Outline of "Probabilistic Hazard Assessment of Tsunami due to Large Earthquakes along the Nankai Trough"

English version

Translated in July, 2023

Secretariat of the Headquarters for Earthquake Research Promotion

This document is a translation from Japanese to English of *"「南海トラフ沿いで発生する大地震の確率論的津波評価」の概要"（地震調査研究推進本部事務局）* published in January, 2020.

Background and Objectives of Tsunami Evaluation

- In light of the devastating disaster caused by the tsunami generated by the March 11, 2011 off the Pacific coast of Tohoku Earthquake, the Subcommittee for Tsunami Evaluations was established under the Earthquake Research Committee to examine methods for predicting tsunamis generated by earthquakes and to assess tsunamis using such methods, in order to contribute to tsunami disaster prevention measures.

- The objective is to examine standard methods for tsunami assessment and prediction of tsunami heights based on scientific knowledge, and to present them in a systematic and easy-to-understand manner. The assessment of tsunami hazards takes into account various sources, including not only the largest earthquake, but also earthquakes of potentially recurring sizes.

Key points of this assessment of tsunami

- The Earthquake Research Committee is conducting tsunami assessments for subduction-zone earthquakes for which long-term evaluations have been conducted, based on the "Tsunami prediction method for earthquakes with characterized source faults (Tsunami Recipe)" (published in January 2017).
- The key points are as follows:

✓ The first assessment focuses on the Nankai Trough, which has already undergone long-term evaluations ("Long-term Evaluation of seismic activity along the Nankai Trough (second edition)," published in May 2013).

✓ The assessment targets tsunamis caused by the earthquakes of M8–9 that are equal to or less than the largest historical Hoei Earthquake, and are considered highly likely to occur in the future. "The largest-possible earthquake," whose occurrence is unknown in historical records, is excluded.

✓ In collaboration with other subcommittees under the Earthquake Research Committee, a probabilistic tsunami hazard assessment (PTHA) is conducted to assess tsunamis from various earthquakes.

Structure of this assessment

Structure of "Probabilistic Tsunami Hazard Assessment due to Large Earthquakes along the Nankai Trough"

- Key points
- Summary document (this document)

} *Summary, etc.*

Main text

Index

Chapter 1 Flow chart of this assessment of tsunami

Chapter 2 Setting and weighting patterns for combinations of source areas

Chapter 3 Tsunami prediction method for assumed source faults

Chapter 4 Results of probabilistic tsunami hazard assessment (PTHA)

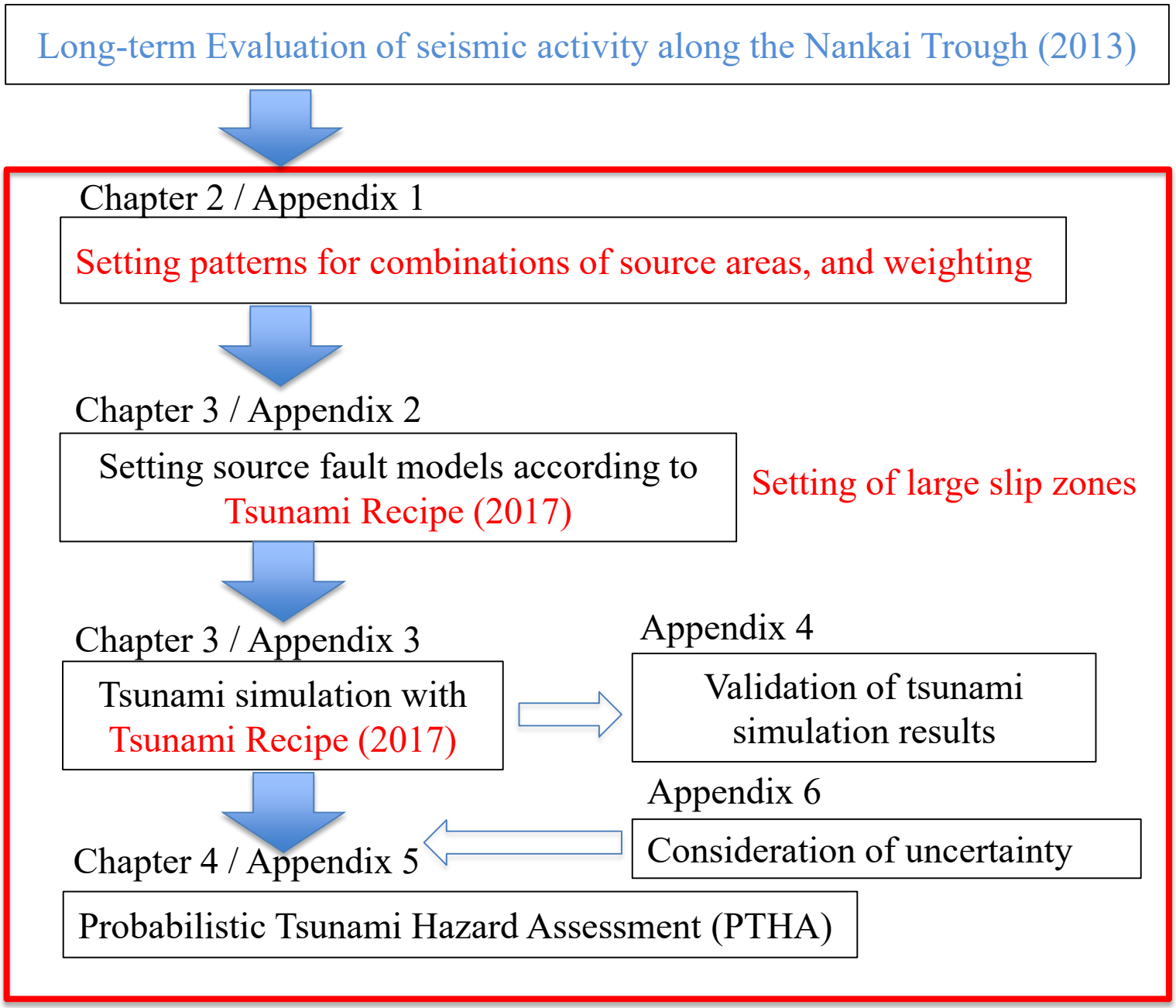
Chapter 5 Precautions regarding utilization

Chapter 6 Future issues

Appendix

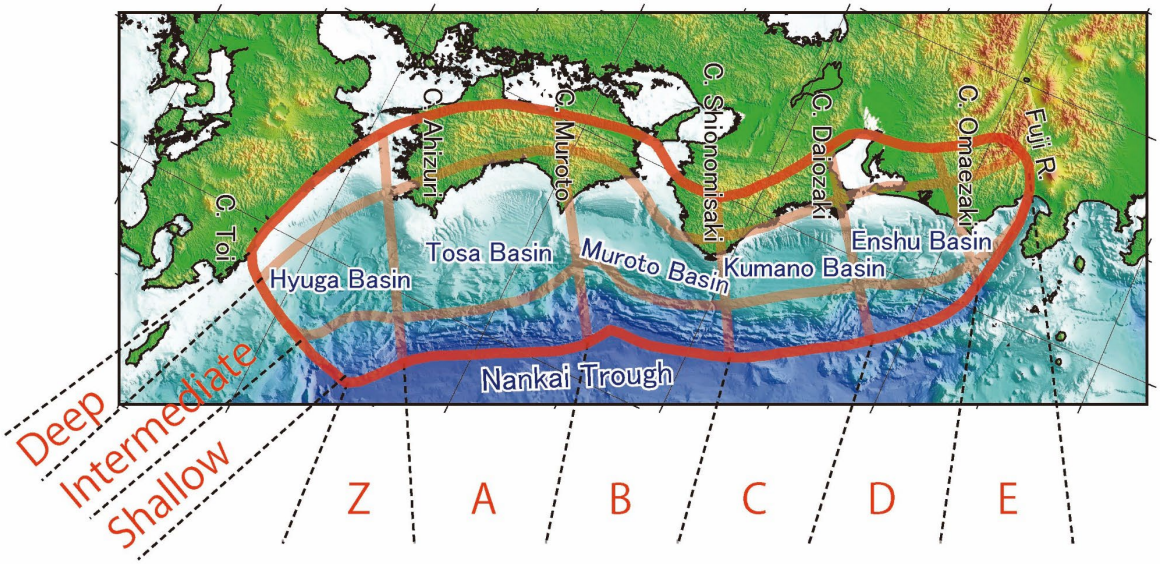
} *Technical materials, etc.*

1. Flow chart of this assessment



- This evaluation targets tsunamis associated with M8–M9-class interplate earthquakes evaluated in the long-term evaluation of seismic activity along the Nankai Trough. The evaluation excludes "the largest-possible earthquake," since its frequency of occurrence is unquantifiable and its associated tsunami is unverifiable according to Tsunami Recipe

- As shown in the figure, the evaluation target area of the Nankai Trough is divided into segments, and their combination patterns are created.
- The following earthquakes are excluded.
  - -Those consisting of only deep part segments
  - -Those that include all of shallow, intermediate, and deep part segments
  - -for E: Those with only shallow part segments from Cape Omaezaki to Fuji River
  - -for Z: Those consisting only of segments between Cape Toi and Cape Ashizuri
- As a result, 176 combination patterns consisting of source areas from M7.6 to M9.0 are created.



Map of evaluation target areas and segments in the Nankai Trough (revised figure in “Long-term Evaluation of seismic activity along the Nankai Trough” (Earthquake Research Committee, 2013))

PTHA requires determining the likelihood (weighting) of each pattern.

The set of 176 patterns are classified into eight sections.
First, weighting is performed for each of the eight sections, and the patterns belonging to the same section are equally weighted.

(1) Branching and weighting distribution according to the number of segments that simultaneously rupture in the strike direction*, considering the long-term evaluation of seismic activity along the Nankai Trough *along strike of the Nankai Trough

Based on combination of source areas of great earthquakes that have occurred along the Nankai Trough in the past, the patterns are classified as follows:

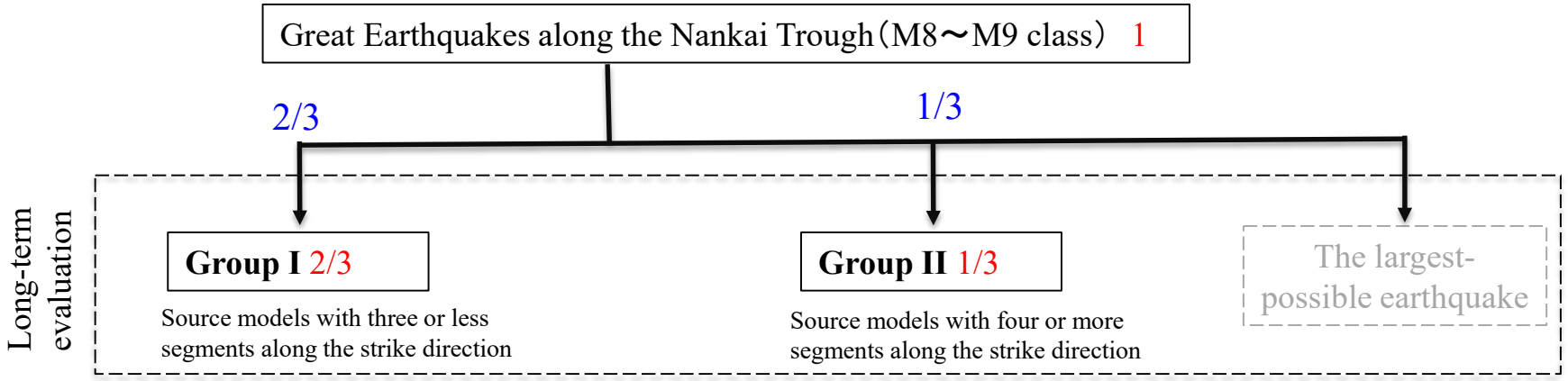
Group I Patterns consisting of source areas where the number of segments that simultaneously rupture in the strike direction is all three or less

Representative patterns: Patterns corresponding to the Ansei Tokai-Nankai Earthquakes and the Showa Tonankai-Nankai Earthquakes

Group II Patterns including source areas with four or more segments that rupture simultaneously in the strike direction

Representative patterns: Patterns corresponding to the Hoei Earthquake

The long-term evaluation of seismic activity along the Nankai Trough indicates that great earthquakes along the Nankai Trough occur repeatedly every 100–200 years, among which Hoei-class great earthquakes occur repeatedly at intervals of 300–600 years. Although there is variation in these frequency of occurrences, considering the recent past frequency of occurrence and the method used in the National Seismic Hazard Maps for Japan, weights of 2/3 and 1/3 are assigned to Groups I and II, respectively.



（2）Branching and weighting distribution according to spread of source areas in the plate-subducting direction (dip direction)

In terms of spread of source areas in the dip direction, both Groups I and II, are divided into two subgroups: “intermediate part only” composed of precedented types and “intermediate part / deep part, intermediate part / shallow part, and shallow part only” composed of unprecedented types. In each group, 4/5 and 1/5 of the overall group weightings are distributed to the to the respective subgroups.

（3）Branching and weighting distribution due to spread of source areas in strike direction

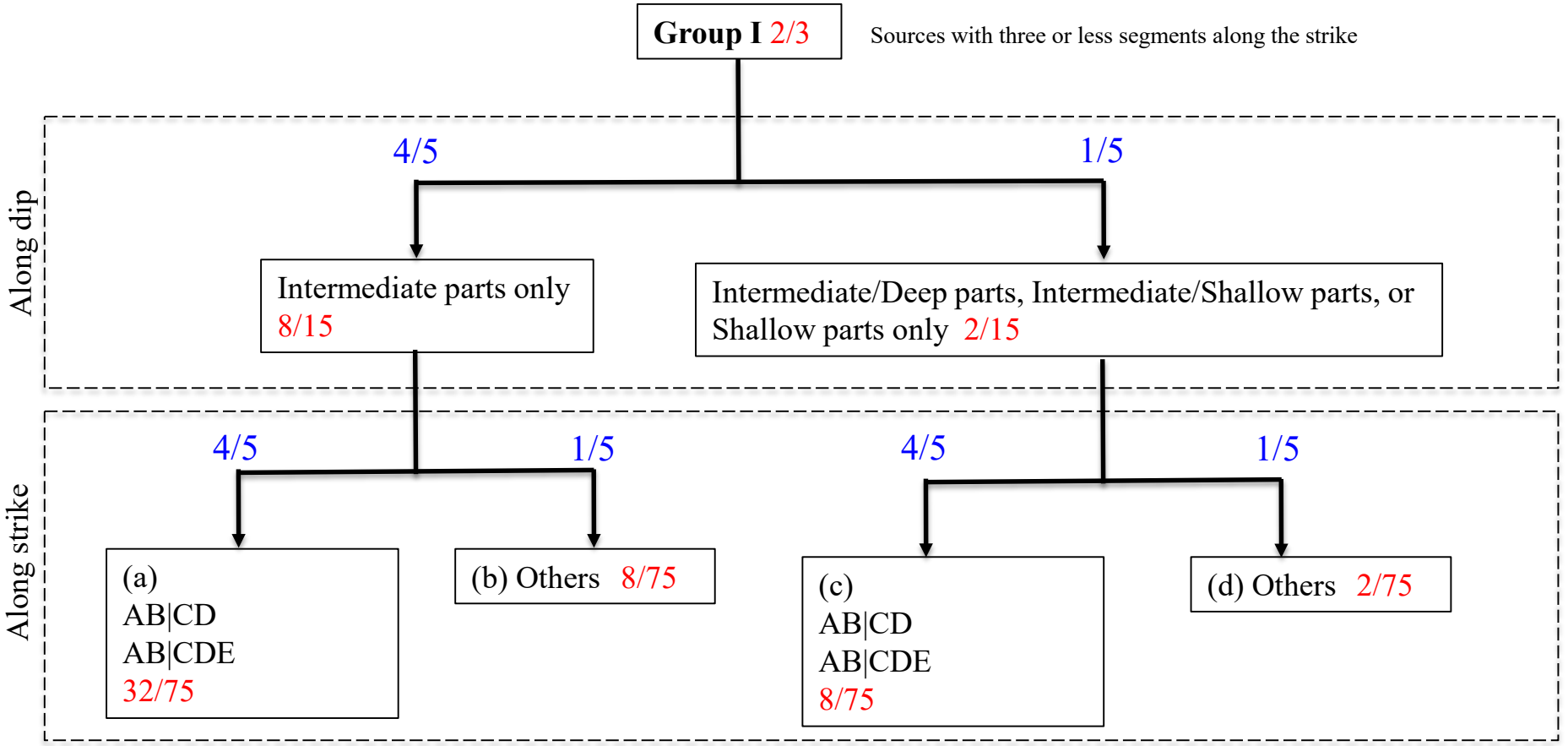
① Two subgroups belonging to Group I

In terms of spread of source areas in the strike direction, the two subgroups are divided into two sub-subgroups: “AB|CD or AB|CDE" composed of precedented types and "others" composed of all other unprecedented types. In each sub-subgroup, 4/5 and 1/5 of the overall subgroup weightings are distributed to the respective sub-subgroups.

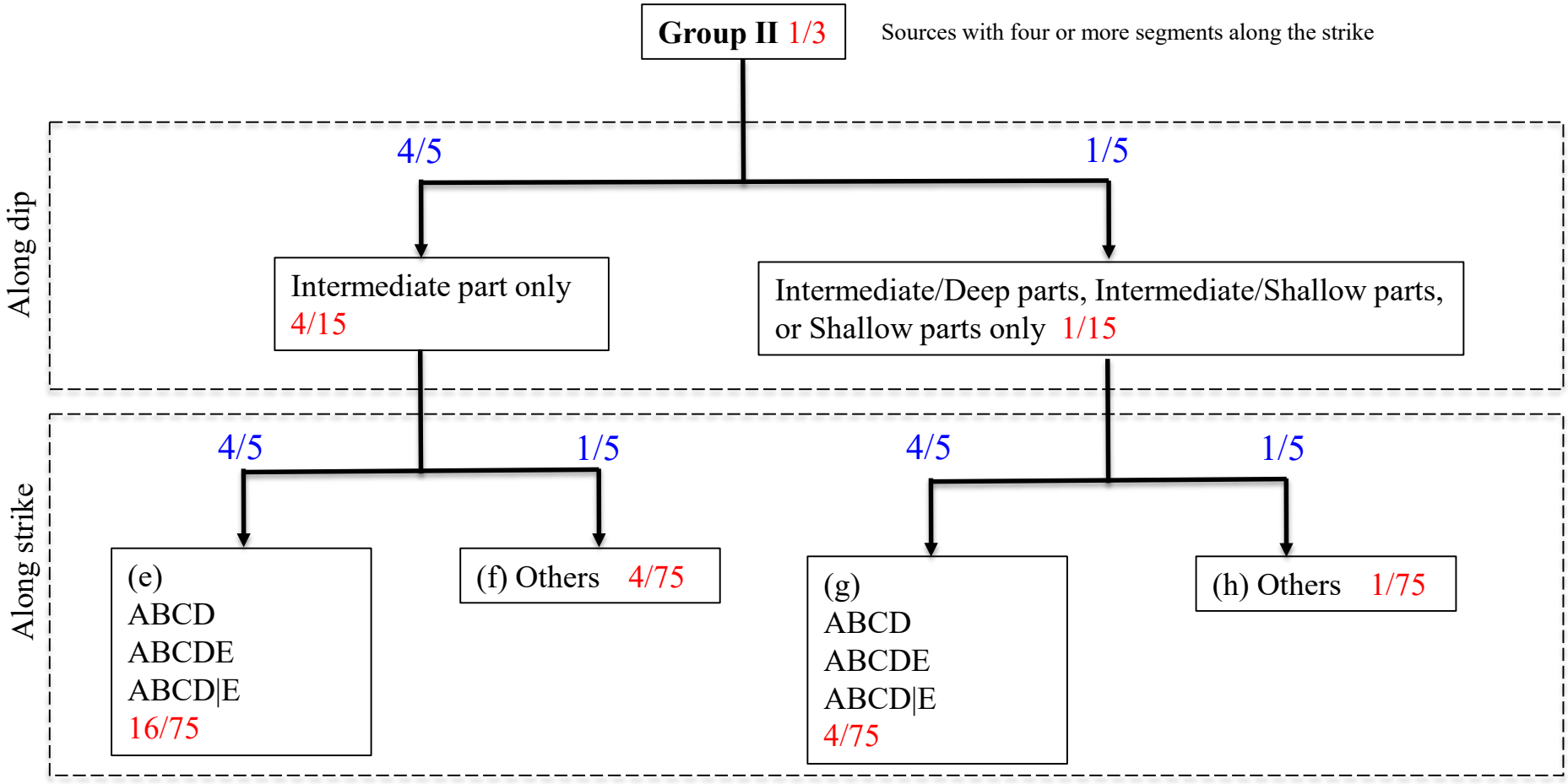
② Two subgroups belonging to Group II

In terms of spread of source areas in the strike direction, the two subgroups are divided into two sub-subgroups: “ABCD, ABCDE, or ABCD|E" composed of precedented types and "others" composed of all other unprecedented types. In each sub-subgroup, 4/5 and 1/5 of the overall subgroup weightings are distributed to the respective sub-subgroups..

2. Weighting（Summary 1）



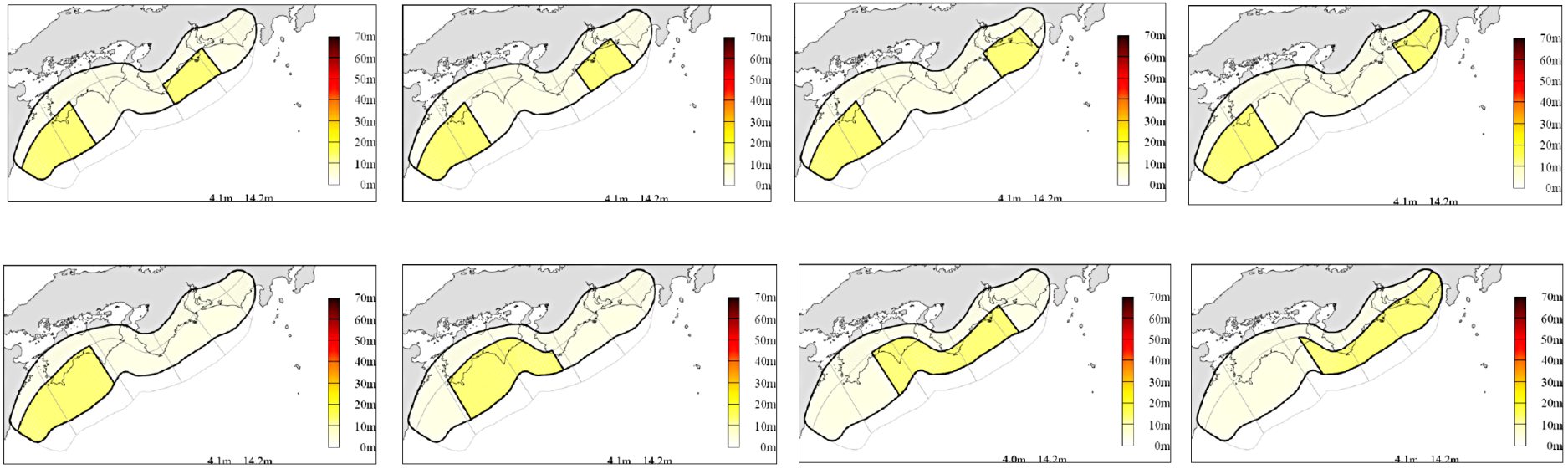
Weights of each part	0.4267	0.1067	0.1067	0.0267
Number of patterns in each part	2	35	6	92
Weight for each pattern	0.2133	0.0030	0.0178	0.0003



Weights of each part	0.2133	0.0533	0.0533	0.0133
Number of patterns in each part	3	8	8	22
Weight for each pattern	0.0711	0.0067	0.0067	0.0006

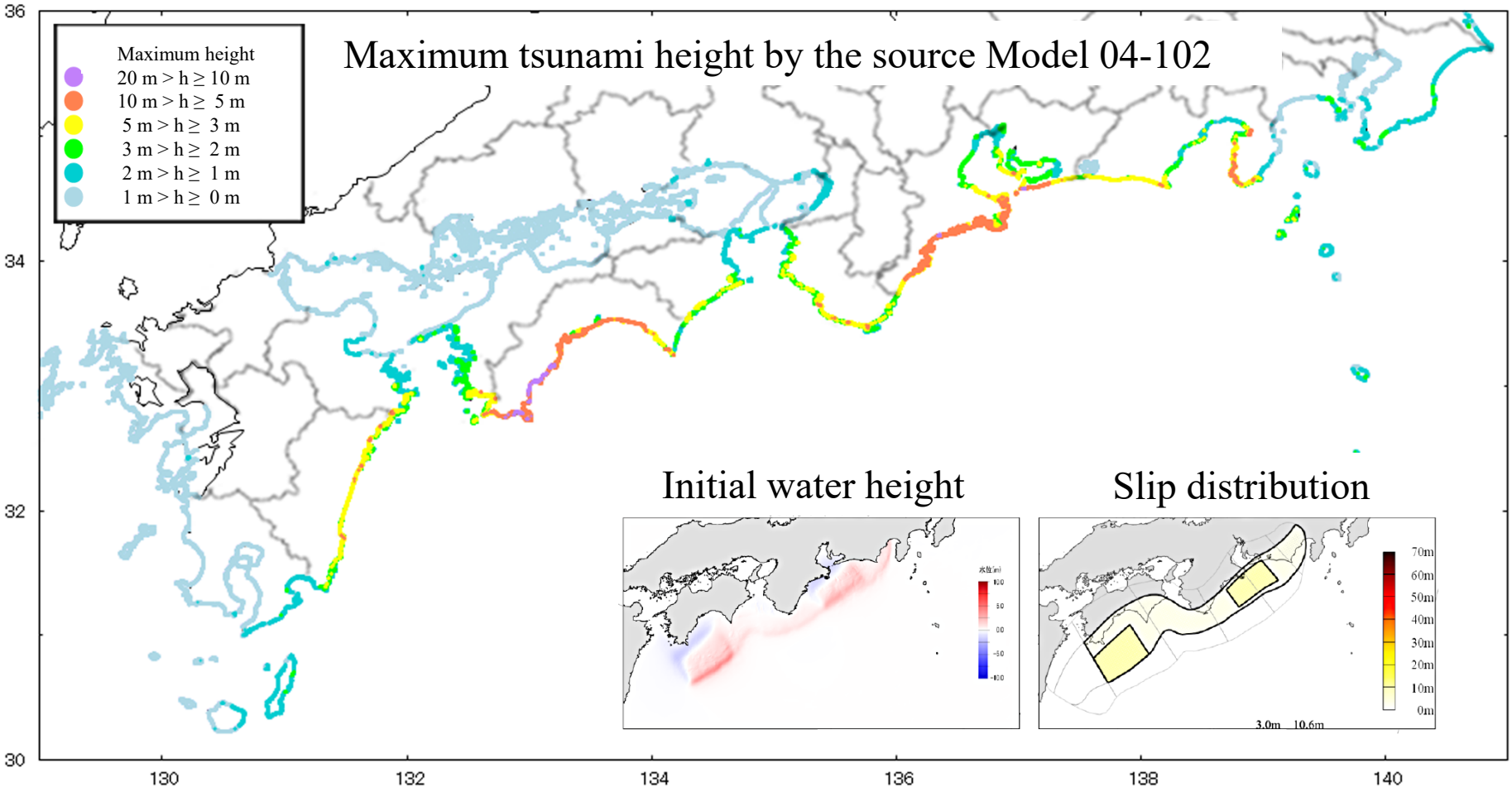
Influence of heterogeneity of fault slip distribution on tsunami generation is taken into consideration according to Tsunami Recipe (2017)

- Large slip zones (30% of the source area) are set to have double slip amount of the background zones.
- No large slip zones are set in the deep part, where large slips unlikely occur.



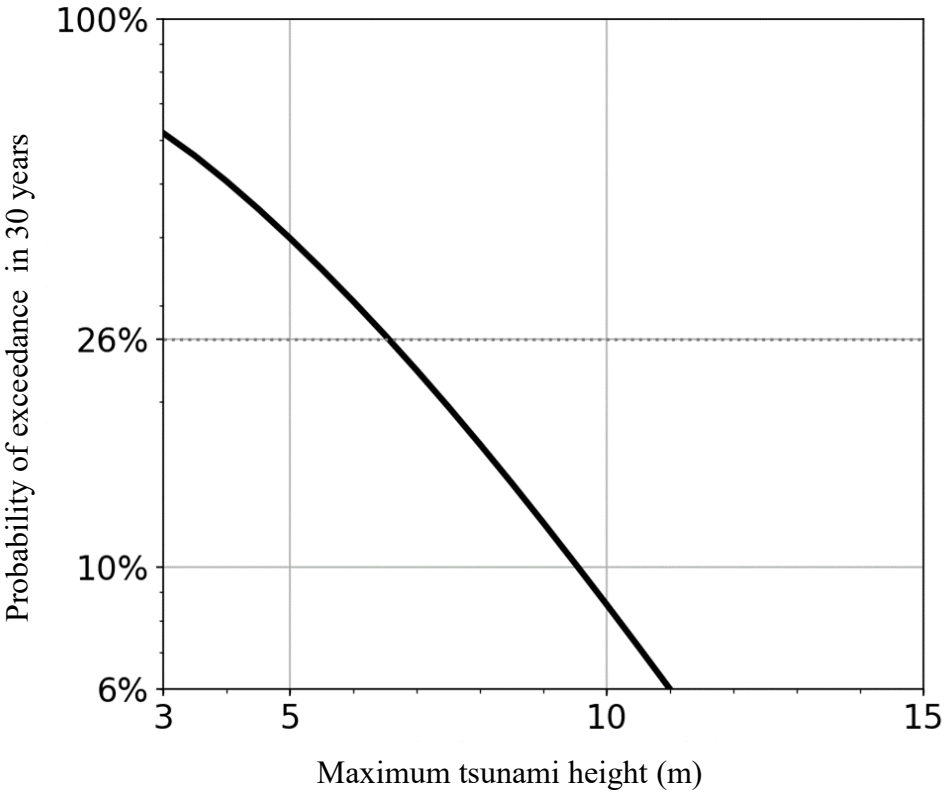
Examples of large slip zone setting in the Nankai Trough (yellow indicates the large slip zones, light yellow indicates the background zones)

Tsunami height is calculated under the configuration of characterized earthquake fault models, according to Tsunami Recipe (2017)



A tsunami hazard curve* is calculated from the superimposition of the tsunami calculation results in 3., which are given appropriate variation and are weighted according to the distribution given in 2.

*Relationship between tsunami height and tsunami probability of exceedance at given certain hazard evaluation point along coastline



- Shown range: the maximum tsunami height is 3 m or higher, and probability of exceedance in 30 years is 6% or more (equivalent to a recurrence-period of 500 years or shorter)
- The dotted line represents 26% (equivalent to a recurrence-period of 100 years)

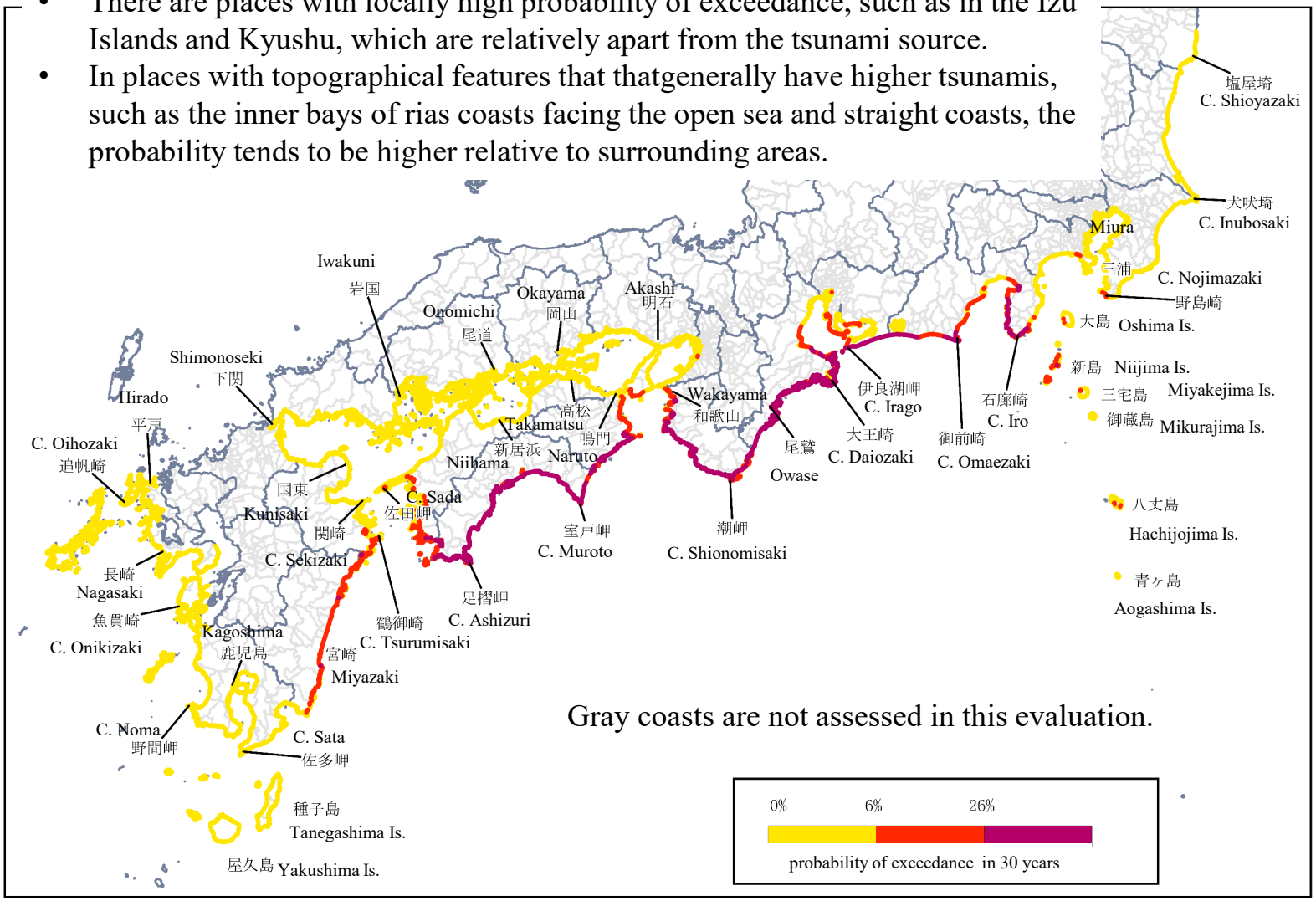
Example of a hazard curve
(Vertical axis is displayed in logarithmic scale)

4. Results of probabilistic tsunami hazard assessment

The probability of tsunami height along the coast being 3 m or higher due to a great earthquake occurring along the Nankai Trough within the next 30 years

Features

- The probability exceeds 26% in wide ranges.
- There are places with locally high probability of exceedance, such as in the Izu Islands and Kyushu, which are relatively apart from the tsunami source.
- In places with topographical features that thatgenerally have higher tsunamis, such as the inner bays of rias coasts facing the open sea and straight coasts, the probability tends to be higher relative to surrounding areas.

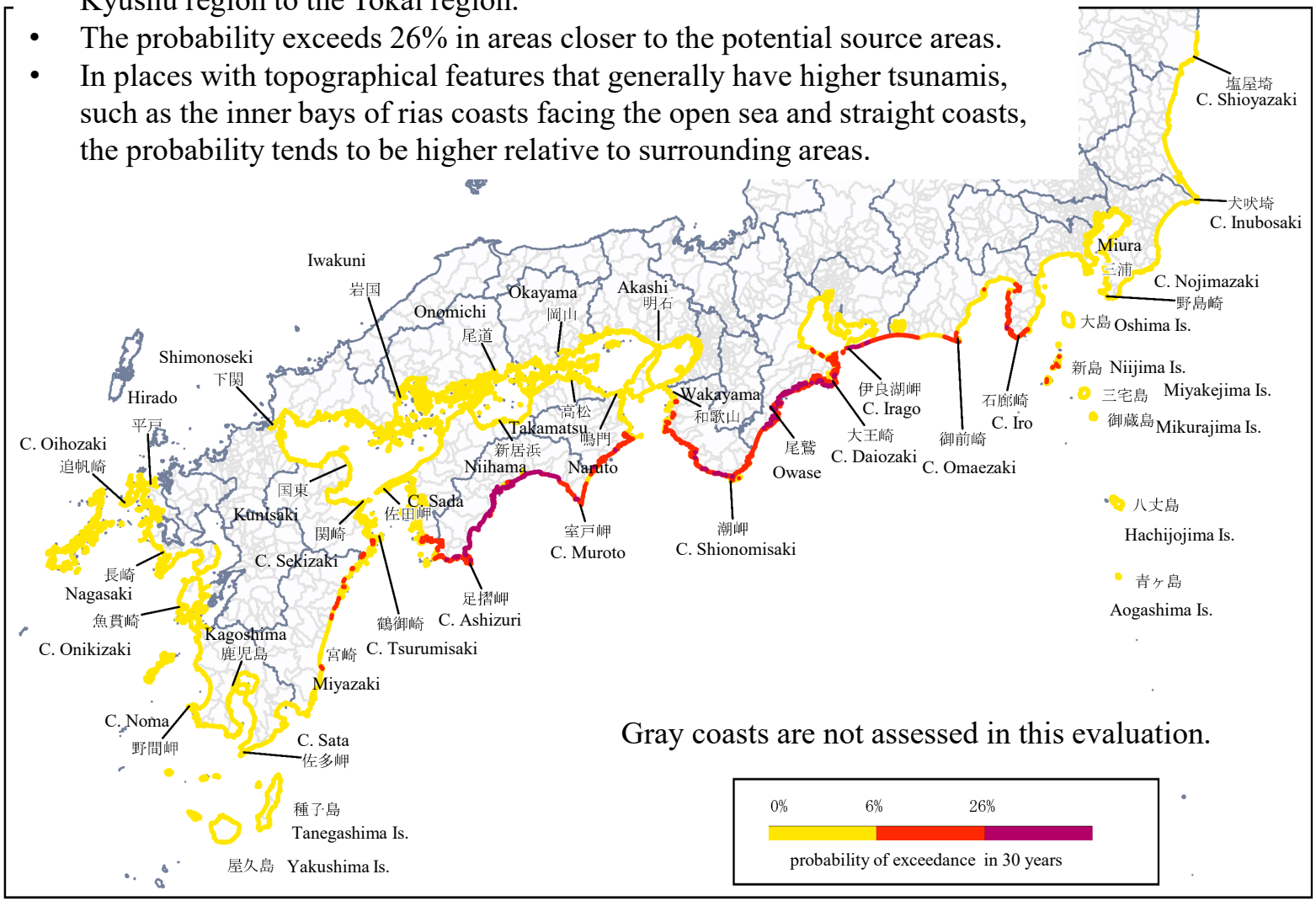


4. Results of probabilistic tsunami hazard assessment

The probability of tsunami height along the coast being 5 m or higher due to a great earthquake occurring along the Nankai Trough within the next 30 years

Features

- The probability exceeds 6% widely, mainly along the Pacific coast from the Kyushu region to the Tokai region.
- The probability exceeds 26% in areas closer to the potential source areas.
- In places with topographical features that generally have higher tsunamis, such as the inner bays of rias coasts facing the open sea and straight coasts, the probability tends to be higher relative to surrounding areas.

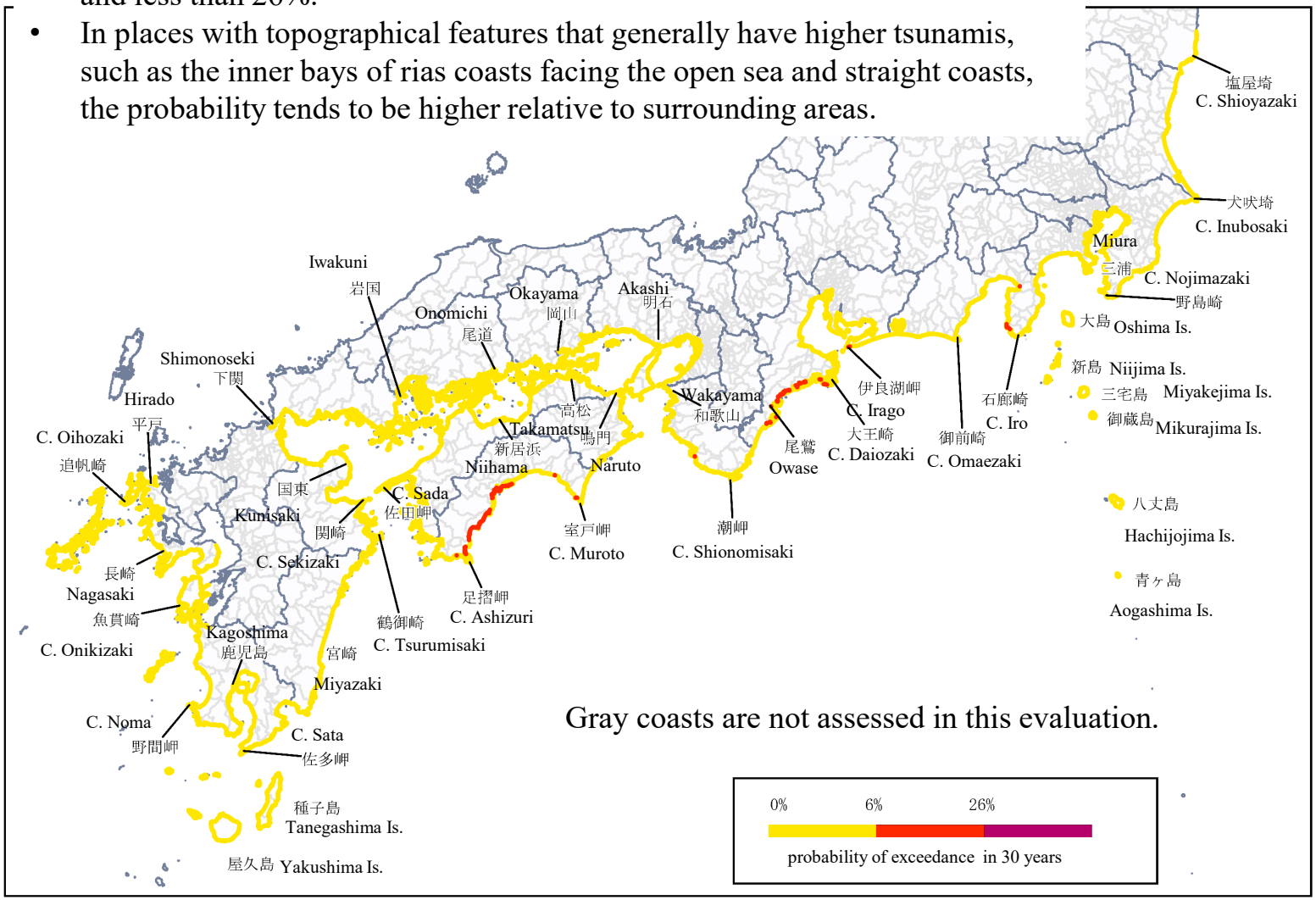


4. Results of probabilistic tsunami hazard assessment

The probability of tsunami height along the coast being 10 m or higher due to a great earthquake occurring along the Nankai Trough within the next 30 years

Features

- Some areas near the potential source areas have probabilities of 6% or more and less than 26%.
- In places with topographical features that generally have higher tsunamis, such as the inner bays of rias coasts facing the open sea and straight coasts, the probability tends to be higher relative to surrounding areas.



4. Results of probabilistic tsunami hazard assessment (continued)

The table shows probability of exceedance in 30 years (≥3 m, ≥5 m, ≥10 m) for each municipality*.

*Subdivided by topographic features, etc., for some cases

Criteria of probability notation

- If it spans multiple categories, all of them are noted with “or”.
- If the portion of the lower category is small, it is excluded.
- If the portion of the upper category is very small, it is noted with “partially”.

(Because, from the perspective of disaster prevention, points with high probability cannot be ignored, but are limited to only a small part of the area)

[Example] Table of probability of exceedance in 30 years for each municipality in Tokushima Prefecture

Prefecture 都道府県名	Municipality 市区町村名	Probability of exceedance in 30 years of X-m or higher tsunami in each municipality due to a great earthquake along the Nankai Trough		
		3 m	5 m	10 m
徳島県	徳島市	6％未満 p<6% or または 6≤ p <26% 6％以上２６％未満	6％未満 p<6%	6％未満 p<6%
	鳴門市（紀伊水道）	6％未満 または 6％以上２６％未満	6％未満	6％未満
	鳴門市（ウチノ海）	6％未満 一部６％以上２６％未満	6％未満	6％未満
	鳴門市（播磨灘）	6％未満	6％未満	6％未満
	小松島市	6％未満 または 6％以上２６％未満	6％未満	6％未満
	阿南市	6％未満 または 6％以上２６％未満 または ２６％以上	6％未満 または 6％以上２６％未満	6％未満
	牟岐町	２６％以上	6％以上２６％未満	6％未満
	美波町	6％以上２６％未満 または ２６％以上	6％以上２６％未満 一部２６％以上	6％未満
	海陽町	6％以上２６％未満 または ２６％以上	6％未満 または 6％以上２６％未満 一部２６％以上	6％未満 一部６％以上２６％未満
	松茂町	6％未満 または 6％以上２６％未満	6％未満	6％未満

- There are presumably many places included in the charts of this tsunami assessment, where the main cause of the most frequent and high tsunamis are mainly due to “other factors” than large earthquakes along the Nankai Trough. We are planning to proceed with tsunami assessment that includes other influential factors, such as the earthquakes excluded from this tsunami assessment. Even so, the values of the probability of exceedance shown here will not decrease, although they may increase.

- This tsunami assessment targets the tsunamis caused by the next earthquake along the Nankai Trough that is equal to or less than the largest historical Hoei Earthquake. The assessment excluded “the largest-possible earthquake”, because a comparison and verification of the evaluation results based on Tsunami Recipe and the actual measurements are impossible. The frequency of occurrence of “the largest-possible earthquake” is unquantifiable; it seldom occurs, but its possibility cannot be ruled out.

- This tsunami assessment excludes earthquakes that occur independently in the Hyuga-nada Sea ("Z" segment in the strike direction). For such earthquakes, we are planning a separate tsunami assessment based on the long-term evaluation of seismic activity along the Hyuga-nada Sea.

- Uncertainty regarding the spread of individual source faults and source areas (earthquake diversity) is factored into this tsunami assessment by combining many assumed source areas, source fault models, and their weighting. Additionally, uncertainty in tsunami calculation due to characterized sources based on the Tsunami Recipe is incorporated into this tsunami assessment by giving variations to the tsunami calculation results. However, there still remain residual uncertainties in this tsunami assessment, such as:
  (a) Uncertainty included in the evaluation of the probability of occurrence of a great earthquake in long-term evaluation
  (b) Unconsidered uncertainty in source fault settings (segmentation, branch faults, etc.)

○ In the PTHA, low probability of exceedance of the maximum tsunami height should not be interpreted as an inundation that the location is generally safe against tsunamis.

○This tsunami assessment evaluates the maximum tsunami height, which should not be confused with the inundation depth. The parameters of the source fault model and the calculation results for each model will be published separately, which are useable as needed to estimate tsunami inundation due to individual earthquakes that are likely to occur in the future (excluding “the largest-possible earthquake”). Additionally, related organizations are preparing to create a system for acquiring data related to this tsunami assessment.

○The probability of exceedance and recurrence period in this tsunami assessment are for tsunamis caused by earthquakes that are highly likely to occur in the future, and they are different from the occurrence probability and recurrence period of tsunamis caused by previous earthquakes.

○Related organizations are investigating and researching how to utilize the PTHA for tsunami disaster prevention measures. More widespread and effective use of this tsunami assessment in tsunami disaster prevention measures requires the presentation of the significance and effectiveness of probabilistic assessments as well as the assumptions and limitations of assessments to users in an easy-to-understand manner, and further research and investigations are needed based on comments from users.

○ This assessment should be updated when the long-term evaluation of seismic activity along the Nankai Trough will be revised. In particular, this tsunami assessment needs to be updated when the following points are updated in the long-term evaluation:

- When the occurrence probability, source area, and magnitude of great earthquakes are changed considerably based on new knowledge.
- When new knowledge is obtained on how to allocate weights for large slip zones, etc.
- When new knowledge is obtained on earthquakes involving branch faults.

○When new knowledge on more reliable tsunami traces is obtained, then the validation of tsunami prediction methods (especially Tsunami Recipe) can be more appropriately confirmed, which will lead to improve the accuracy of the PTHA.

Source area combination patterns, weights distributed to each pattern, number of cases included in each pattern

	Depth	Source areas Z	A	B	C	D	E	Weight	N
1	Shallow							0.0711	151
	Intermediate		■	■	■	■			
	Deep								
2	Shallow							0.0030	678
	Intermediate		■	■	■	■			
	Deep								
3	Shallow							0.2133	144
	Intermediate		■	■	■	■			
	Deep								
4	Shallow							0.0030	648
	Intermediate		■	■	■	■			
	Deep								
5	Shallow							0.0030	684
	Intermediate		■	■	■	■			
	Deep								
6	Shallow							0.0030	3,096
	Intermediate		■	■	■	■			
	Deep								
7	Shallow							0.0030	648
	Intermediate		■	■	■	■			
	Deep								
8	Shallow							0.0030	2,916
	Intermediate		■	■	■	■			
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
9	Shallow							0.0711	150
	Intermediate		■	■	■	■			
	Deep								
10	Shallow							0.0030	1,017
	Intermediate		■	■	■	■			
	Deep								
11	Shallow							0.2133	144
	Intermediate		■	■	■	■			
	Deep								
12	Shallow							0.0030	972
	Intermediate		■	■	■	■			
	Deep								
13	Shallow							0.0067	684
	Intermediate		■	■	■	■			
	Deep								
14	Shallow							0.0030	4,644
	Intermediate		■	■	■	■			
	Deep								
15	Shallow							0.0030	648
	Intermediate		■	■	■	■			
	Deep								
16	Shallow							0.0030	4,374
	Intermediate		■	■	■	■			
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
17	Shallow							0.0711	906
	Intermediate		■	■	■	■	■		
	Deep								
18	Shallow							0.0030	4,068
	Intermediate		■	■	■	■	■		
	Deep								
19	Shallow							0.0030	864
	Intermediate		■	■	■	■	■		
	Deep								
20	Shallow							0.0030	3,888
	Intermediate		■	■	■	■	■		
	Deep								
21	Shallow							0.0030	4,104
	Intermediate		■	■	■	■	■		
	Deep								
22	Shallow							0.0030	18,576
	Intermediate		■	■	■	■	■		
	Deep								
23	Shallow							0.0030	3,888
	Intermediate		■	■	■	■	■		
	Deep								
24	Shallow							0.0030	17,496
	Intermediate		■	■	■	■	■		
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
25	Shallow							0.0067	150
	Intermediate	■	■	■	■	■			
	Deep								
26	Shallow							0.0067	678
	Intermediate	■	■	■	■	■			
	Deep								
27	Shallow							0.0030	144
	Intermediate	■	■	■	■	■			
	Deep								
28	Shallow							0.0030	648
	Intermediate	■	■	■	■	■			
	Deep								
29	Shallow							0.0030	1,368
	Intermediate	■	■	■	■	■			
	Deep								
30	Shallow							0.0030	6,192
	Intermediate	■	■	■	■	■			
	Deep								
31	Shallow							0.0030	1,296
	Intermediate	■	■	■	■	■			
	Deep								
32	Shallow							0.0030	5,832
	Intermediate	■	■	■	■	■			
	Deep								

Source area combination patterns, weights distributed to each pattern, number of cases included in each pattern (continued)

	Depth	Source areas Z	A	B	C	D	E	Weight	N
33	Shallow / Intermediate / Deep		■	■	■	■	■	0.0067	150
34	Shallow / Intermediate / Deep		■	■	■	■		0.0067	1,017
35	Shallow / Intermediate / Deep		■	■		■	■	0.0030	144
36	Shallow / Intermediate / Deep		■	■		■		0.0030	972
37	Shallow / Intermediate / Deep		■		■	■	■	0.0067	1,368
38	Shallow / Intermediate / Deep		■	■	■			0.0030	9,288
39	Shallow / Intermediate / Deep		■	■		■	■	0.0030	1,296
40	Shallow / Intermediate / Deep		■	■	■	■		0.0030	8,748
41	Shallow / Intermediate / Deep		■	■	■	■	■	0.0067	900
42	Shallow / Intermediate / Deep		■	■	■			0.0067	4,068
43	Shallow / Intermediate / Deep		■	■		■	■	0.0030	864
44	Shallow / Intermediate / Deep		■	■				0.0030	3,888
45	Shallow / Intermediate / Deep		■		■	■	■	0.0030	8,208
46	Shallow / Intermediate / Deep		■	■	■			0.0030	37,152
47	Shallow / Intermediate / Deep		■	■		■	■	0.0030	7,776
48	Shallow / Intermediate / Deep		■	■				0.0030	34,992
49	Shallow / Intermediate / Deep			■	■	■		0.0067	86
50	Shallow / Intermediate / Deep			■	■			0.0003	396
51	Shallow / Intermediate / Deep			■		■		0.0178	81
52	Shallow / Intermediate / Deep			■	■	■		0.0003	324
53	Shallow / Intermediate / Deep			■	■	■		0.0003	396
54	Shallow / Intermediate / Deep			■	■			0.0003	1,620
55	Shallow / Intermediate / Deep			■	■	■		0.0003	324
56	Shallow / Intermediate / Deep			■	■	■	■	0.0003	1,296
57	Shallow / Intermediate / Deep			■	■	■	■	0.0067	86
58	Shallow / Intermediate / Deep			■	■			0.0003	396
59	Shallow / Intermediate / Deep			■		■	■	0.0178	81
60	Shallow / Intermediate / Deep			■	■		■	0.0003	324
61	Shallow / Intermediate / Deep			■		■	■	0.0006	396
62	Shallow / Intermediate / Deep			■	■	■		0.0003	1,620
63	Shallow / Intermediate / Deep			■	■		■	0.0003	324
64	Shallow / Intermediate / Deep			■	■	■	■	0.0003	1,296

Source area combination patterns, weights distributed to each pattern, number of cases included in each pattern (continued)

	Depth	Source areas Z	A	B	C	D	E	Weight	N
65	Shallow		■	■	■	■	■	0.0067	516
	Intermediate		■	■	■	■	■		
	Deep		■	■	■	■	■		
66	Shallow		■	■	■	■	■	0.0003	2,376
	Intermediate		■	■	■	■	■		
	Deep								
67	Shallow		■	■	■	■	■	0.0003	486
	Intermediate		■	■	■	■	■		
	Deep								
68	Shallow		■	■	■	■	■	0.0003	1,944
	Intermediate		■	■	■	■	■		
	Deep								
69	Shallow		■	■	■	■	■	0.0003	2,376
	Intermediate		■	■	■	■	■		
	Deep								
70	Shallow		■	■	■	■	■	0.0003	9,720
	Intermediate		■	■	■	■	■		
	Deep								
71	Shallow		■	■	■	■	■	0.0003	1,944
	Intermediate		■	■	■	■	■		
	Deep								
72	Shallow		■	■	■	■	■	0.0003	7,776
	Intermediate		■	■	■	■	■		
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
73	Shallow		■	■	■	■	■	0.0006	86
	Intermediate		■	■	■	■	■		
	Deep		■	■	■	■	■		
74	Shallow		■	■	■	■	■	0.0006	354
	Intermediate		■	■	■	■	■		
	Deep								
75	Shallow		■	■	■	■	■	0.0003	81
	Intermediate		■	■	■	■	■		
	Deep								
76	Shallow		■	■	■	■	■	0.0003	324
	Intermediate		■	■	■	■	■		
	Deep								
77	Shallow		■	■	■	■	■	0.0003	594
	Intermediate		■	■	■	■	■		
	Deep								
78	Shallow		■	■	■	■	■	0.0003	2,430
	Intermediate		■	■	■	■	■		
	Deep								
79	Shallow		■	■	■	■	■	0.0003	486
	Intermediate		■	■	■	■	■		
	Deep								
80	Shallow		■	■	■	■	■	0.0003	1,944
	Intermediate		■	■	■	■	■		
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
81	Shallow	■	■	■	■	■	■	0.0006	86
	Intermediate	■	■	■	■	■	■		
	Deep								
82	Shallow	■	■	■	■	■	■	0.0006	354
	Intermediate	■	■	■	■	■	■		
	Deep								
83	Shallow	■	■	■	■	■	■	0.0003	81
	Intermediate	■	■	■	■	■	■		
	Deep								
84	Shallow	■	■	■	■	■	■	0.0003	324
	Intermediate	■	■	■	■	■	■		
	Deep								
85	Shallow	■	■	■	■	■	■	0.0006	594
	Intermediate	■	■	■	■	■	■		
	Deep								
86	Shallow	■	■	■	■	■	■	0.0003	2,430
	Intermediate	■	■	■	■	■	■		
	Deep								
87	Shallow	■	■	■	■	■	■	0.0003	486
	Intermediate	■	■	■	■	■	■		
	Deep								
88	Shallow	■	■	■	■	■	■	0.0003	1,944
	Intermediate	■	■	■	■	■	■		
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
89	Shallow	■	■	■	■	■	■	0.0006	516
	Intermediate	■	■	■	■	■	■		
	Deep								
90	Shallow	■	■	■	■	■	■	0.0006	2,124
	Intermediate	■	■	■	■	■	■		
	Deep								
91	Shallow	■	■	■	■	■	■	0.0003	486
	Intermediate	■	■	■	■	■	■		
	Deep								
92	Shallow	■	■	■	■	■	■	0.0003	1,944
	Intermediate	■	■	■	■	■	■		
	Deep								
93	Shallow	■	■	■	■	■	■	0.0003	3,564
	Intermediate	■	■	■	■	■	■		
	Deep								
94	Shallow	■	■	■	■	■	■	0.0003	14,580
	Intermediate	■	■	■	■	■	■		
	Deep								
95	Shallow	■	■	■	■	■	■	0.0003	2,916
	Intermediate	■	■	■	■	■	■		
	Deep								
96	Shallow	■	■	■	■	■	■	0.0003	11,664
	Intermediate	■	■	■	■	■	■		
	Deep								

Source area combination patterns, weights distributed to each pattern, number of cases included in each pattern (continued)

	Depth	Source areas Z	A	B	C	D	E	Weight	N
97	Shallow							0.0067	58
	Intermediate		■	■	■	■			
	Deep								
98	Shallow							0.0003	348
	Intermediate		■	■	■	■			
	Deep								
99	Shallow							0.0178	54
	Intermediate		■	■	■	■			
	Deep								
100	Shallow							0.0003	324
	Intermediate		■	■	■	■			
	Deep								
101	Shallow							0.0003	240
	Intermediate		■	■	■	■			
	Deep								
102	Shallow							0.0003	1,404
	Intermediate		■	■	■	■			
	Deep								
103	Shallow							0.0003	216
	Intermediate		■	■	■	■			
	Deep								
104	Shallow							0.0003	1,296
	Intermediate		■	■	■	■			
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
105	Shallow							0.0067	40
	Intermediate		■	■	■	■			
	Deep								
106	Shallow							0.0003	348
	Intermediate		■	■	■	■			
	Deep								
107	Shallow							0.0178	36
	Intermediate		■	■	■	■			
	Deep								
108	Shallow							0.0003	324
	Intermediate		■	■	■	■			
	Deep								
109	Shallow							0.0006	168
	Intermediate		■	■	■	■			
	Deep								
110	Shallow							0.0003	1,404
	Intermediate		■	■	■	■			
	Deep								
111	Shallow							0.0003	144
	Intermediate		■	■	■	■			
	Deep								
112	Shallow							0.0003	1,296
	Intermediate		■	■	■	■			
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
113	Shallow							0.0067	174
	Intermediate		■	■	■	■	■		
	Deep								
114	Shallow							0.0003	1,044
	Intermediate		■	■	■	■	■		
	Deep								
115	Shallow							0.0003	162
	Intermediate		■	■	■	■	■		
	Deep								
116	Shallow							0.0003	972
	Intermediate		■	■	■	■	■		
	Deep								
117	Shallow							0.0003	720
	Intermediate		■	■	■	■	■		
	Deep								
118	Shallow							0.0003	4,212
	Intermediate		■	■	■	■	■		
	Deep								
119	Shallow							0.0003	648
	Intermediate		■	■	■	■	■		
	Deep								
120	Shallow							0.0003	3,888
	Intermediate		■	■	■	■	■		
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
121	Shallow							0.0006	28
	Intermediate		■	■	■	■			
	Deep								
122	Shallow							0.0006	168
	Intermediate		■	■	■	■			
	Deep								
123	Shallow							0.0003	24
	Intermediate		■	■	■	■			
	Deep								
124	Shallow							0.0003	144
	Intermediate		■	■	■	■			
	Deep								
125	Shallow							0.0003	360
	Intermediate		■	■	■	■			
	Deep								
126	Shallow							0.0003	2,106
	Intermediate		■	■	■	■			
	Deep								
127	Shallow							0.0003	324
	Intermediate		■	■	■	■			
	Deep								
128	Shallow							0.0003	1,944
	Intermediate		■	■	■	■			
	Deep								

Source area combination patterns, weights distributed to each pattern, number of cases included in each pattern (continued)

	Depth	Source areas Z	A	B	C	D	E	Weight	N
129	Shallow							0.0006	20
	Intermediate	■	■	■	■	■			
	Deep								
130	Shallow							0.0006	168
	Intermediate	■	■	■	■				
	Deep					■	■		
131	Shallow							0.0003	16
	Intermediate	■	■	■					
	Deep				■	■	■		
132	Shallow							0.0003	144
	Intermediate	■	■	■	■				
	Deep					■	■		
133	Shallow							0.0006	252
	Intermediate	■	■						
	Deep			■	■	■	■		
134	Shallow							0.0003	2,106
	Intermediate	■	■	■	■				
	Deep					■	■		
135	Shallow							0.0003	216
	Intermediate	■	■						
	Deep			■	■	■	■		
136	Shallow							0.0003	1,944
	Intermediate	■	■	■					
	Deep				■	■	■		

	Depth	Source areas Z	A	B	C	D	E	Weight	N
137	Shallow							0.0006	84
	Intermediate	■	■	■	■	■			
	Deep						■		
138	Shallow							0.0006	504
	Intermediate	■	■	■	■				
	Deep					■	■		
139	Shallow							0.0003	72
	Intermediate	■	■	■					
	Deep				■	■	■		
140	Shallow							0.0003	432
	Intermediate	■	■	■	■				
	Deep					■	■		
141	Shallow							0.0003	1,080
	Intermediate	■	■						
	Deep			■	■	■	■		
142	Shallow							0.0003	6,318
	Intermediate	■	■	■	■				
	Deep					■	■		
143	Shallow							0.0003	972
	Intermediate	■	■						
	Deep			■	■	■	■		
144	Shallow							0.0003	5,832
	Intermediate	■	■	■	■				
	Deep					■	■		

	Depth	Source areas Z	A	B	C	D	E	Weight	N
145	Shallow							0.0067	42
	Intermediate		■	■	■	■			
	Deep								
146	Shallow							0.0003	96
	Intermediate		■	■	■	■			
	Deep					■			
147	Shallow							0.0178	36
	Intermediate		■	■	■	■			
	Deep								
148	Shallow							0.0003	72
	Intermediate		■	■	■	■			
	Deep					■			
149	Shallow							0.0003	120
	Intermediate		■	■	■	■	■		
	Deep								
150	Shallow							0.0003	288
	Intermediate		■	■	■	■			
	Deep					■			
151	Shallow							0.0003	96
	Intermediate		■	■	■	■	■		
	Deep								
152	Shallow							0.0003	192
	Intermediate		■	■	■	■	■		
	Deep					■			

	Depth	Source areas Z	A	B	C	D	E	Weight	N
153	Shallow							0.0067	42
	Intermediate		■	■	■	■	■		
	Deep								
154	Shallow							0.0003	96
	Intermediate		■	■	■	■	■		
	Deep					■	■		
155	Shallow							0.0178	36
	Intermediate		■	■	■	■	■		
	Deep								
156	Shallow							0.0003	72
	Intermediate		■	■	■	■	■		
	Deep					■	■		
157	Shallow							0.0006	120
	Intermediate		■	■	■	■	■		
	Deep								
158	Shallow							0.0003	288
	Intermediate		■	■	■	■	■		
	Deep								
159	Shallow							0.0003	96
	Intermediate		■	■	■	■	■		
	Deep								
160	Shallow							0.0003	192
	Intermediate		■	■	■	■	■		
	Deep								

[Reference] Source area combination patterns（6/6）

Source area combination patterns, weights distributed to each pattern, number of cases included in each pattern (continued)

	Depth	Source areas Z	A	B	C	D	E	Weight	N
161	Shallow	■	■	■	■	■		0.0006	42
	Intermediate								
	Deep								
162	Shallow	■	■	■	■	■		0.0006	96
	Intermediate								
	Deep								
163	Shallow	■	■	■	■	■		0.0003	36
	Intermediate								
	Deep								
164	Shallow	■	■	■	■	■		0.0003	72
	Intermediate								
	Deep								
165	Shallow	■	■	■	■	■		0.0003	180
	Intermediate								
	Deep								
166	Shallow	■	■	■	■	■		0.0003	432
	Intermediate								
	Deep								
167	Shallow	■	■	■	■	■		0.0003	144
	Intermediate								
	Deep								
168	Shallow	■	■	■	■	■		0.0003	288
	Intermediate								
	Deep								

	Depth	Source areas Z	A	B	C	D	E	Weight	N
169	Shallow	■	■	■	■	■	■	0.0006	42
	Intermediate								
	Deep								
170	Shallow	■	■	■	■	■	■	0.0006	96
	Intermediate								
	Deep								
171	Shallow	■	■	■	■	■	■	0.0003	36
	Intermediate								
	Deep								
172	Shallow	■	■	■	■	■	■	0.0003	72
	Intermediate								
	Deep								
173	Shallow	■	■	■	■	■	■	0.0006	180
	Intermediate								
	Deep								
174	Shallow	■	■	■	■	■	■	0.0003	432
	Intermediate								
	Deep								
175	Shallow	■	■	■	■	■	■	0.0003	144
	Intermediate								
	Deep								
176	Shallow	■	■	■	■	■	■	0.0003	288
	Intermediate								
	Deep								

N is number of cases.