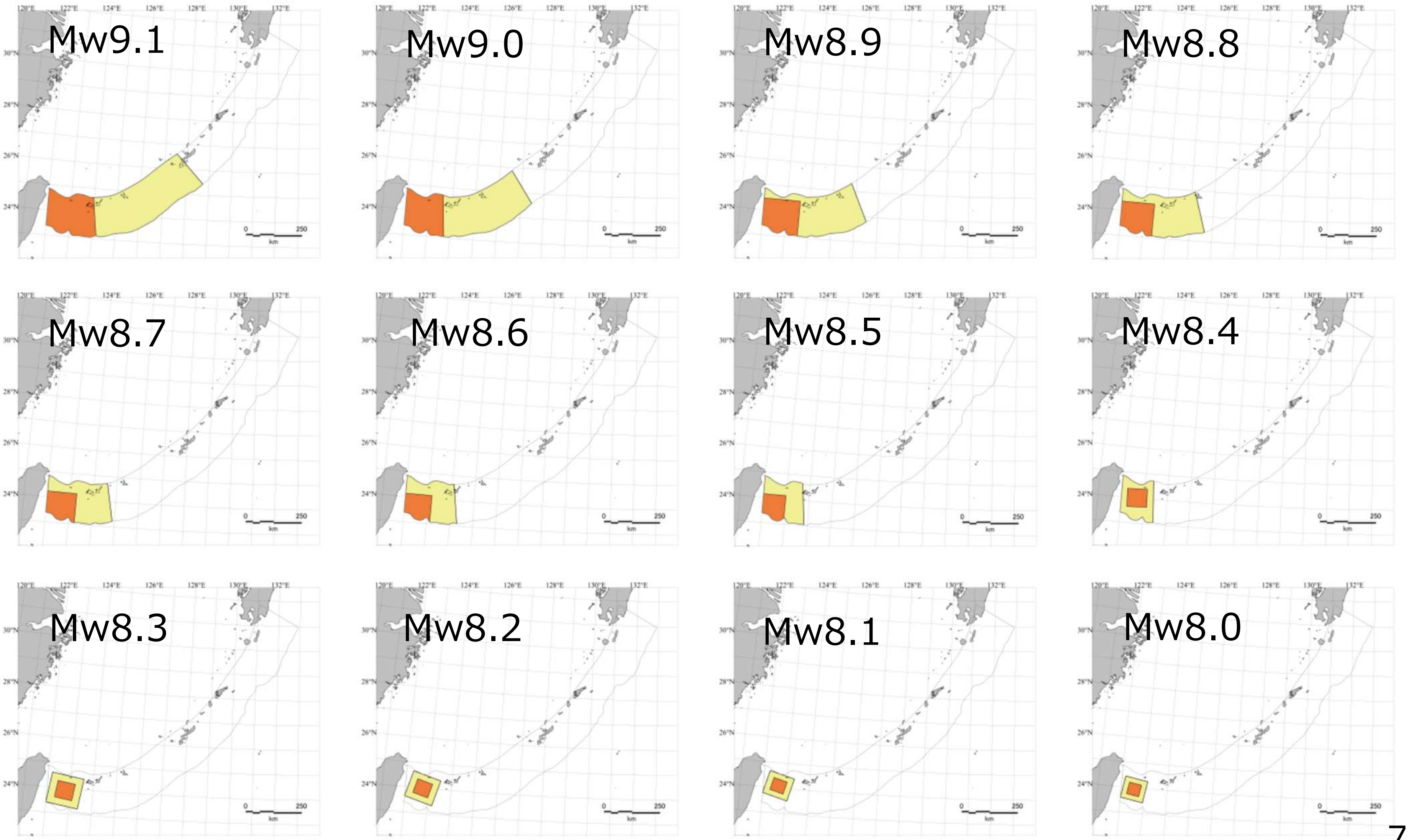


2. Earthquake fault models

- Examples of CEFMs (Mw8.0-9.1)

Large slip area

Background slip area



3. Tsunami propagation simulation

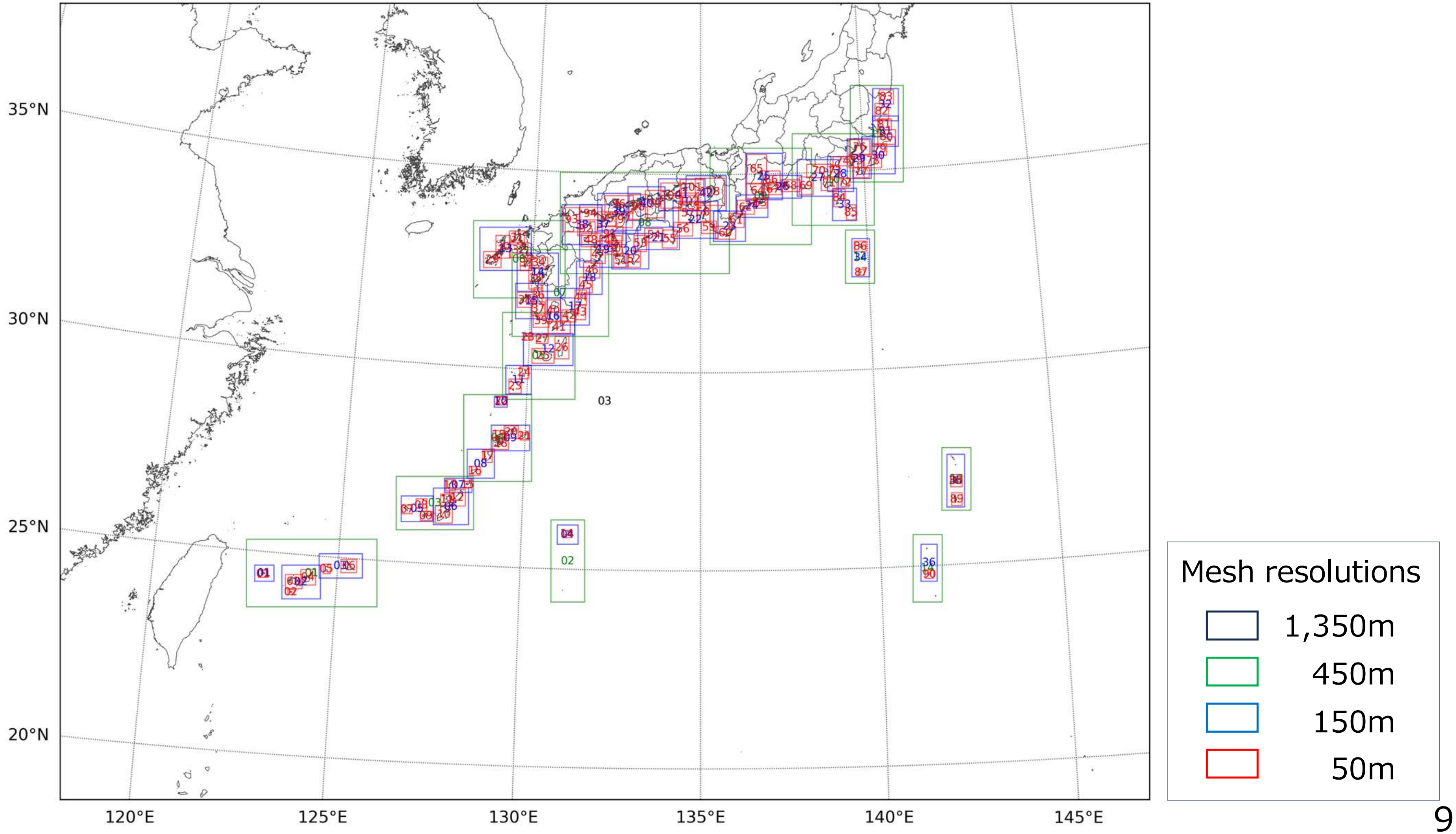
- We simulated tsunami propagation for each earthquake fault model (3,693 CEFMs) based on the calculation conditions shown in the table.

Governing equation	Non-linear long wave theory
Numerical solution	Finite-difference method (FDM) with a leapfrog scheme on a staggered grid
Mesh resolutions	1,350 m, 450 m, 150 m, 50 m
Boundary condition	Land side: run up Offshore side: open
Structures	Not considered
Calculation time	5-12 hours
Initial water level	Seabed movement calculated by Okada[3], considering the effect of horizontal deformation by Tanioka and Satake[4].
Rupture processes	A slip across the entire source fault occurs simultaneously and instantaneously.
Baseline tidal level	Tokyo Peil (T.P.) + 0 m
Censored water depth	10^{-2} m
Roughness coefficient	0.025 $m^{-1/3}$ s

3. Okada (1992): Internal deformation due to shear and tensile faults in a half-space, Bulletin of the Seismological Society of America, Vol.82, pp.1018-1040. https://doi.org/10.1785/BSSA0820021018
4. Tanioka and Satake (1996): Tsunami generation by horizontal displacement of ocean bottom, Geophysical Research Letters, Vol.23, No.8, pp.861-864. https://doi.org/10.1029/96GL00736

3. Tsunami propagation simulation

- We simulated tsunami propagation for each earthquake fault model (3,693 CEFMs) with a minimum grid size of 50 meters, as shown in the figure, to obtain maximum tsunami height at every coastal point.



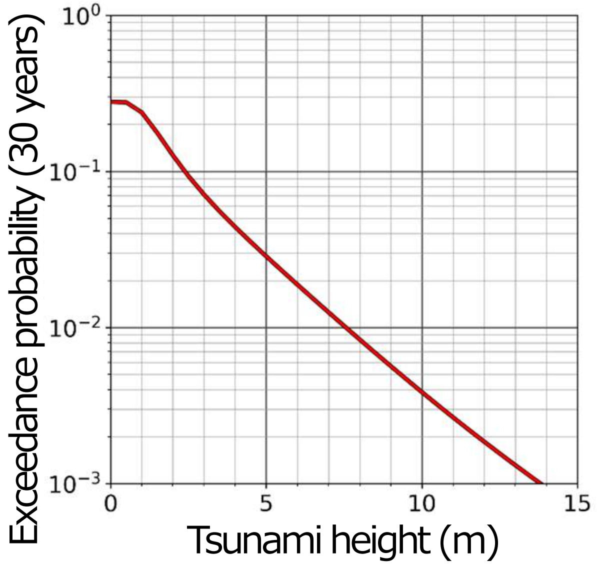
4. Tsunami hazard curves

- We assumed that earthquakes in the Ryukyu subduction zone are occurred to follow a stationary Poisson process and that frequency of those follows a G-R law with b=0.9 (Japanese standard).

- Using JMA earthquake catalog from Jan. 1, 1983 to Dec. 31, 2010, we derived an annual frequency of 8.15 x 10^{-2} for earthquakes (≥ M7.0) in the whole Ryukyu arc except the area around Yonaguni Is. where abnormal high seismicity is being observed; we applied different annual frequency of 3.32 x 10^{-2} there.

- Finally, we obtain tsunami hazard curves at coastal point (every 50 m mesh on the coastlines).

Tsunami hazard curve



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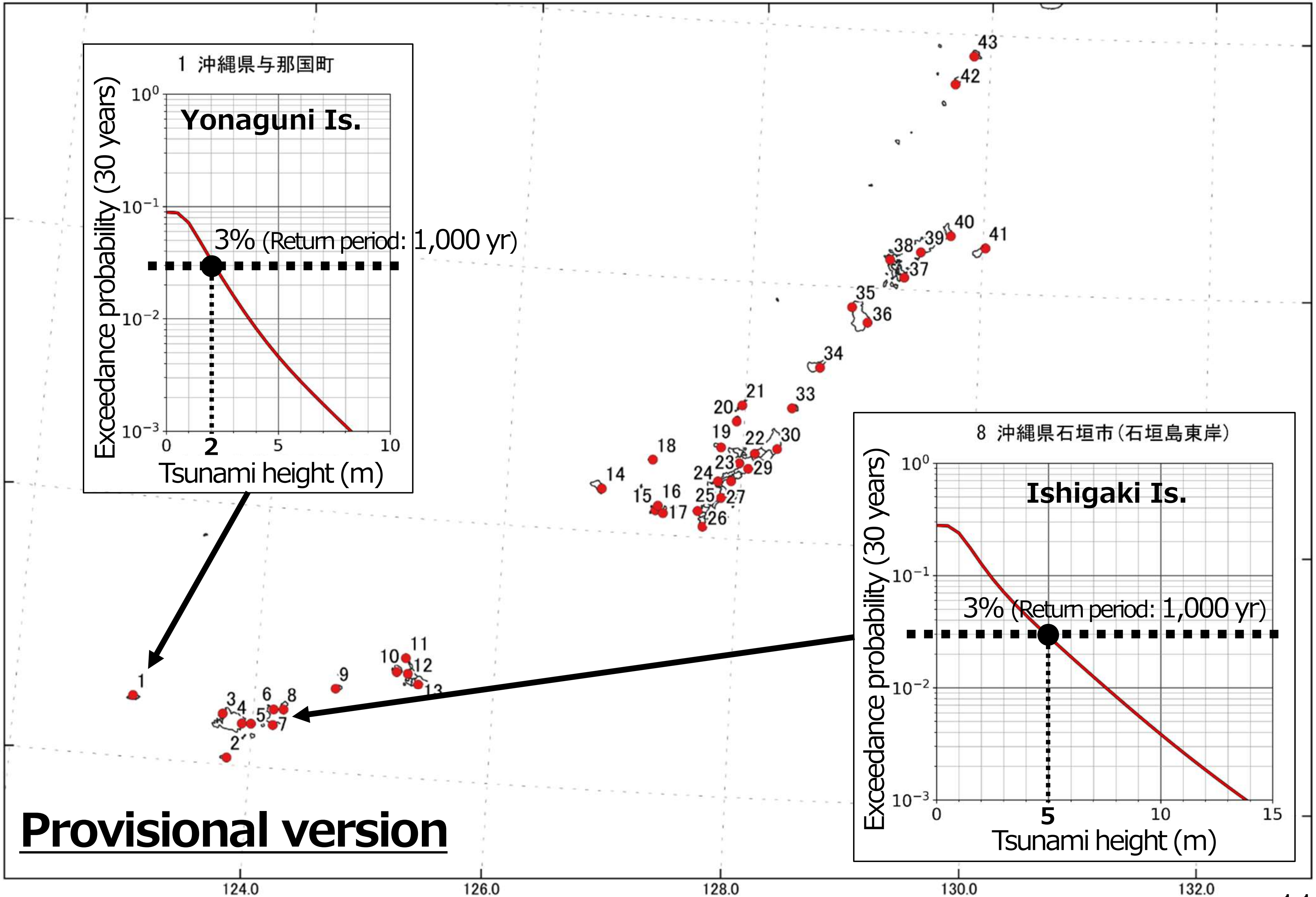
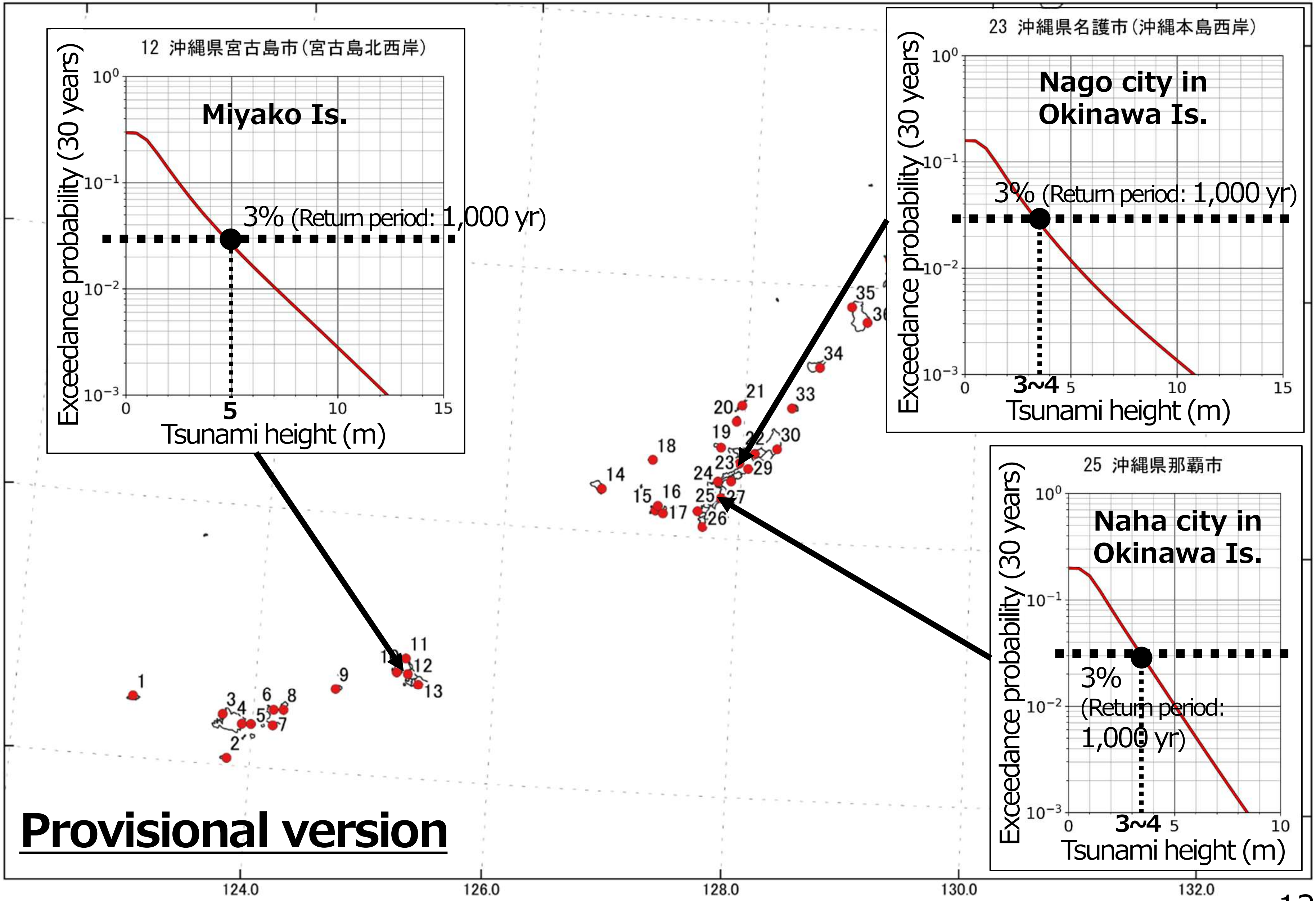
4. Tsunami hazard curves



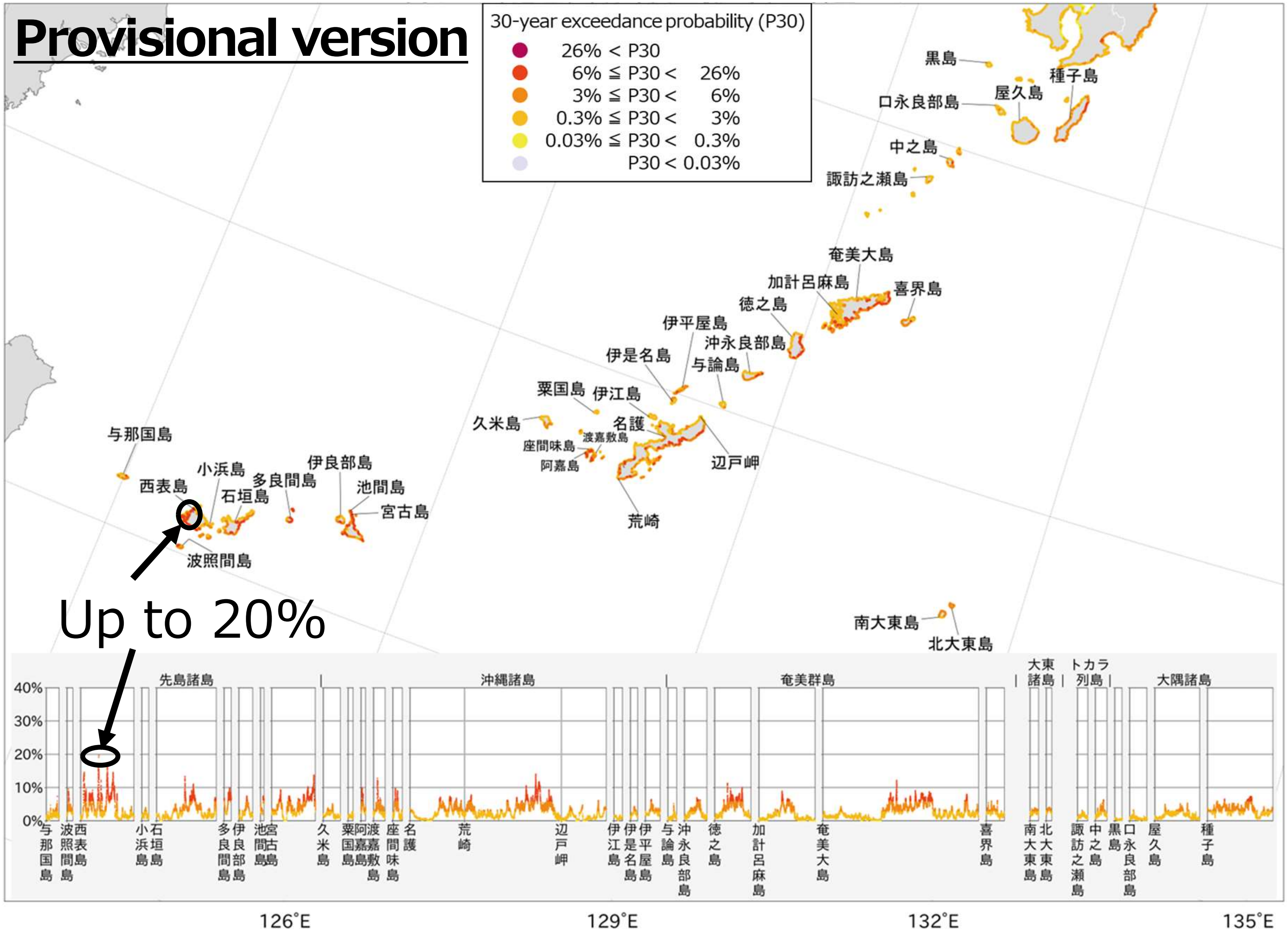
TBC


12 沖縄県宮古島市(宮古島北西岸)
Miyako Is.
3% (Return period: 1,000 yr)
Exceedance probability (30 years)
5
Tsunami height (m)
23 沖縄県名護市(沖縄本島西岸)
Nago city in Okinawa Is.
3% (Return period: 1,000 yr)
3~4
Tsunami height (m)
25 沖縄県那覇市
Naha city in Okinawa Is.
3% (Return period: 1,000 yr)
3~4
Tsunami height (m)
Provisional version

5. Probabilistic tsunami hazard maps

TBC

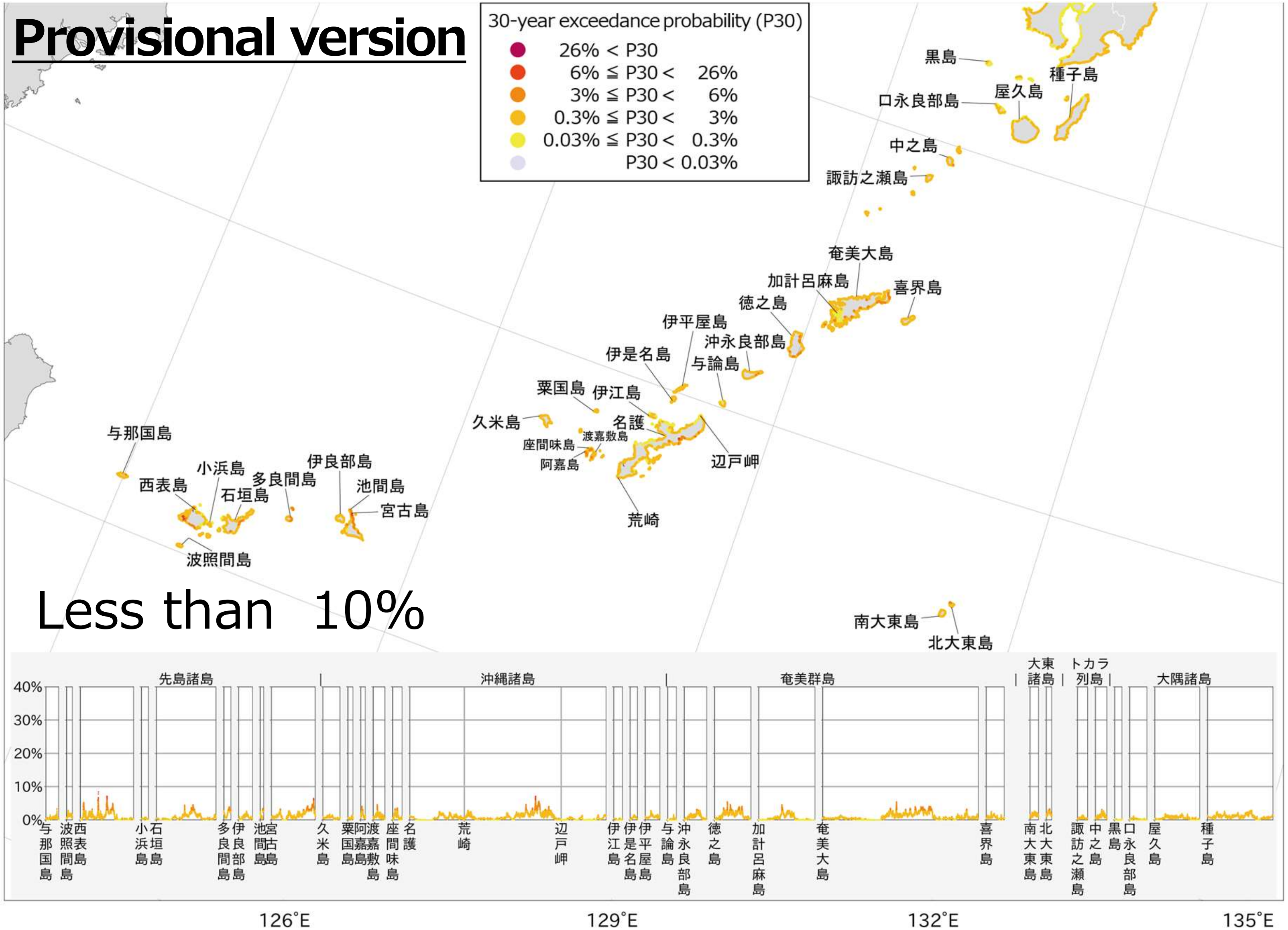
- 30-year exceedance probability that tsunami heights are over **3 m**



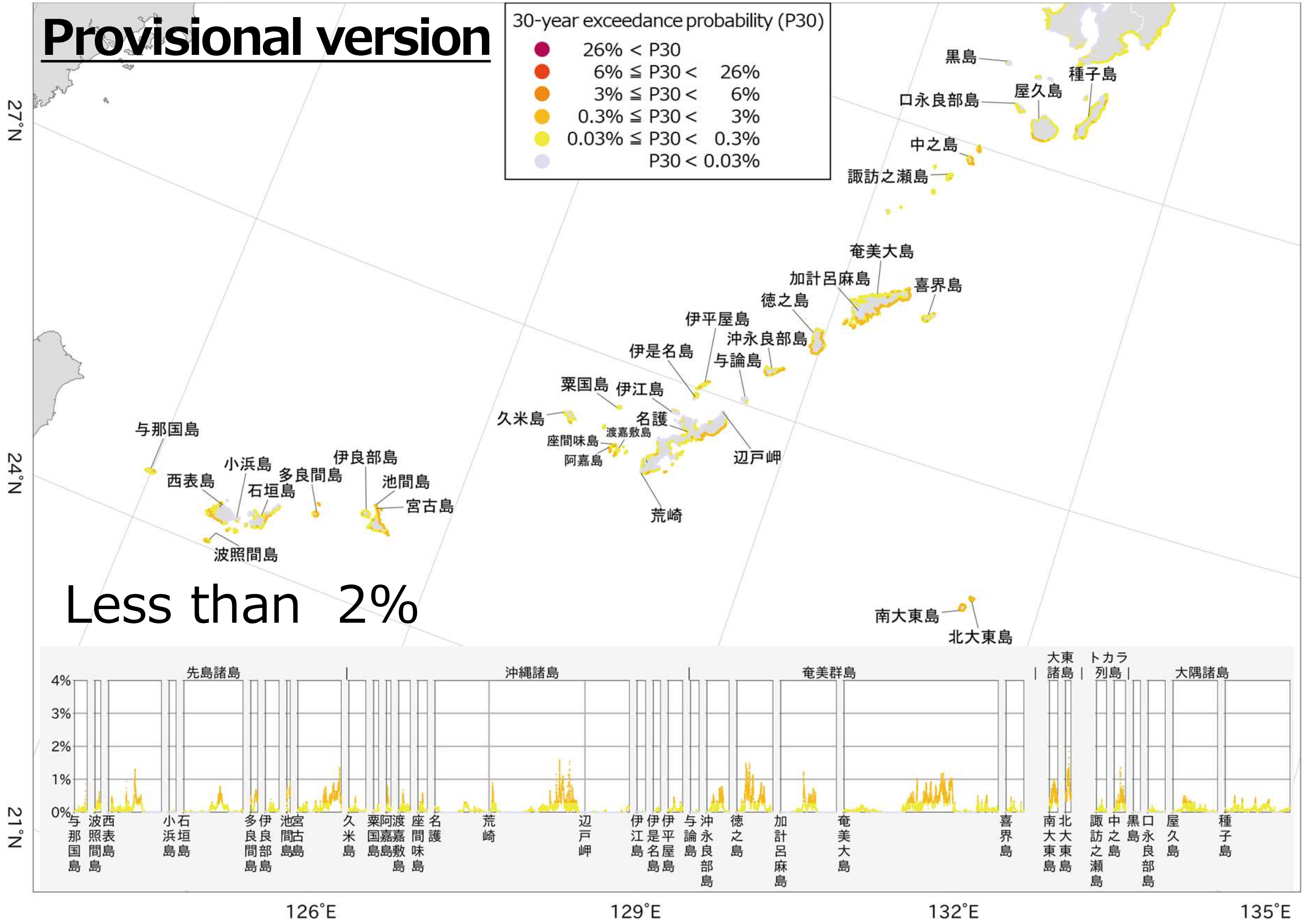
5. Probabilistic tsunami hazard maps

TBC

- 30-year exceedance probability that tsunami heights are over **5 m**



- 30-year exceedance probability that tsunami heights are over **10 m**



6. Conclusions

- We modeled interplate earthquakes occurring along the Ryukyu Trench (Mw7.0～9.4) and assessed a probabilistic tsunami hazard in the view point of long-term mean hazard.
- We placed CEFMs on the 3D upper surface of the subducting Philippine Sea plate; from the southwest edge of Hyuga-nada Sea to 122° east longitude at the depth of 0–60 km.
- Long-term mean hazard assessment suggested that 30-year exceedance probability for tsunami height to be greater than 3 m showed 10% or more (up to 20%) at some coastlines in Ryukyu islands. ←Provisional ver.
- As a future plan, we plan to assess a probabilistic tsunami hazard focusing on not only interplate earthquakes but also intraplate earthquakes and earthquakes occurring in offshore active fault.

Thank you for

your kind attention.

Appendix

Parameter of CEFMs

Mw	Mo(Nm)	面積(km2)	平均すべり量(m)	大すべり量(m)	背景すべり量(m)	波源断層モデル数 ()は震源域数	大すべり域の配置
7.0	3.98E+19	1.01E+03	0.79	1.57	0.45	1078	正方形（中央1個）
7.2	7.94E+19	1.61E+03	0.99	1.98	0.56	702	正方形（中央1個）
7.4	1.58E+20	2.55E+03	1.24	2.49	0.71	441	正方形（中央1個）
7.6	3.16E+20	4.04E+03	1.57	3.13	0.90	245	正方形（中央1個）
7.8	6.31E+20	6.40E+03	1.97	3.94	1.13	156	正方形（中央1個）
8.0	1.26E+21	1.01E+04	2.48	4.96	1.42	93	正方形（中央1個）
8.1	1.78E+21	1.28E+04	2.78	5.57	1.59	77	正方形（中央1個）
8.2	2.51E+21	1.61E+04	3.12	6.25	1.79	48	正方形（中央1個）
8.3	3.55E+21	2.02E+04	3.51	7.01	2.00	38	正方形（中央1個）
8.4	5.01E+21	2.55E+04	3.93	7.87	2.25	31(31)	正方形（中央1個）
8.5	7.08E+21	3.21E+04	4.41	8.82	2.52	153(17)	正方形（ハーフピッチ）
8.6	1.00E+22	4.04E+04	4.95	9.90	2.83	135(15)	正方形（ハーフピッチ）
8.7	1.41E+22	5.09E+04	5.55	11.11	3.17	132(13)	正方形（ハーフピッチ）
8.8	2.00E+22	6.40E+04	6.23	12.46	3.56	110(11)	正方形（ハーフピッチ）
8.9	2.82E+22	8.06E+04	6.99	13.99	4.00	100(10)	正方形（ハーフピッチ）
9.0	3.98E+22	1.01E+05	7.85	15.69	4.48	49(7)	傾斜方向に飽和（走向方向にハーフピッチ）
9.1	5.62E+22	1.28E+05	8.80	17.61	5.03	42(6)	傾斜方向に飽和（走向方向にハーフピッチ）
9.2	7.94E+22	1.61E+05	9.88	19.76	5.64	35(5)	傾斜方向に飽和（走向方向にハーフピッチ）
9.3	1.12E+23	2.02E+05	11.08	22.17	6.33	21(3)	傾斜方向に飽和（走向方向にハーフピッチ）
9.4	1.58E+23	2.54E+05	12.41	24.82	7.09	7(1)	傾斜方向に飽和（走向方向にハーフピッチ）