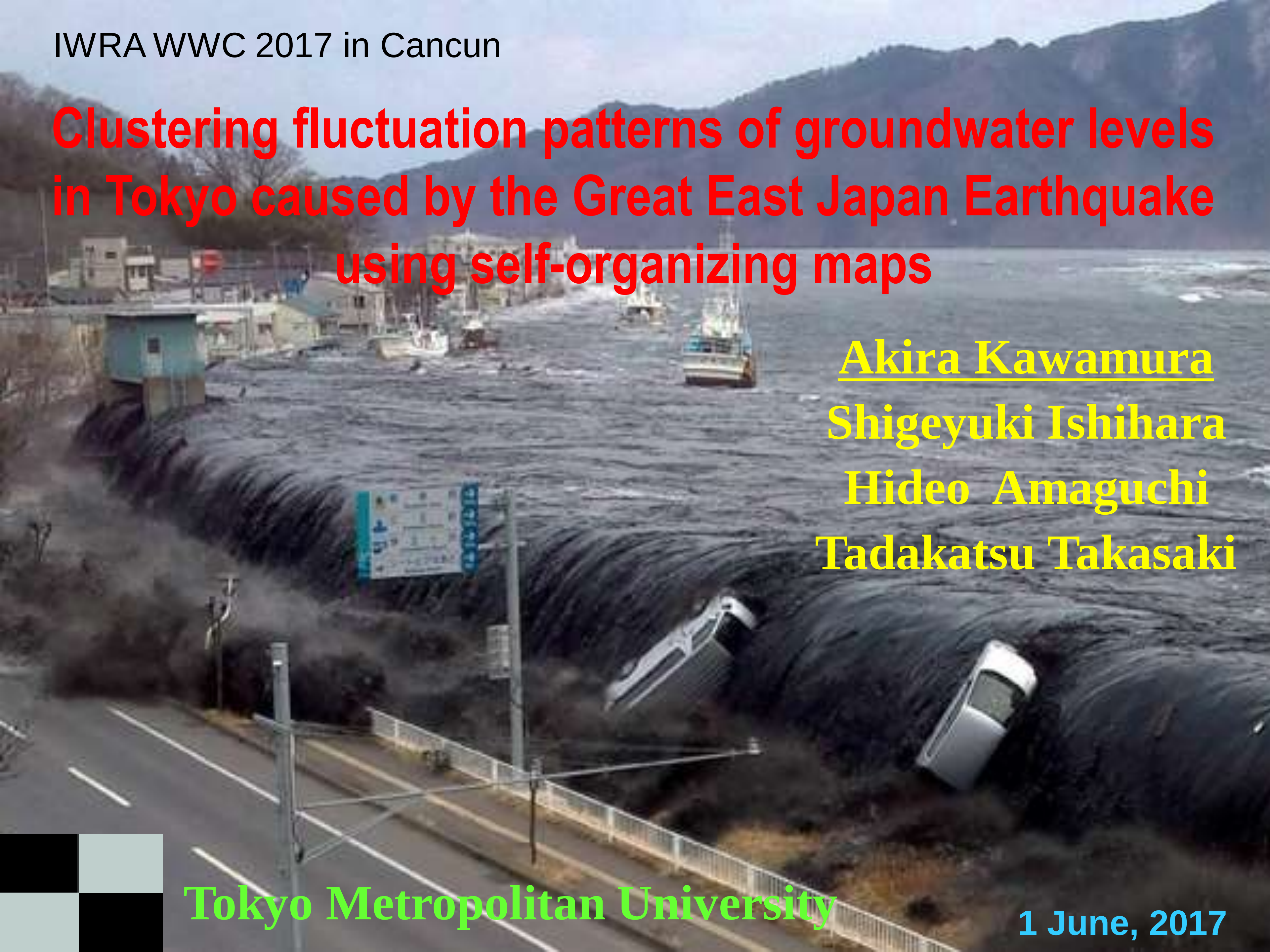

IWRA WWC 2017 in Cancun

Clustering fluctuation patterns of groundwater levels in Tokyo caused by the Great East Japan Earthquake using self-organizing maps

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   and Data Used

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   using Self-Organizing Maps (SOM)

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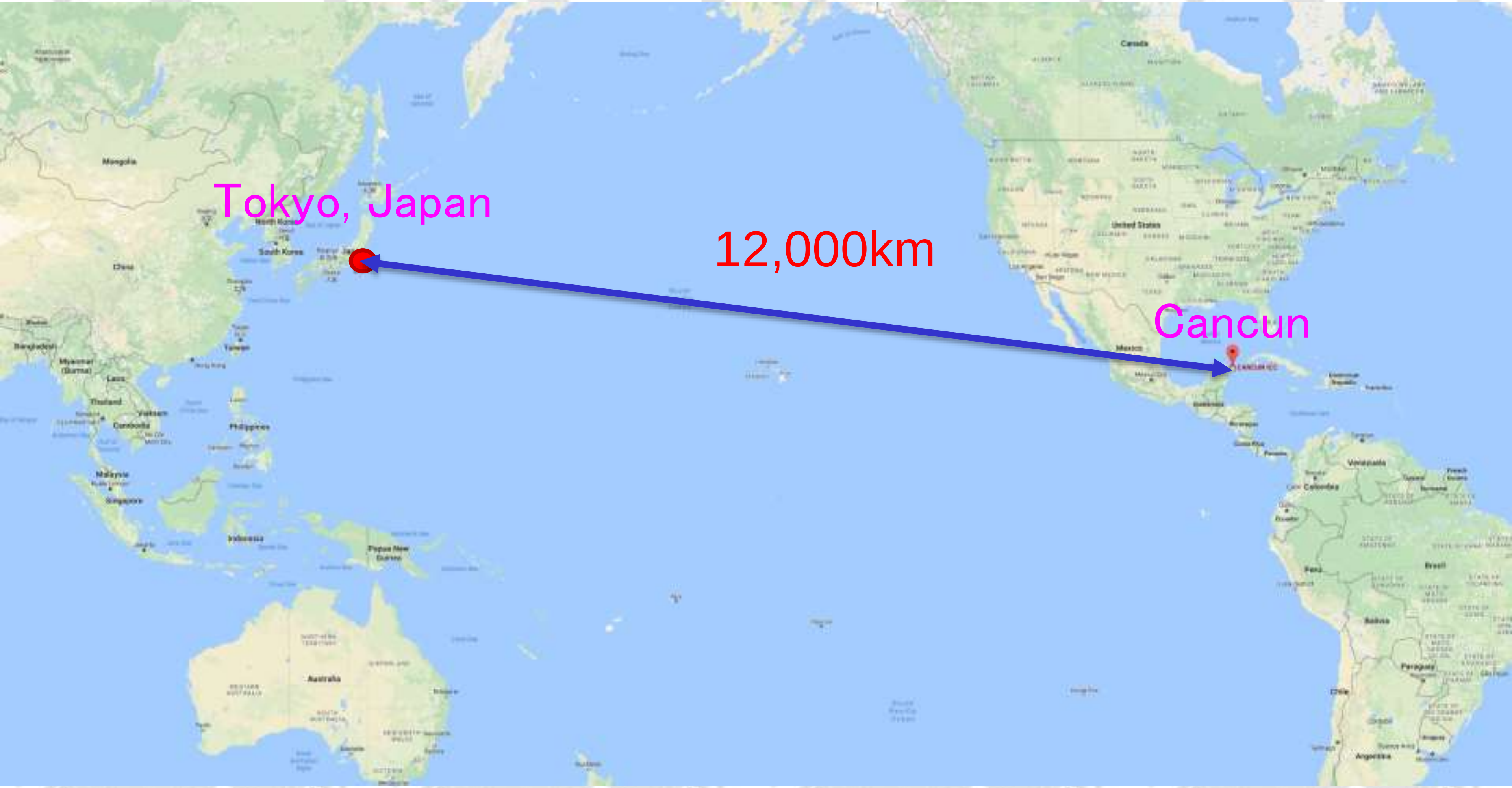
   and Discuss Their Causes

5. Conclusions

Location of Tokyo



©明

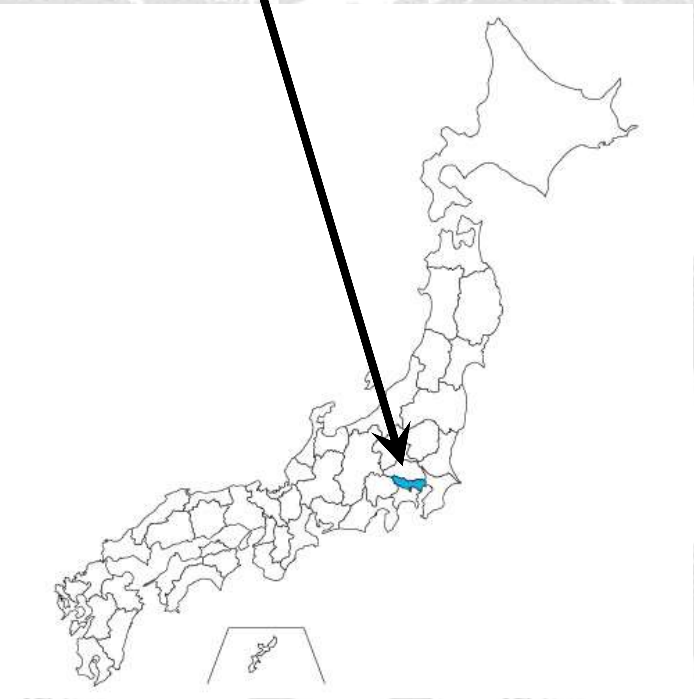
Tokyo Metropolis

Third smallest prefecture (2188km^2) out of 47 (1/23 of Quintana Roo)

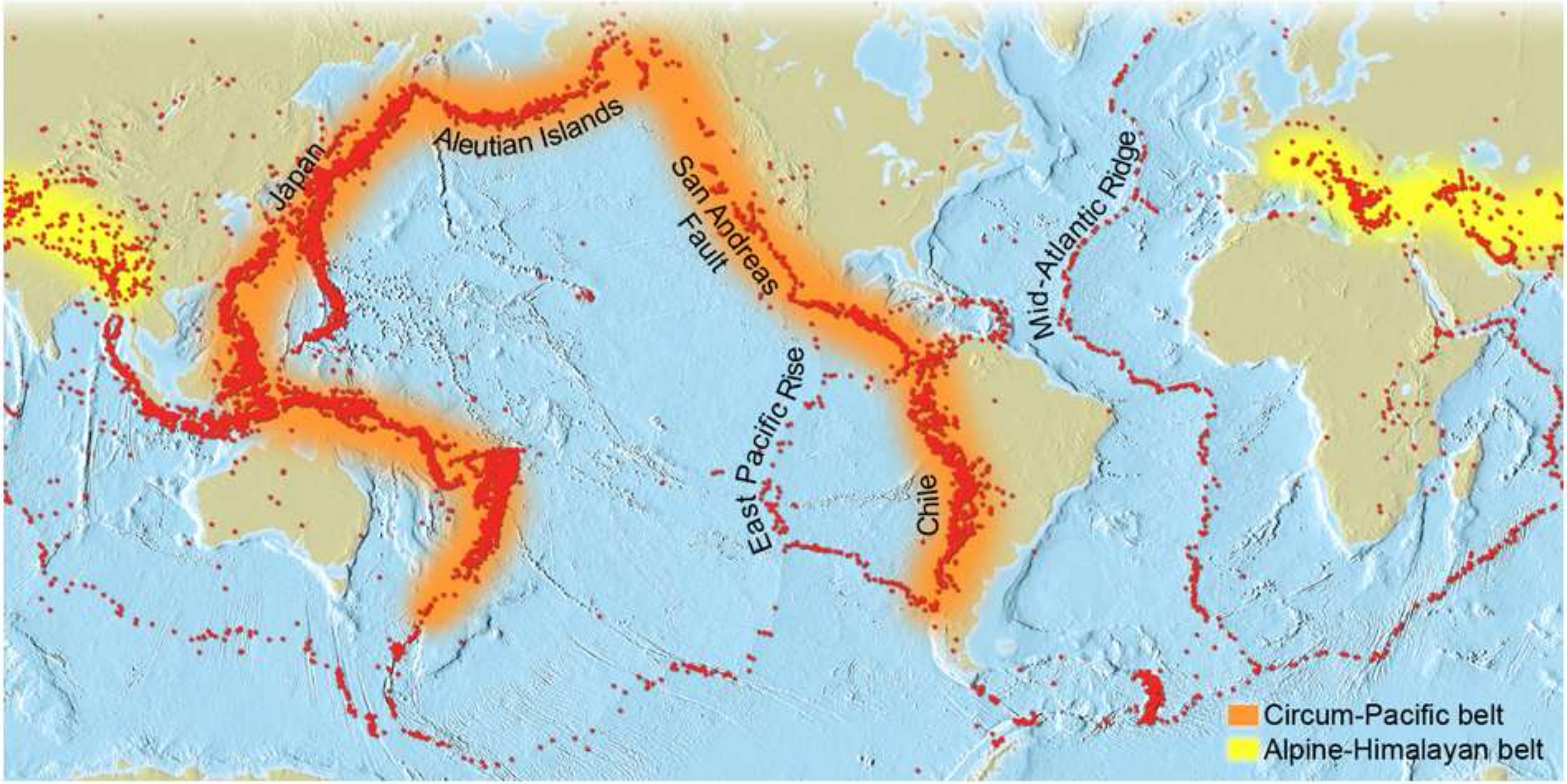
The largest population (13.2 million) (8.8 times larger than Quintana Roo)

The highest population density (6000/km^2)

1/10 of whole National Budget



Distribution of Earthquakes (Mw>5)



Distribution of nearly 15,000 earthquakes with magnitudes equal to or greater than 5 for a 10-year period.

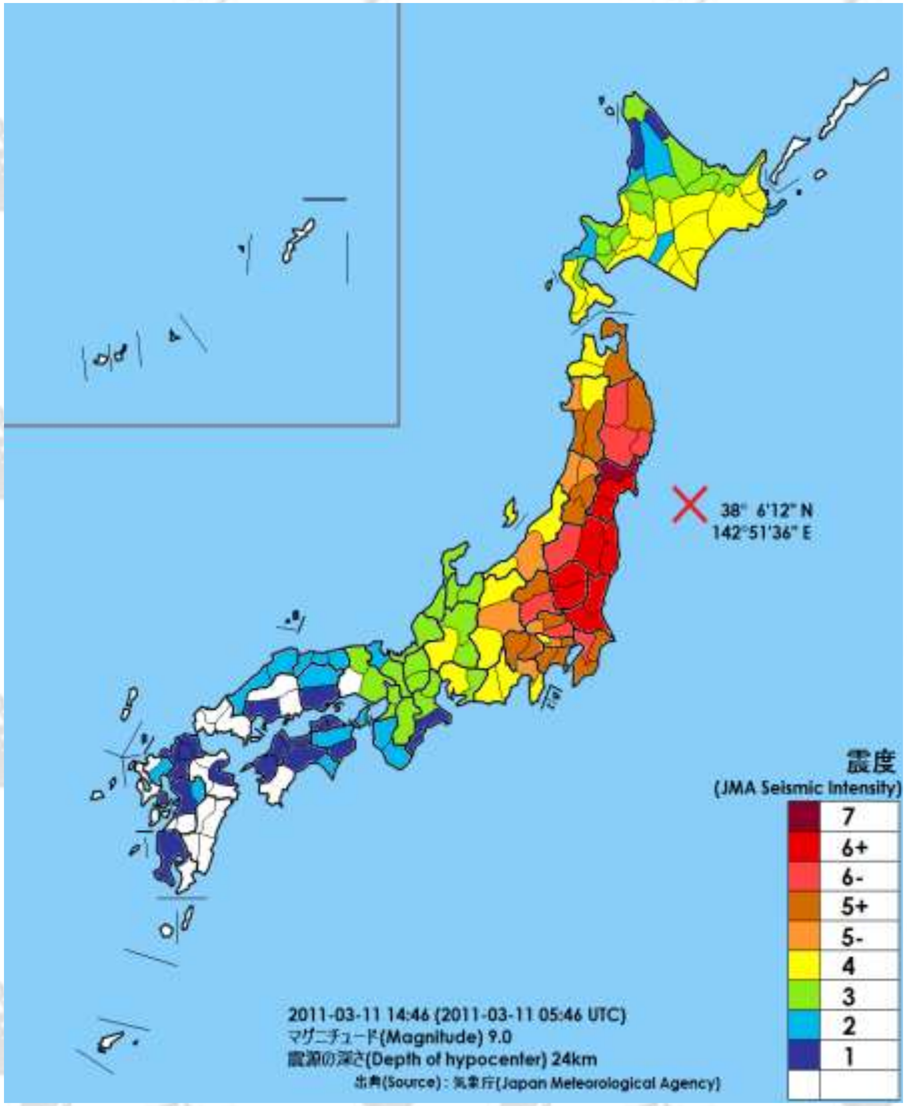
Whole Japanese Archipelago is in serious peril of severe earthquakes, because it is situated in the Circum-Pacific Seismic Zone.

Background

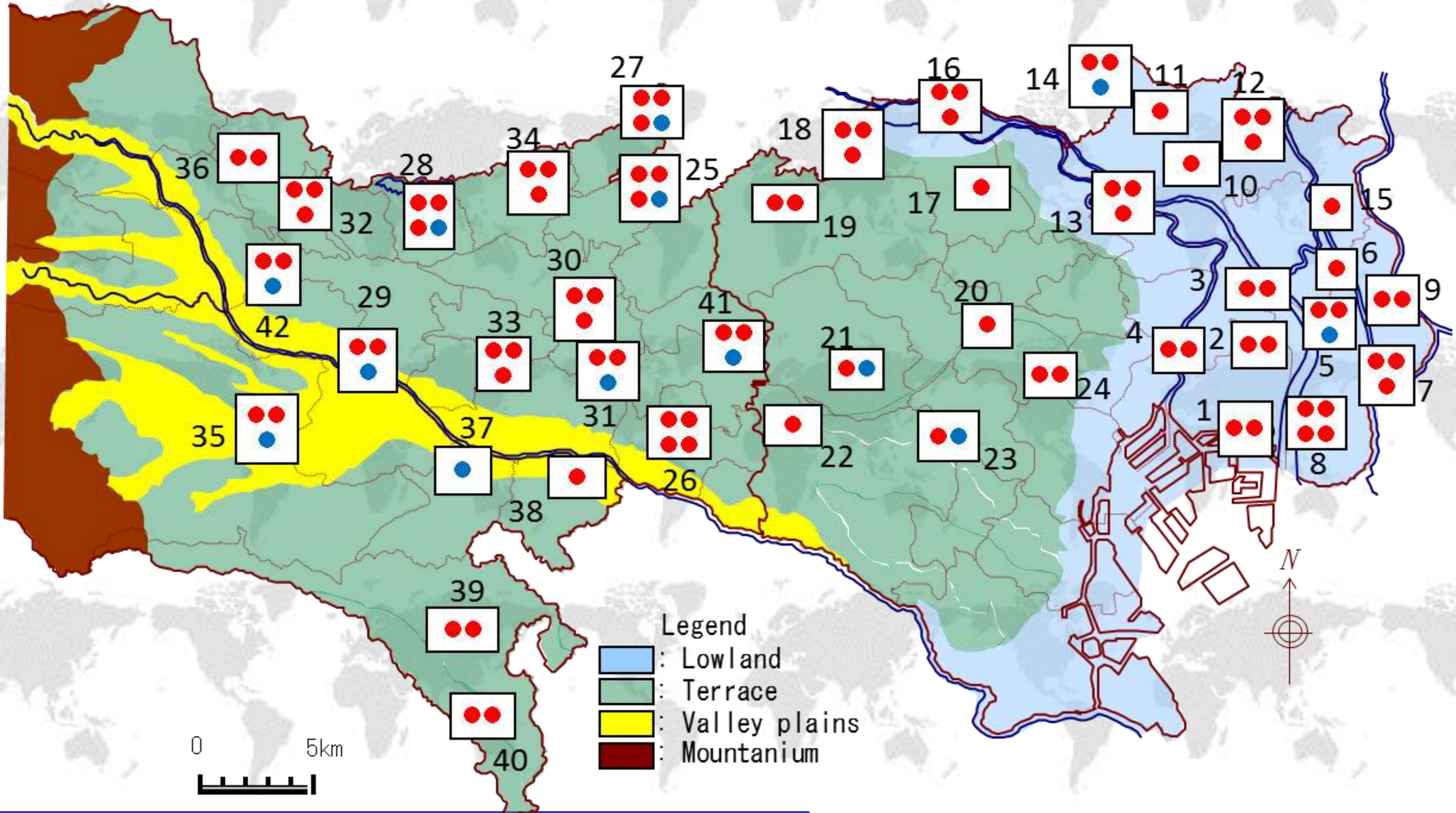
- Most of the megacities not only in Japan but also Southeast Asian countries are located on the alluvial plains where the ground is very soft and especially vulnerable for groundwater related disasters.
- Since groundwater is a crucial water resource for most of the cities around the world, it is very important to understand and evaluate the impact of a huge earthquake on groundwater.
- However, so far, almost no such studies have been carried out mainly because no densely distributed groundwater level observations were available at a short time interval when a large earthquake occurred.

The Great East Japan Earthquake

- **The most powerful earthquake ever recorded in Japan with a magnitude of 9.0 (Mw) (4th strongest in the world), occurred at 14:46 JST on March 11, 2011**
- **More than 18,000 people were sacrificed or missing mostly by Tsunami**
- **In Tokyo, 5 upper intensity was observed, where more than 400km away from the epicenter**



Groundwater Monitoring Network in Tokyo



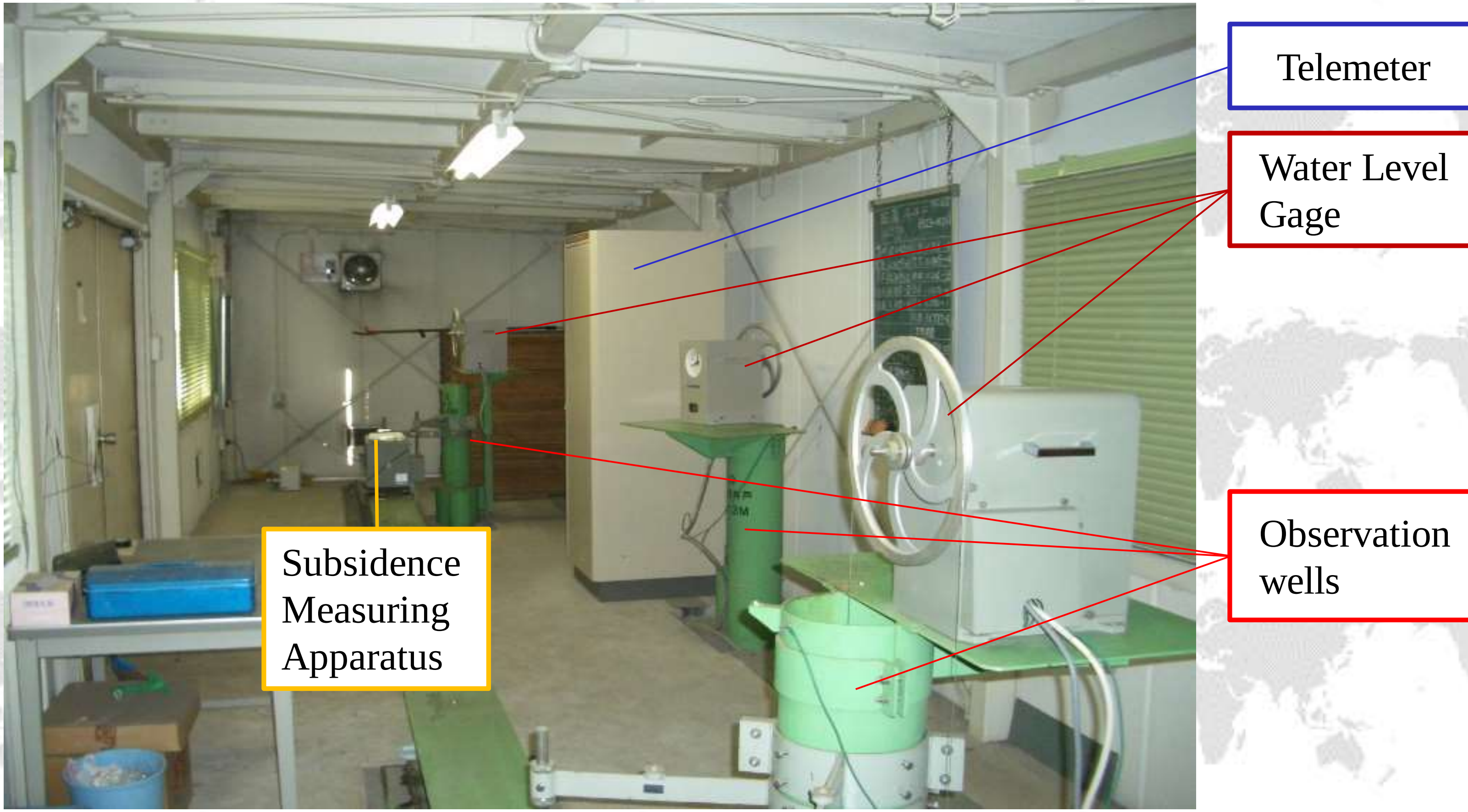
□ observation sites ··· 42 sites

● Confined wells ··· 89 wells

● Unconfined wells ··· 13 wells

The hourly groundwater levels have been observed since 1952

Inside a Groundwater Observation House



- 42 observation sites in Tokyo.
- Most observation sites have several different depth observation wells.

Objective

- Taking full advantage of the unique rare case data from the dense groundwater monitoring network in Tokyo,
- We identify the fluctuation patterns of groundwater levels caused by the Great East Japan Earthquake using SOM,
- Which has never been investigated in Tokyo area.

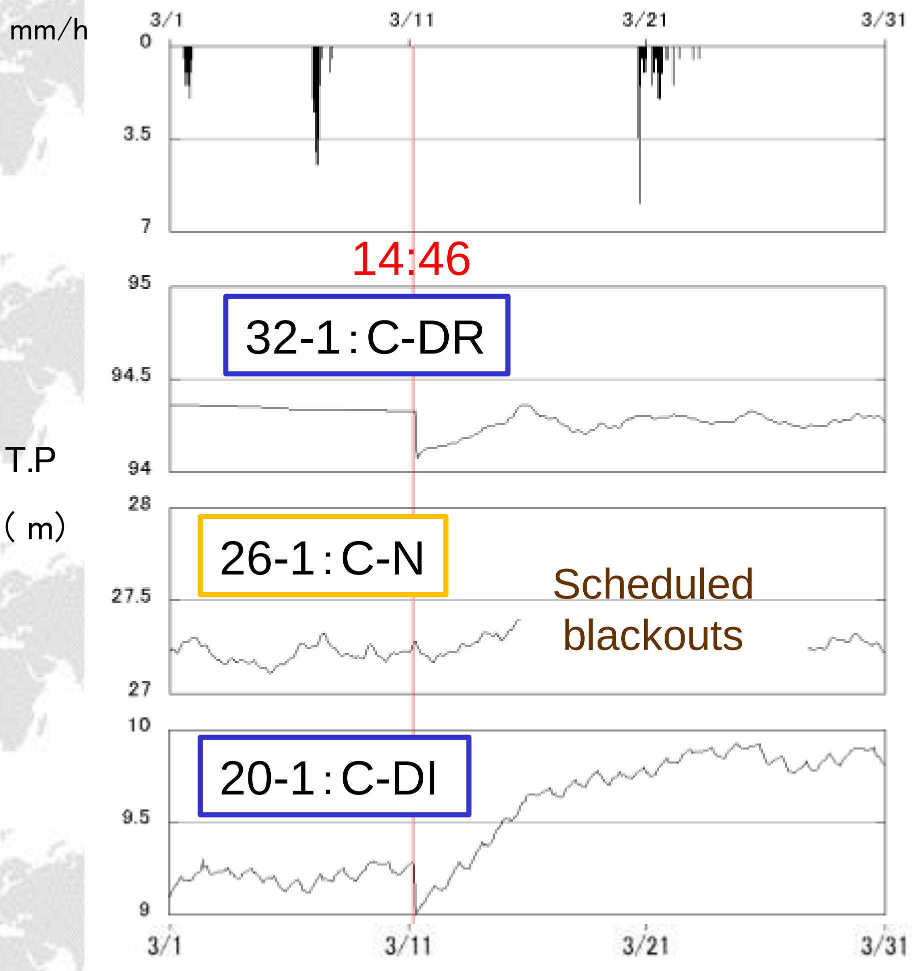
Data Used for the Objective

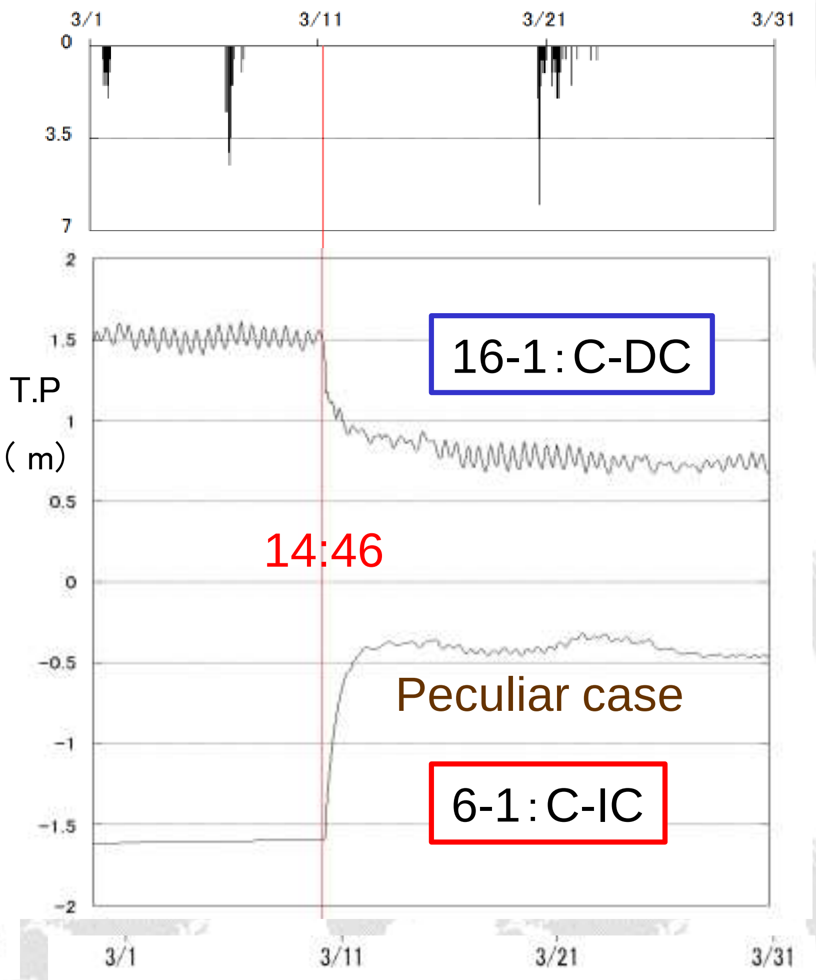
- **One-month hourly time series data of 98 wells (85 confined and 13 unconfined wells) in March, 2011, excluding missing data wells.**
- **The fluctuation patterns of the time series were analyzed and identified by SOM.**

Groundwater level changes by the Earthquake

Confined Wells

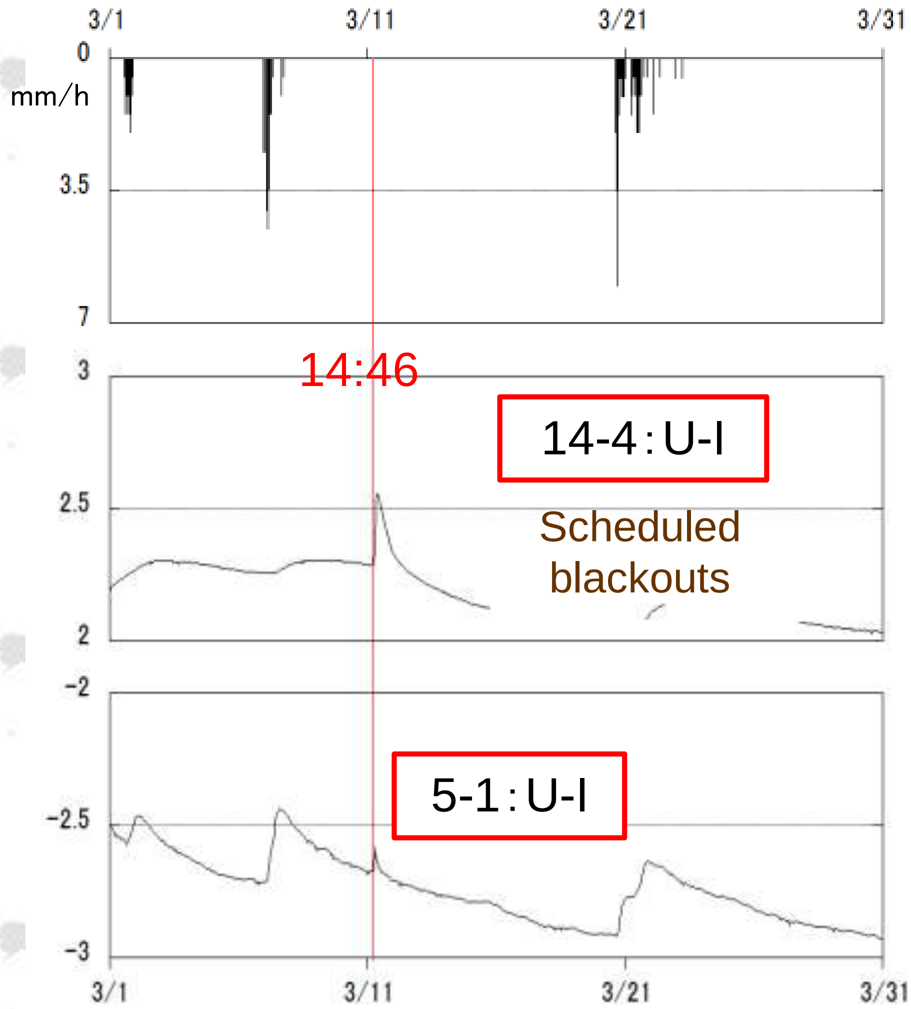
The effects of rain → None





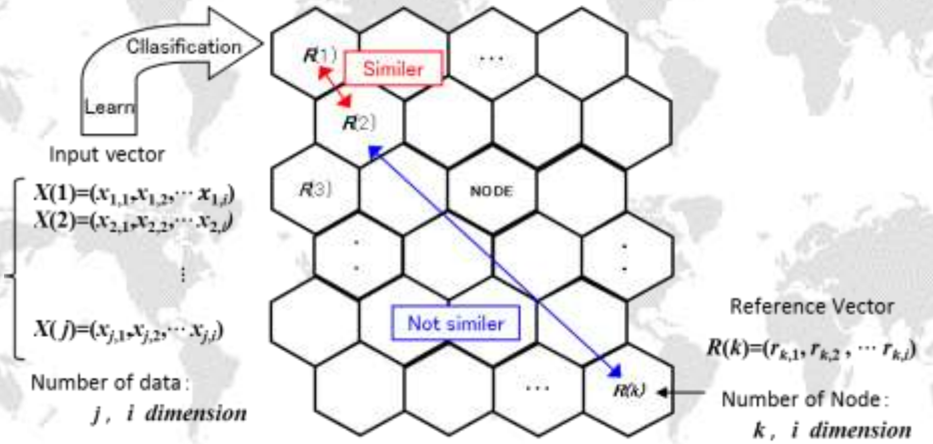
Groundwater level changes by the Earthquake

Unconfined Wells



SOM Method

- SOM was developed by Kohonen, which is one of unsupervised training Neural Networks
- SOM projects high-dimensional, complex data onto two-dimensional regularly-arranged nodes
- SOM obtains useful and informative reference vectors of all nodes
- In this study, SOM is used to cluster fluctuation of groundwater level changes



©明

Input data for SOM

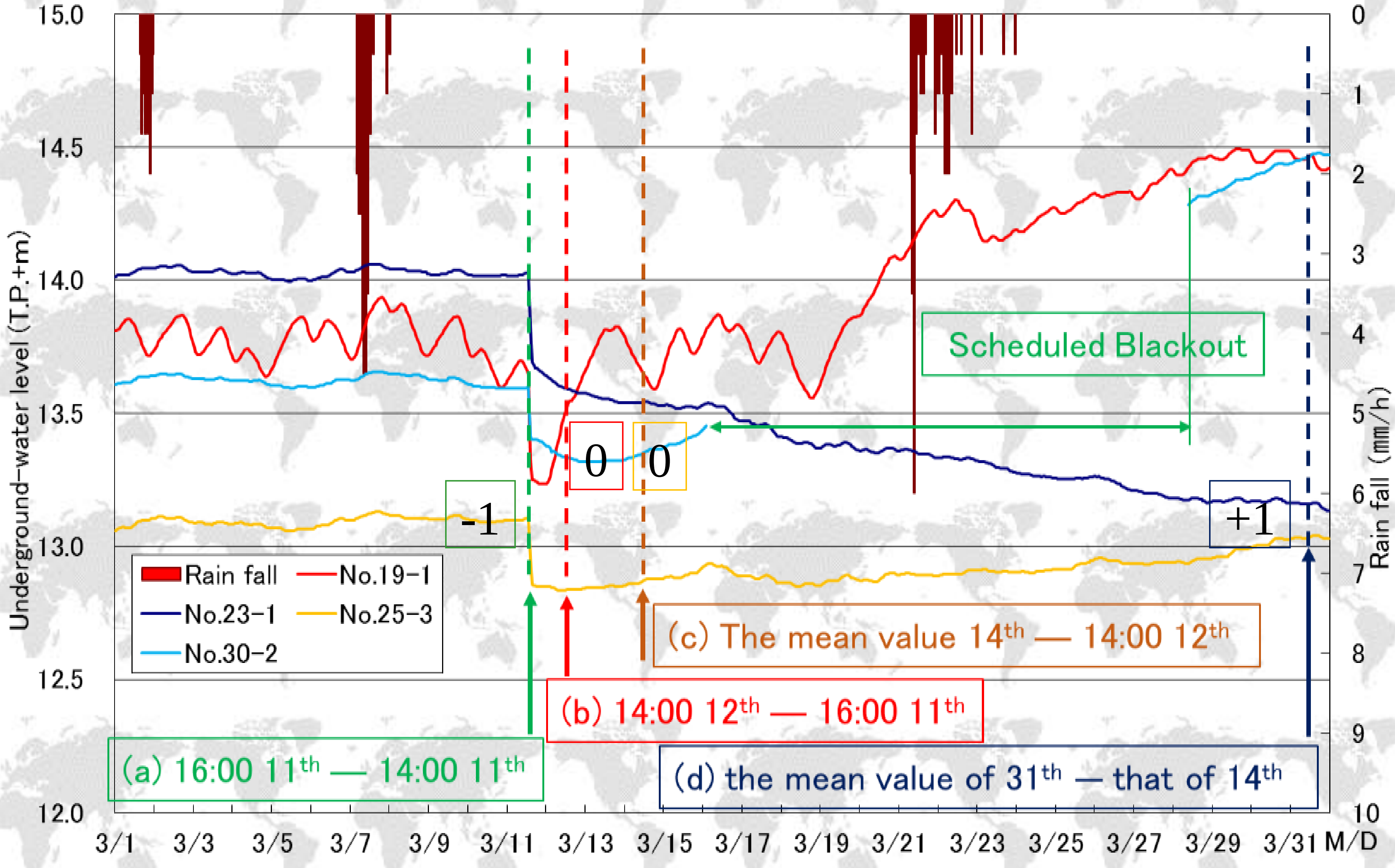
Site No.	Well No.	Difference in water level (a)	(b)	(c)	(d)	Strainer depth (e)	Site name
1	1	−12.5	−11.2	4.8	0.1	−72	Minamisuna
	2	−14.8	−7.8	3.9	−0.8	−132	
2	1	−14.0	−15.0	−0.1	2.2	−63	Kameido
	2	−27.3	−0.1	−0.4	1.4	−146	
42	1	−11.0	16.7	13.7	35.6	16	Akishima
	2	−16.0	−2.4	15.3	87.4	−91	
	③	0.5	4.3	6.8	20.9	106	

1) Well No. ○ ; Unconfined groundwater, 2) (a)～(d) ; cm, (e) ; m

(a) 16:00, 11 March – 14:00 of the same day
(b) 14:00, 12 March ー16:00, 11 March
(c) the mean value of 14 March ー14:00, 12 March
(d) the mean value of 31 March – that of 14 March
(e) The altitude value of the depth of the screen. (T.P. : standard mean sea level of Tokyo Bay)

Considering the crustal deformation in Tokyo after the Earthquake was 4 cm at the most,
± less than 5 cm fluctuation water level in (a) to (d) is shown as 0,
and ±5 cm or any value greater is shown as +1 or -1

Input data for SOM



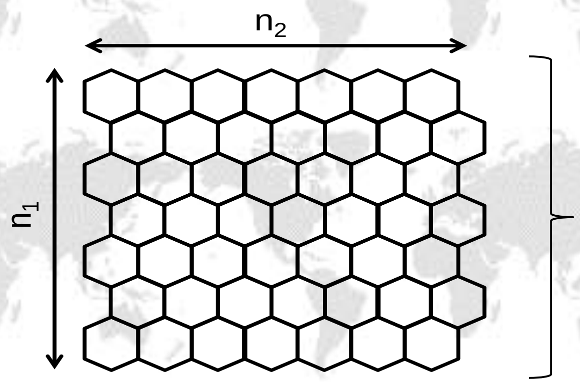
SOM Implementation

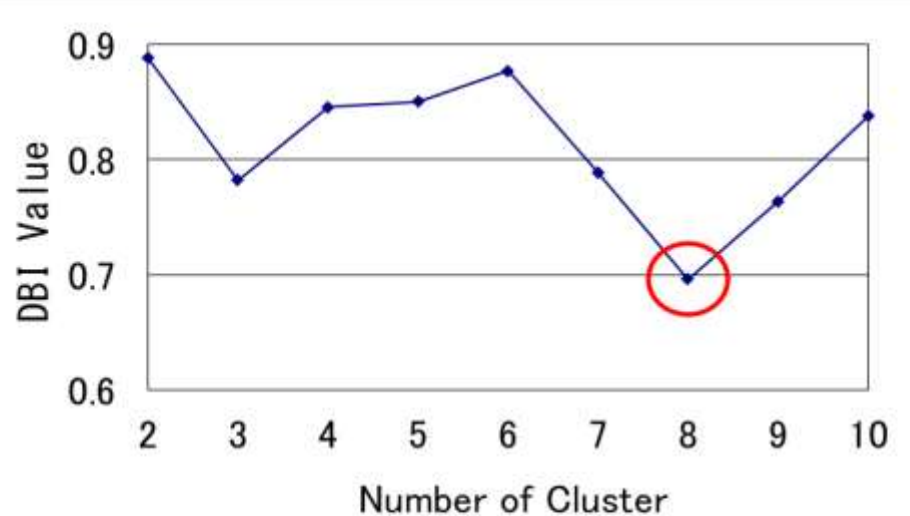
Map size $M = 5\sqrt{n}$

M : Number of total node,

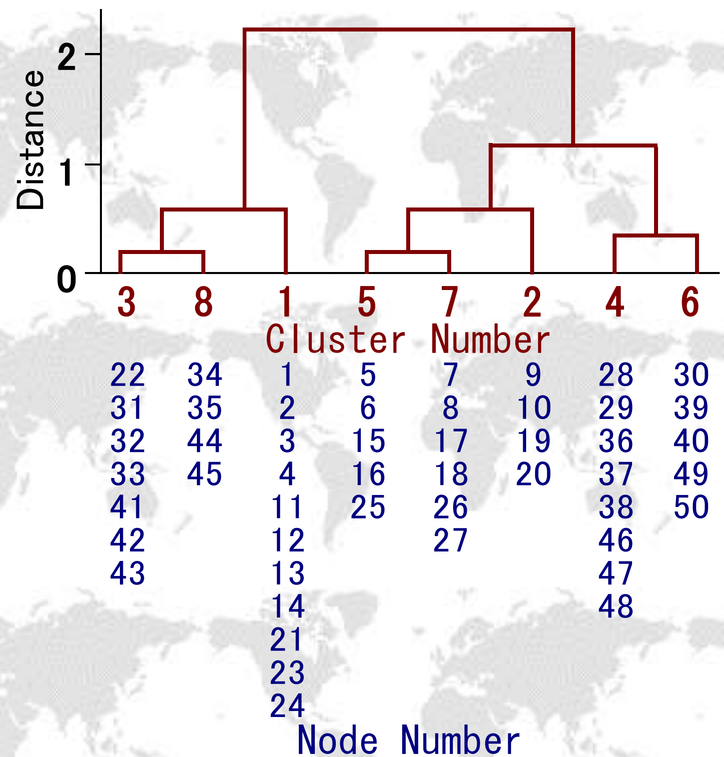
n : Number of Input data

$n = 98 \rightarrow M = 50$ node



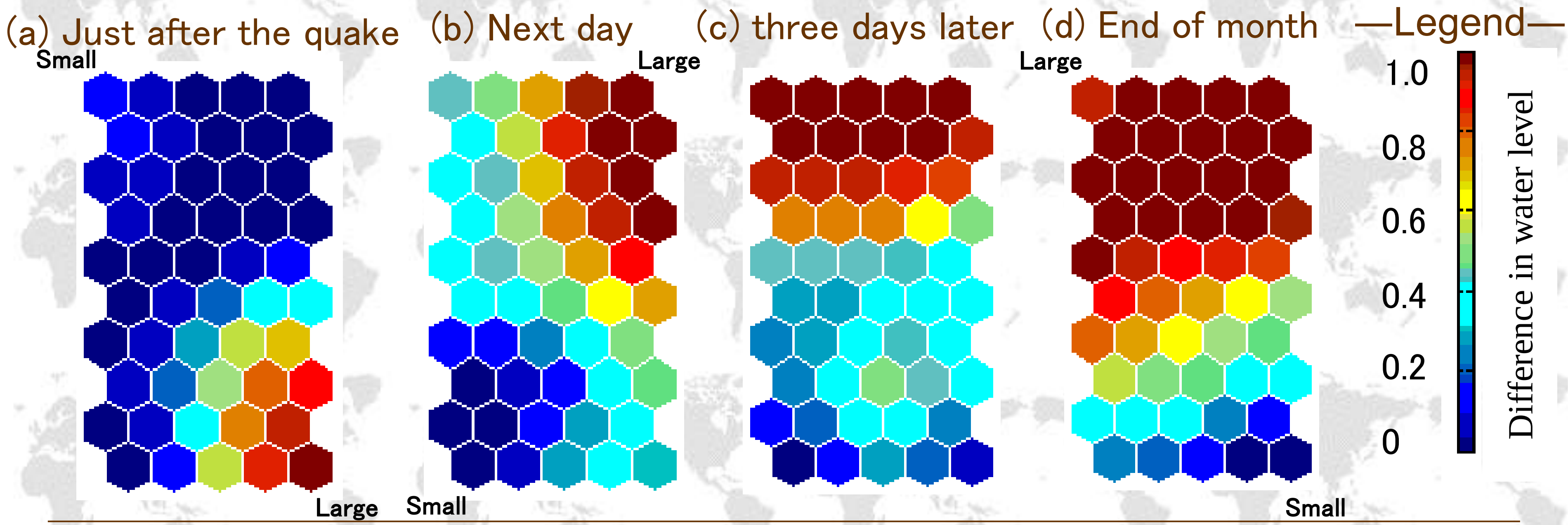


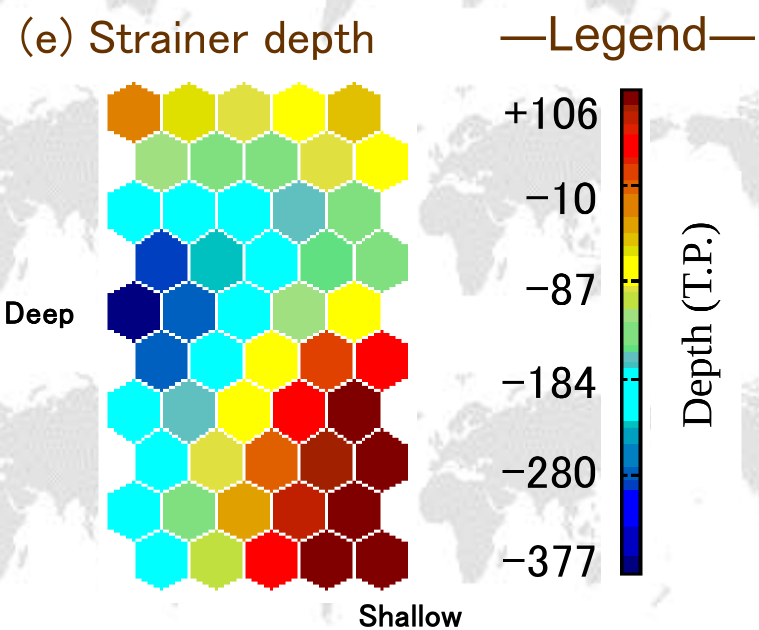
DBIValue

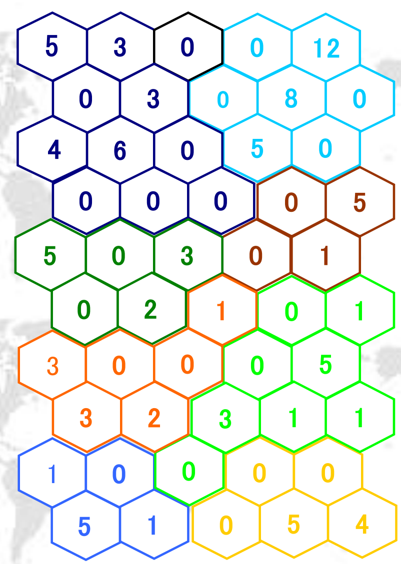


Ward's method

Identified Values for 5 Variables by SOM







(a)〜(d): Difference in underground water level (standardized)

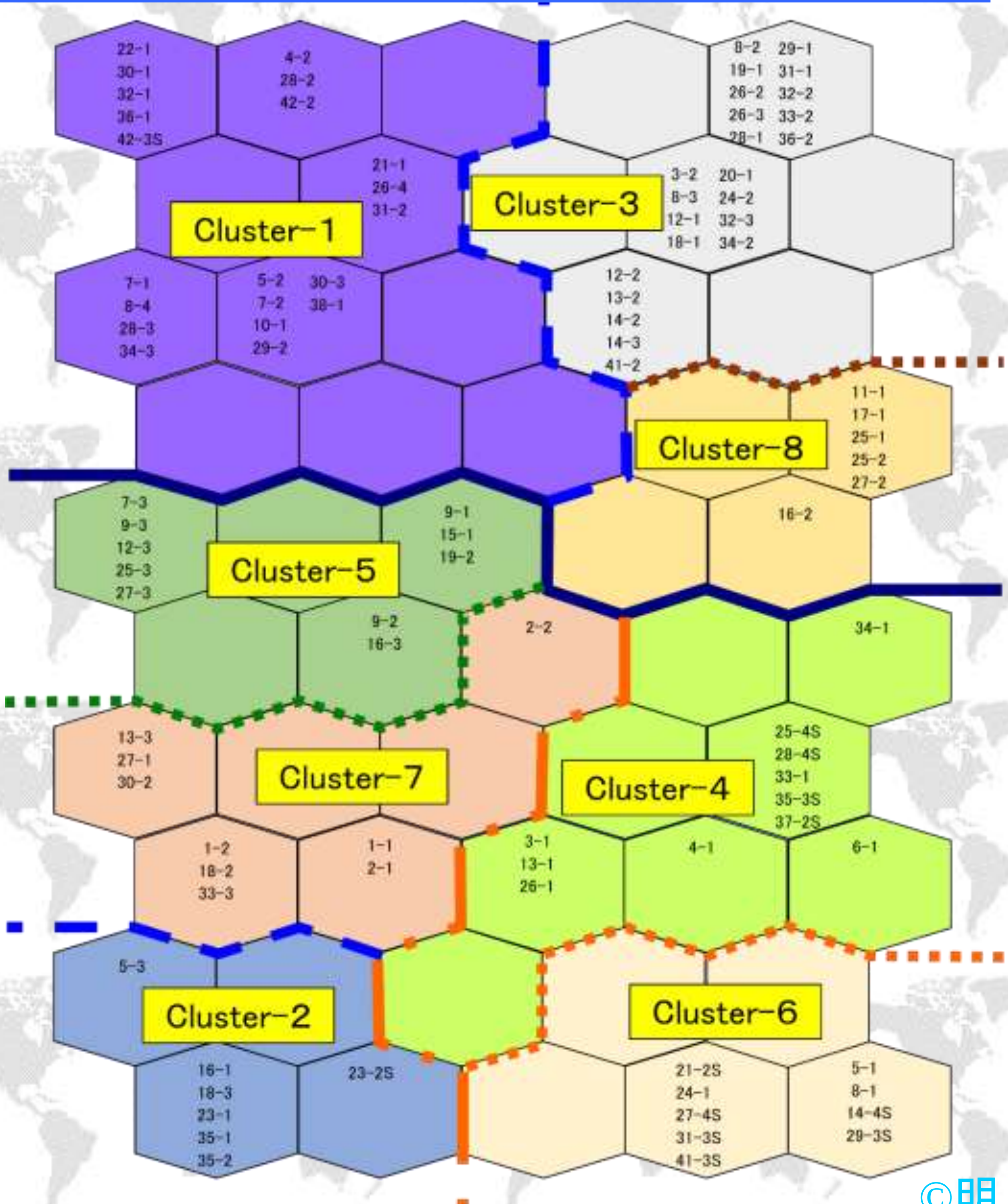
(d): Depth of screen (standard mean sea level of Tokyo Bay)

Number of Wells belong to each node

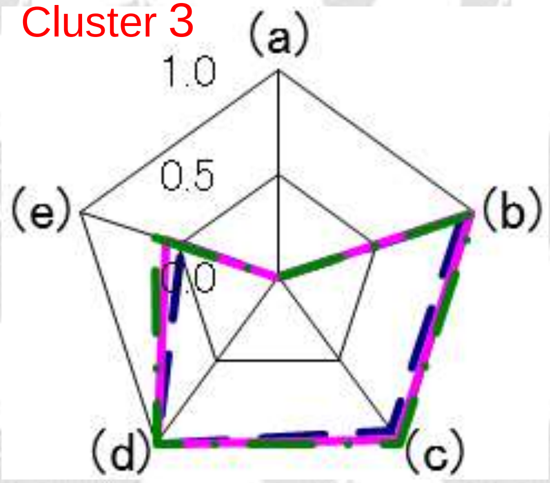
SOM Clustering Result

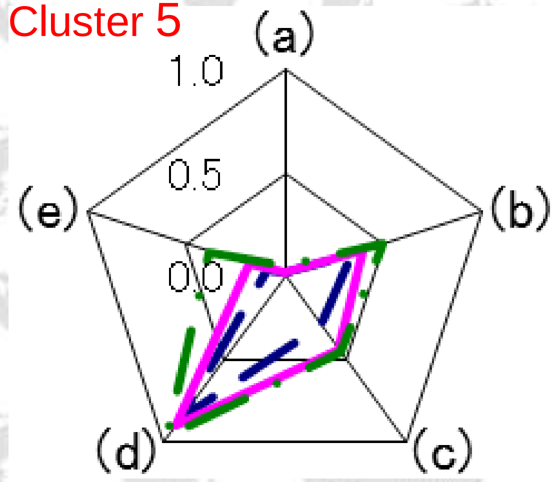
Group	Cluster-No.	Numbers of wells
Group 1	Cluster-1	21
	Cluster-3	25
	Cluster-8	6
Group 2	Cluster-5	10
	Cluster-7	9
	Cluster-2	7
Group 3	Cluster-4	11
	Cluster-6	9
	Total	98

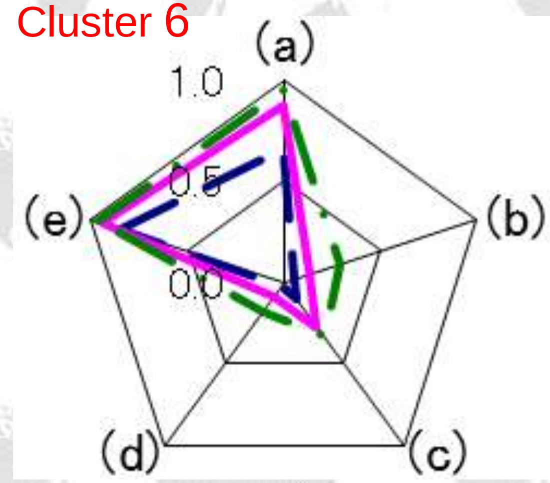
The fluctuation patterns of groundwater level could be classified into eight clusters, which are summed up to three groups.



Rader Charts of Main Clusters





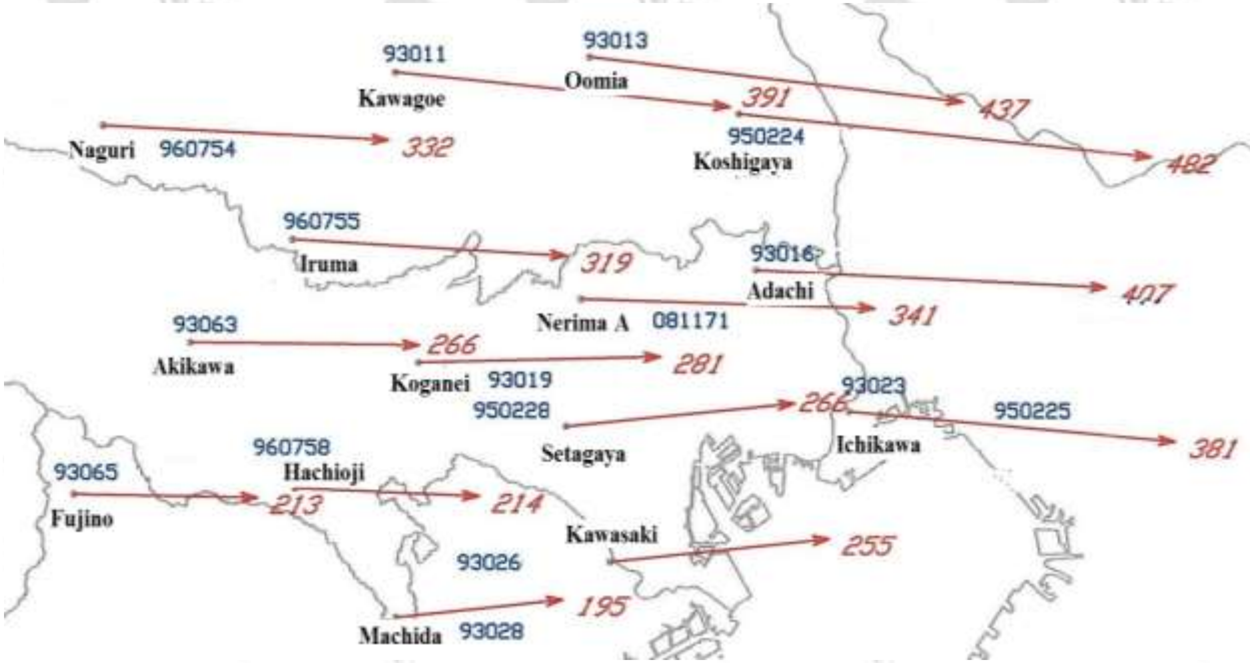


Cluster 3: Sharp drawdown just after the earthquake, and rised higher than the original level.

Cluster 5: Sharp drawdown just after the earthquake, and recovered to the original level.

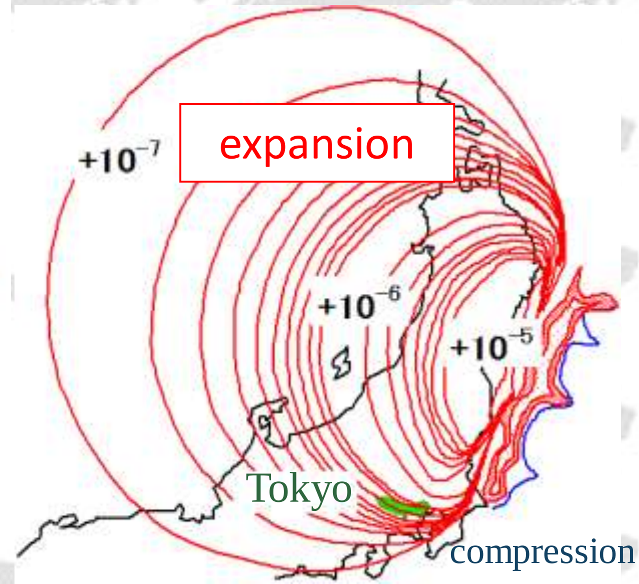
Cluster 6: Abrupt rise just after the earthquake, and decreased. Shallow wells.

Cause of Sharp Drawdowns



Legend	
○ Nerima A	Erectorical Trianguation Points
→ 341	direction of horizontality fluctuation
	amount of fluctuation
081171	No. of Erectorical Trianguation Point

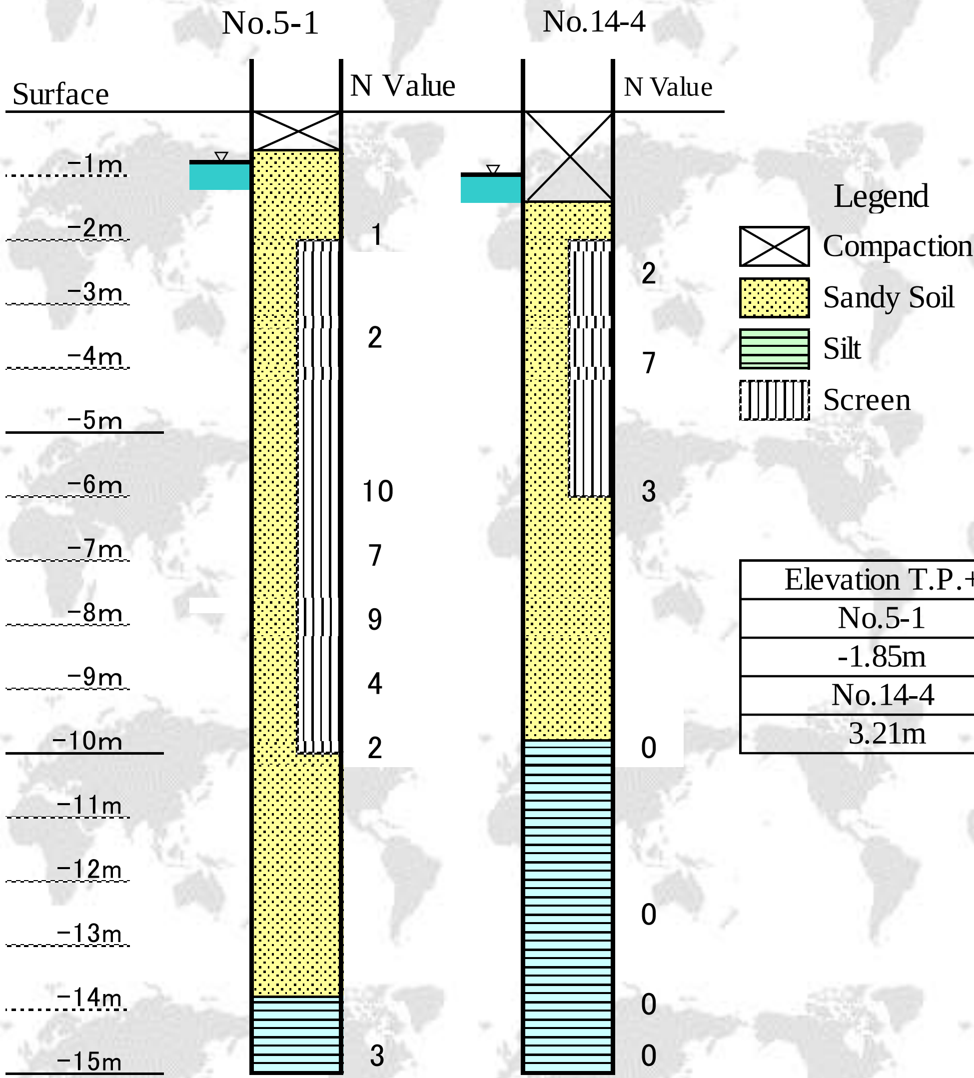
Ground Movements in Tokyo



Crustal Deformation for East Japan Area

◎ Pressure release by crustal expansion

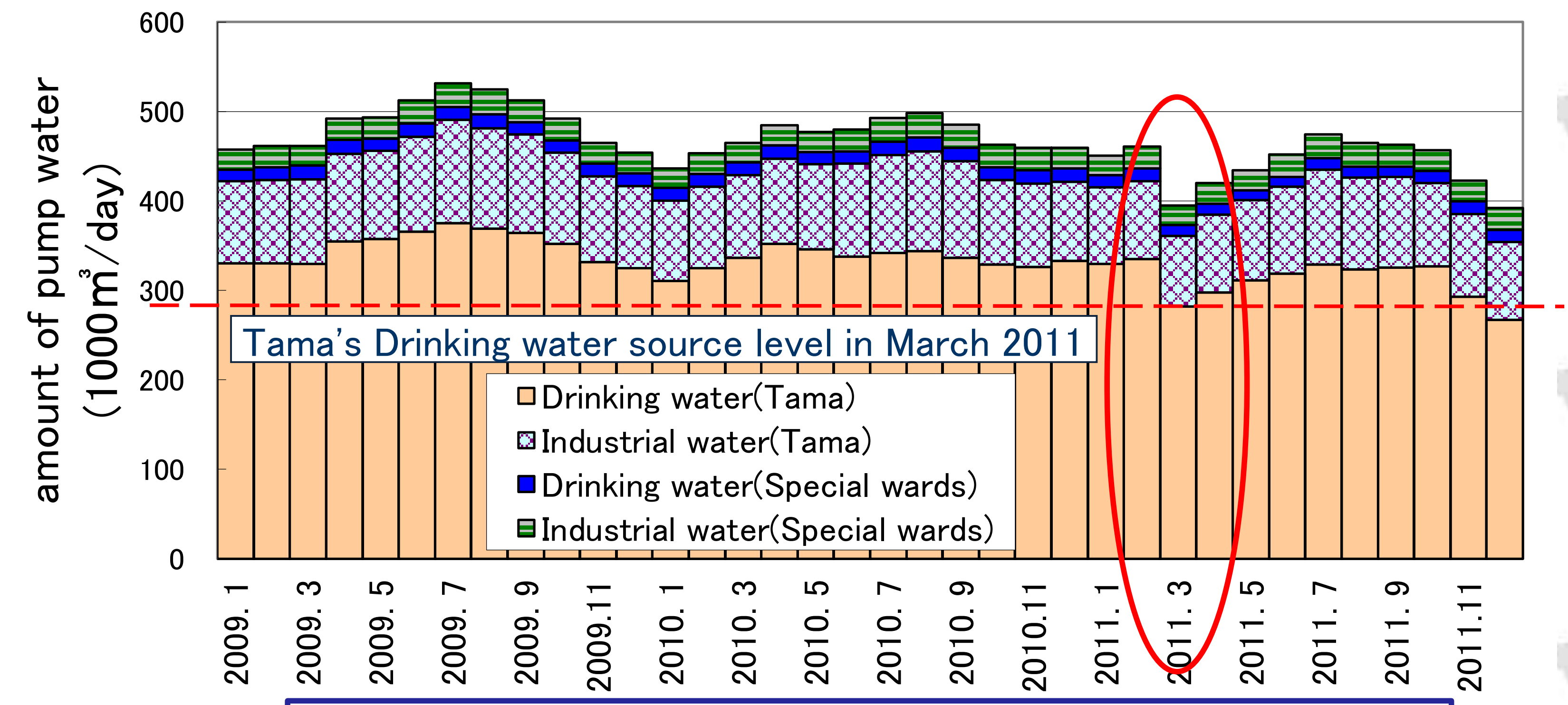
Cause of Abrupt Rises



Elevation T.P.+
No.5-1
-1.85m
No.14-4
3.21m

◎ **Phenomenon of soil liquefaction**

Cause of Rising Tendency after Drawdown



Monthly Amount of Groundwater Pumping Rate for 3 years from 2009 to 2011

◎ **Decrease of Groundwater Pumping Rate**

Conclusions

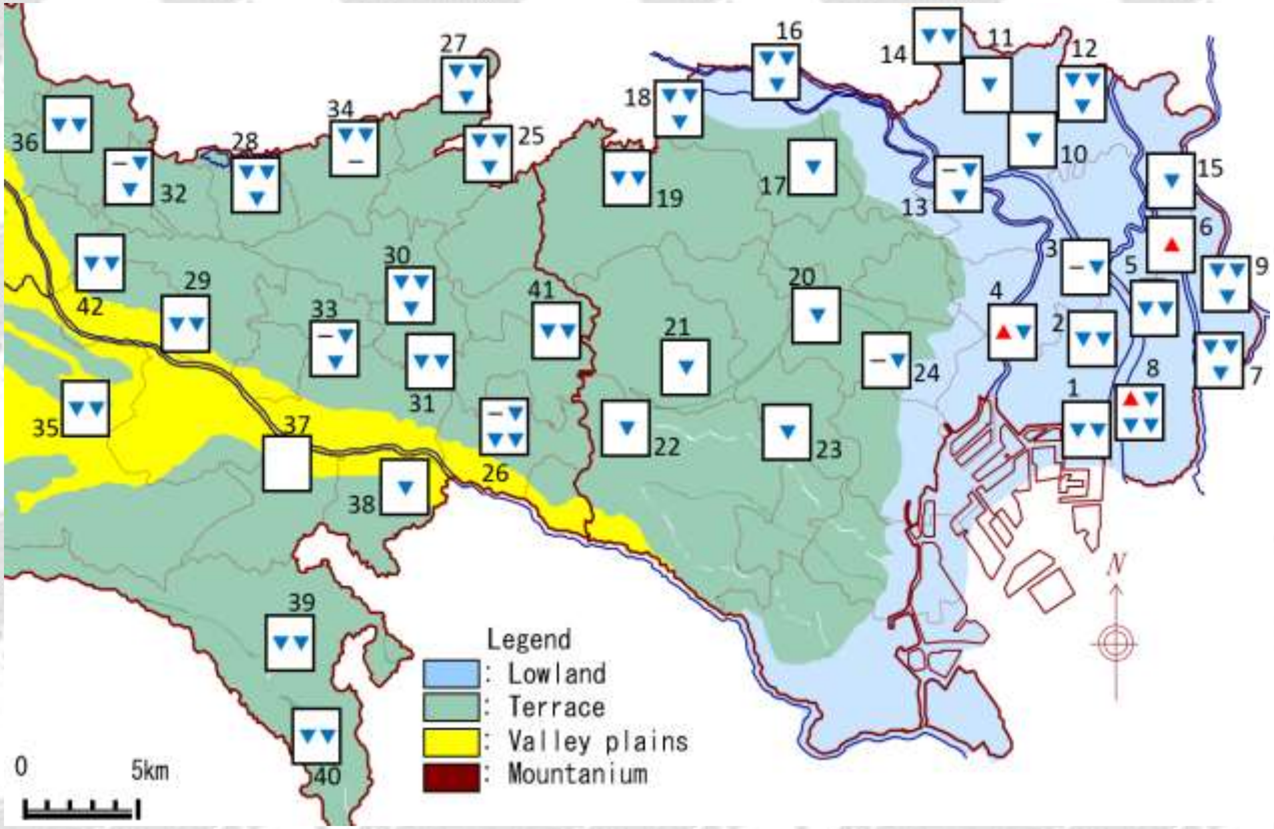
- The Great East Japan Earthquake triggered the fluctuations of groundwater level in Tokyo.
- By applying SOM, The fluctuation patterns of groundwater level were classified into eight clusters and three groups.
- Sharp drawdown just after the Earthquake was the typical phenomenon for confined wells, which is caused by the pressure release derived from crustal expansion.
- Abrupt rise just after the Earthquake, esp. for shallow wells will be caused by the soil liquefaction
- The most common fluctuation pattern is the drawdown followed by the rising tendency, which is mainly caused by decreased groundwater pumping rate.


Thank you for your kind attention!

Distribution of Change Patterns Just after the Earthquake

89 Confined Wells

Confined groundwater 89 wells | •Just after the earthquake (14:00~16:00)



▲ : Water level Rising over 5cm

▼ : Water level Drawdown over 5cm

— : Water level NO change

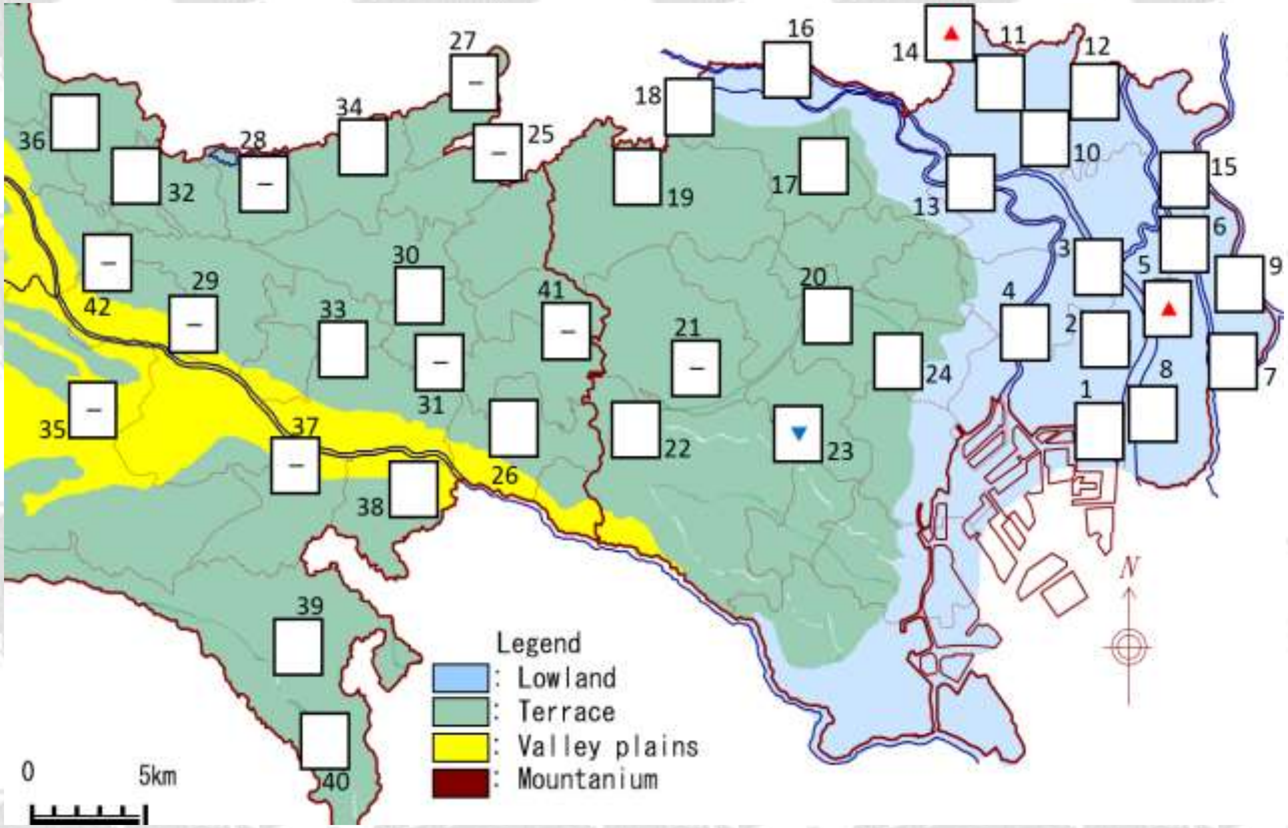
▲ : **3**wells(Lowland) ▼ : **79**wells(All zone) — : **7**wells(Terrace)

Distribution of Change Patterns Just after the Earthquake

13 Unconfined Wells

Unconfined groundwater 13 wells

• Just after the earthquake (14:00~16:00)



▲ : Water level Rising over 5cm

▼ : Water level Drawdown over 5cm

— : Water level No Change

▲ : **2**wells(Lowland) ▼ : **1**wells(All zone) — : **10**wells(Terrace)

Categorization of the Fluctuation Patterns

89 Confined Wells

Confined		Groudwater level fluctuations	wells	
C−D	C−D I	Confined groundwater − Decrease then Increase	45	89%
	C−D C	Confined groundwater − Decrease Continuing until end of March	21	
	C−D R	Confined groundwater − Decrease then Recover to the level before the earthquake	13	
C−I	C−I I	Confined groundwater − Increase, temporary decrease, Increase again	1	3%
	C−I C	Confined groundwater − Increase, Continuing until end of March	1	
	C−I D	Confined groundwater − Increase then Decrease	1	
C−N	C−N	Confined groundwater − No significant changes	7	8%

Grouping of Fluctuation Patterns

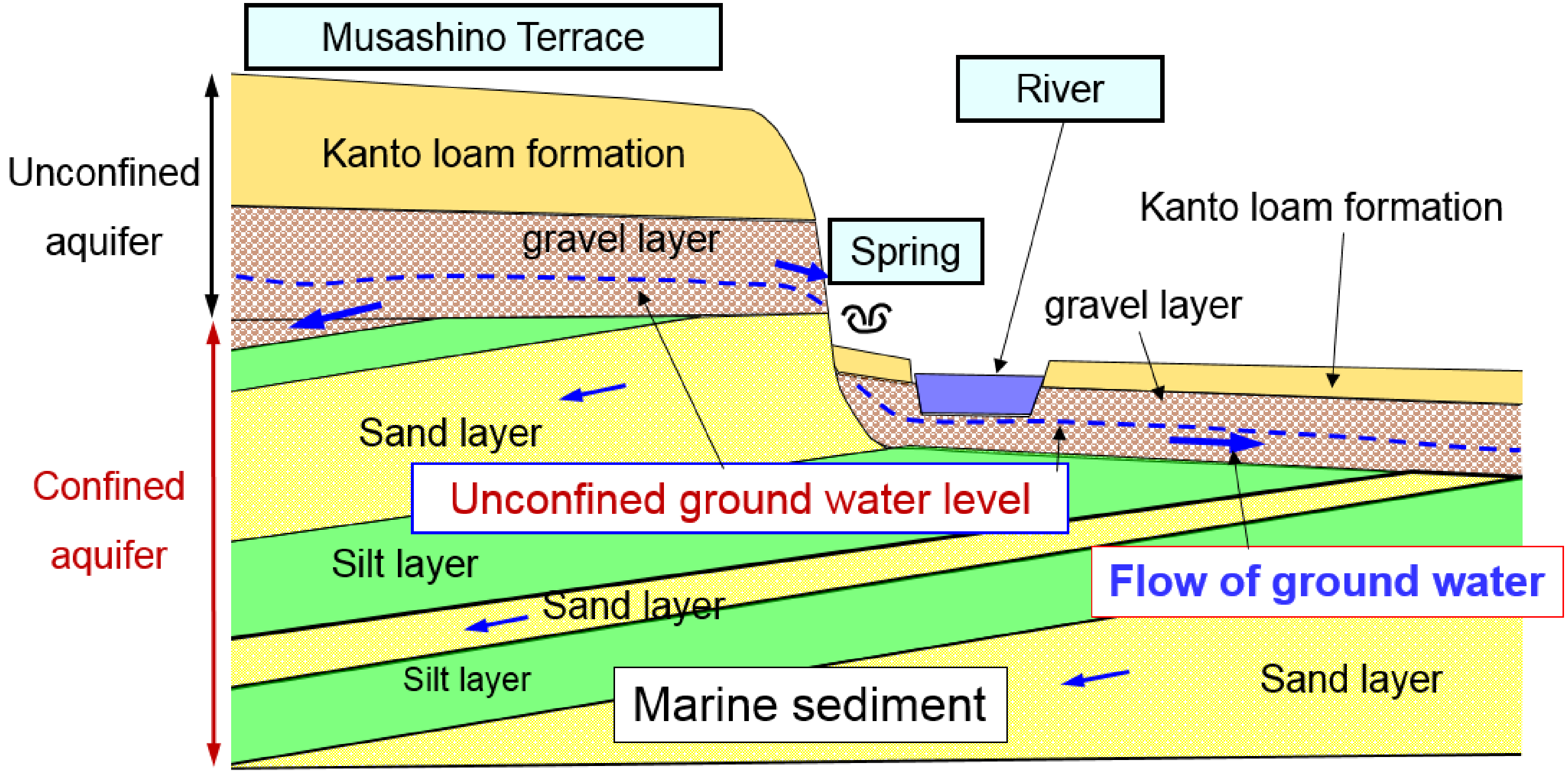
Unconfined Wells

Confined	Groudwater level fluctuations	wells	
U–D	Unconfined groundwater – Decrease	1	8%
U–I	Unconfined groundwater – Increase	2	15%
U–N	Unconfined groundwater – No significant changes	10	77%

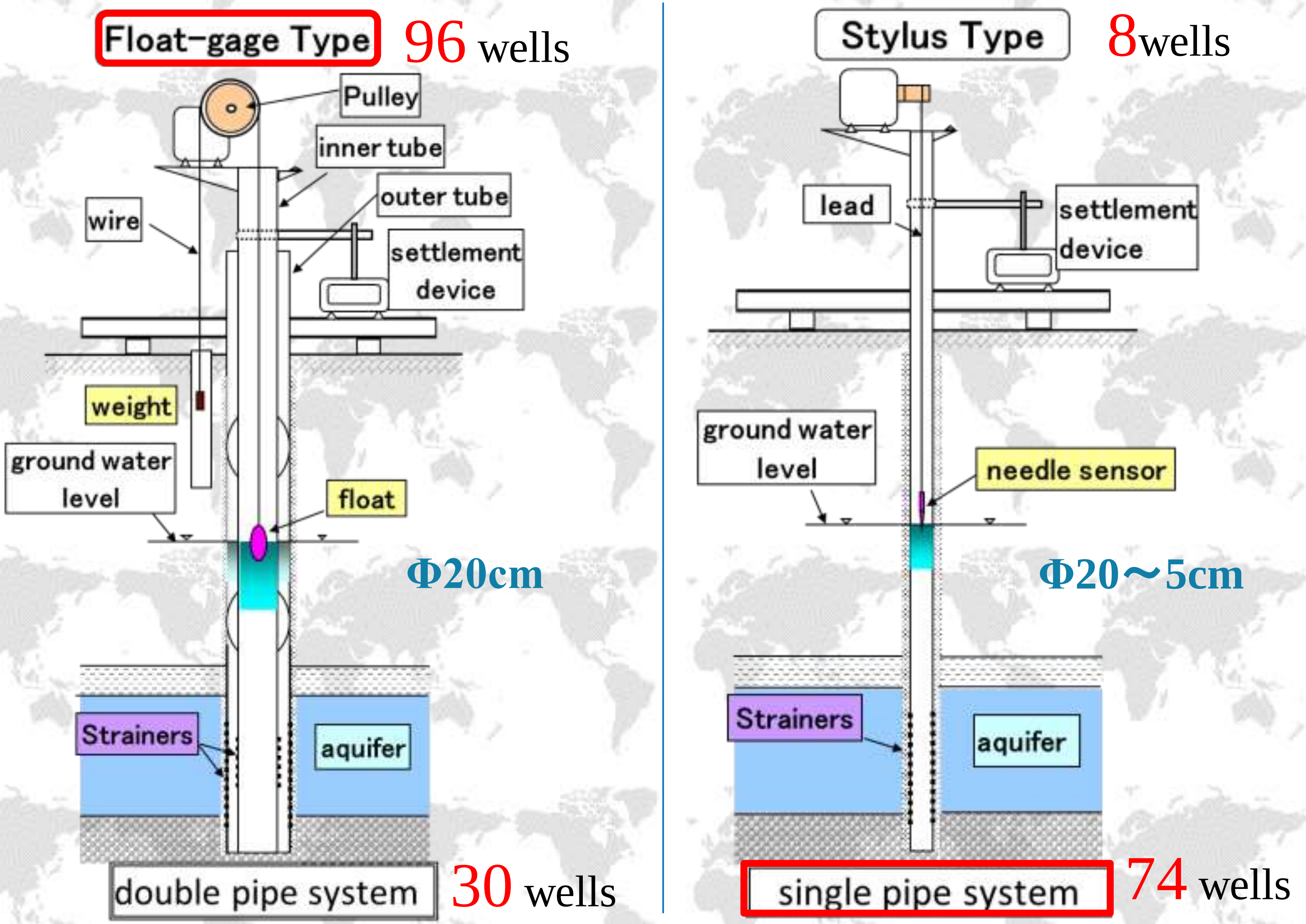
Consideration of Confined wells

Factor of no significant changes

- Diminution of pressure was little because of not minute geological formations.

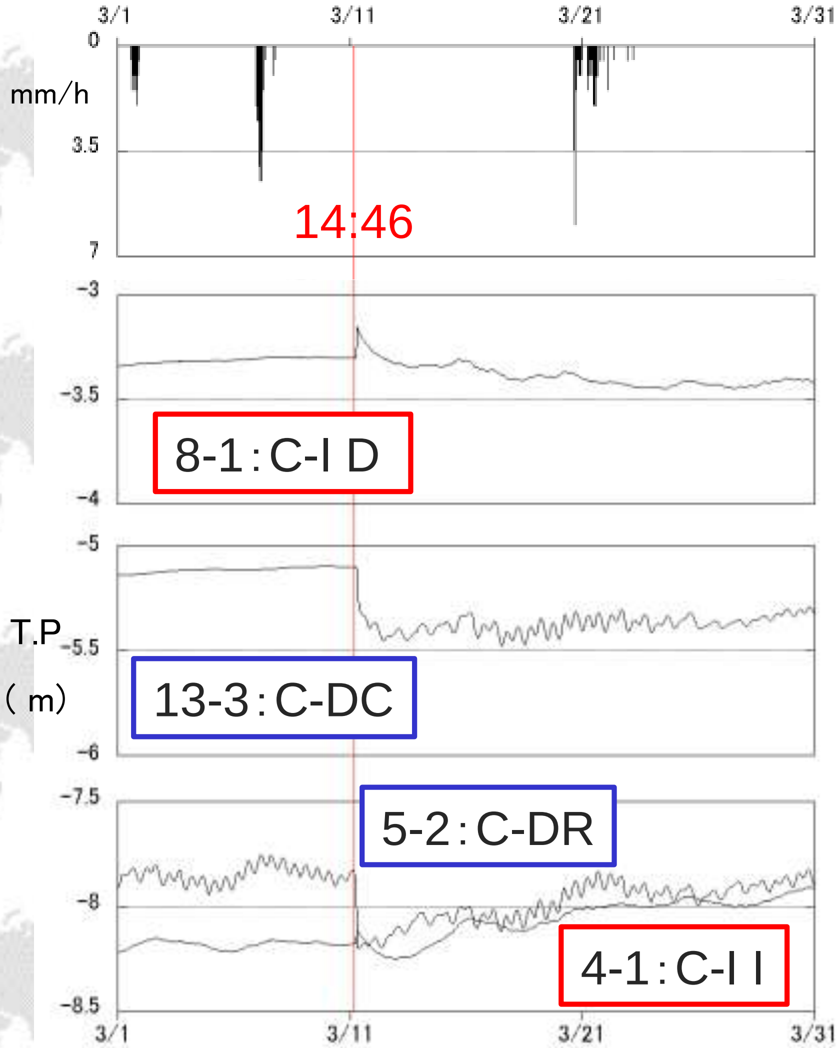


Types of Observation Wells



Groundwater level changes by the Earthquake

Confined Wells

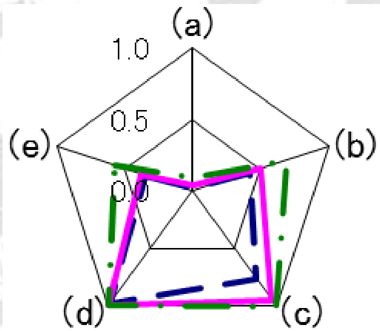


Water level lowering			
Max	site No.	Min	site No.
−83.3cm	8−2	−0.4cm	3−1

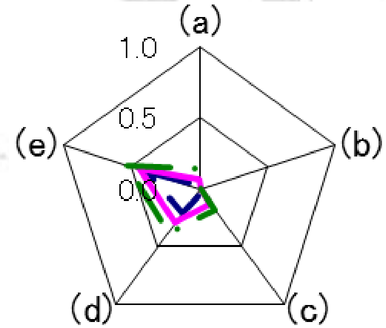
Water level rising			
Max	site No.	Min	site No.
+14.8cm	8−1	+0.9cm	33−1

3-3　クラスター別の水位変動パターン特性

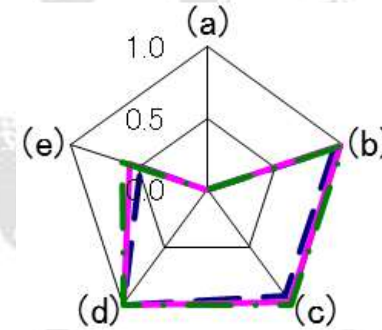
Cluster－1



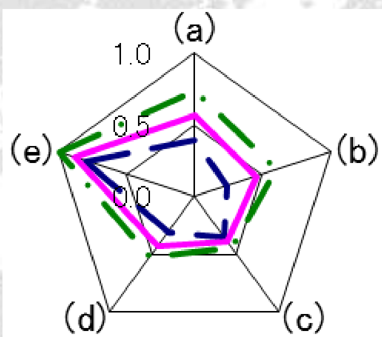
Cluster－2



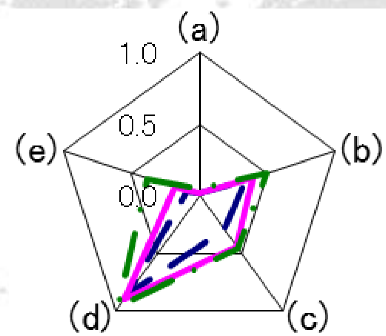
Cluster－3



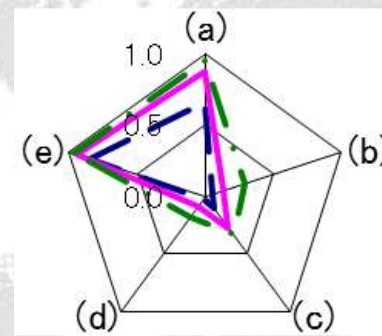
Cluster－4



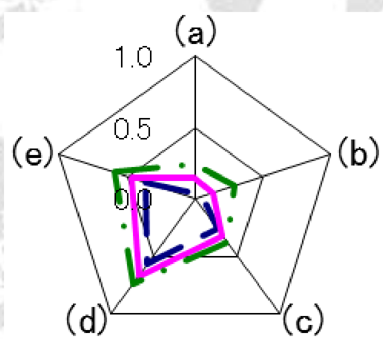
Cluster－5



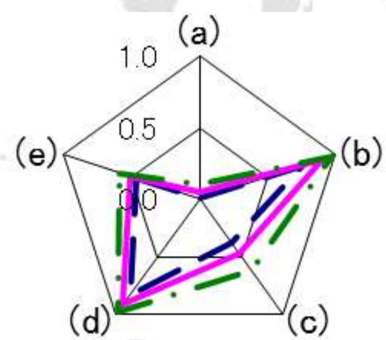
Cluster－6



Cluster－7



Cluster－8



(a) 地震直後　(b) 翌　日
(c) 3日後　(d) 月　末
(e) 深　度

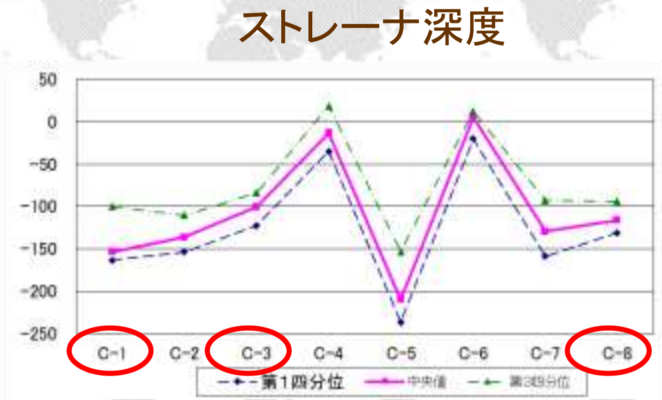
－ 凡　例 －

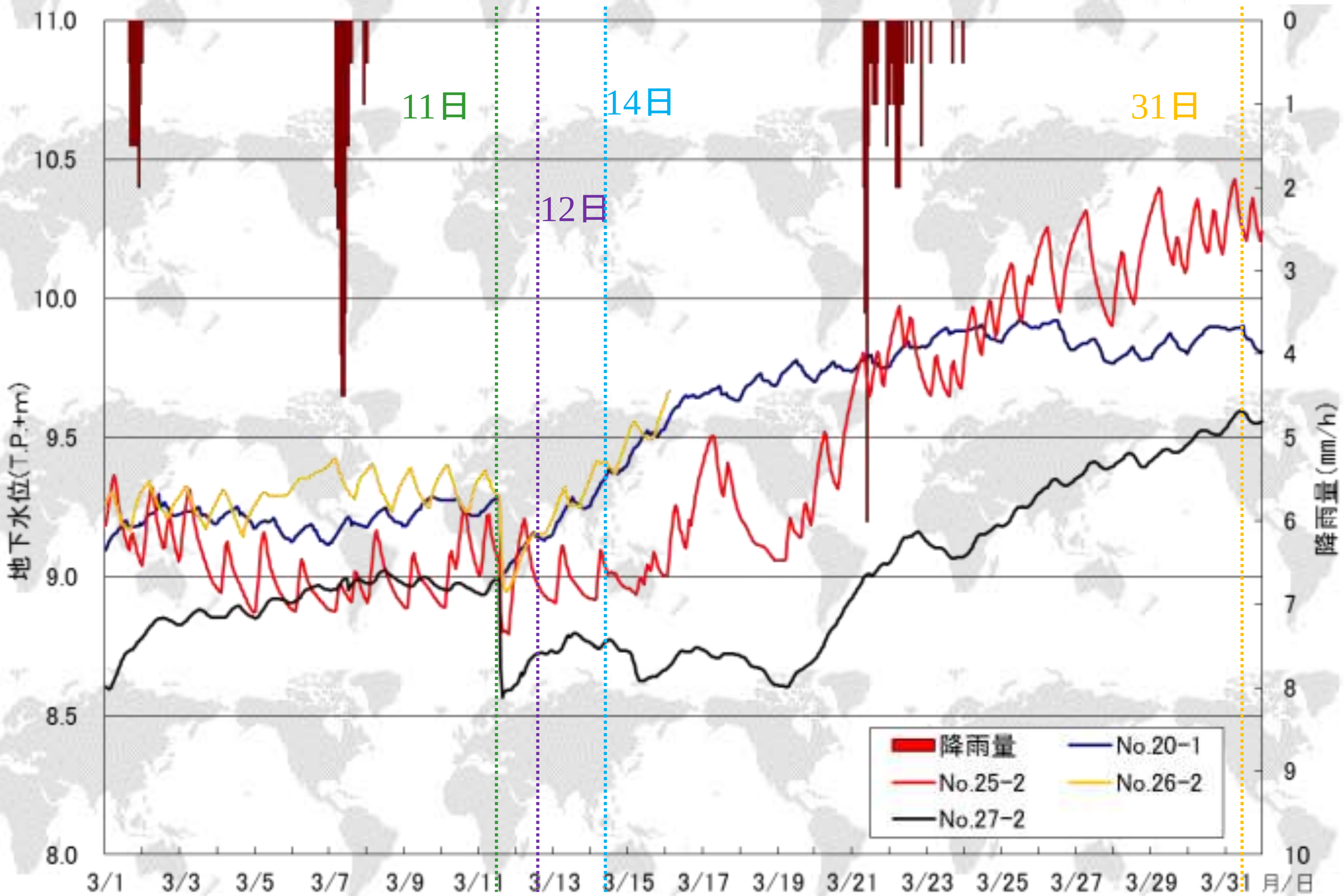
——：第1四分位
——：中　央　値
－—－：第3四分位

3−3　　Group−1の分布特性

・Cluster−１，Cluster−３，Cluster−８

・Group−1：
地震直後に大きく水位低下，翌日までに回復
14日までに上昇・31日まで継続，深度は中間的



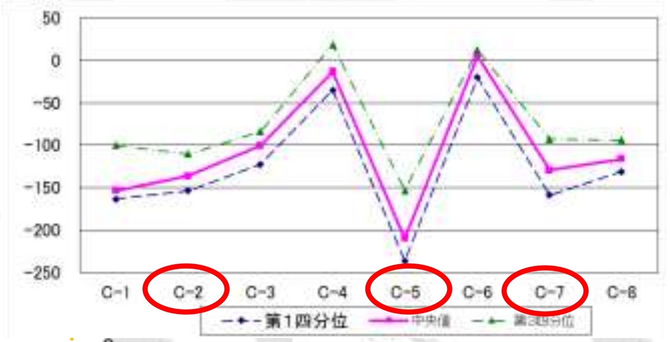


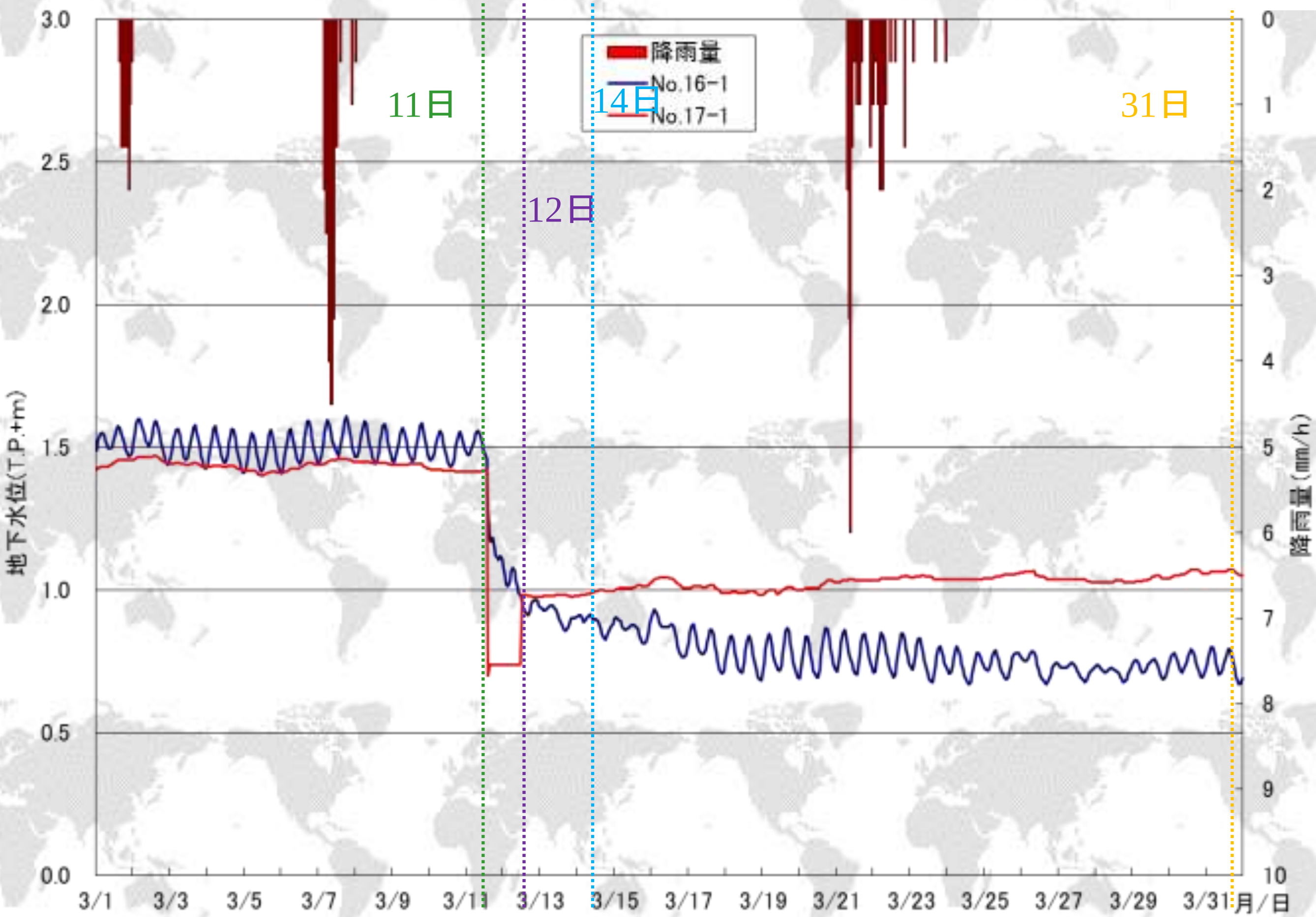
3-3　　Group-2の分布特性

・Cluster-2,　Cluster-5,　Cluster-7

・Group-2：
直後に比較的大きな水位低下・翌日まで継続,
14日までに戻り傾向・31日まで継続，深度は深め

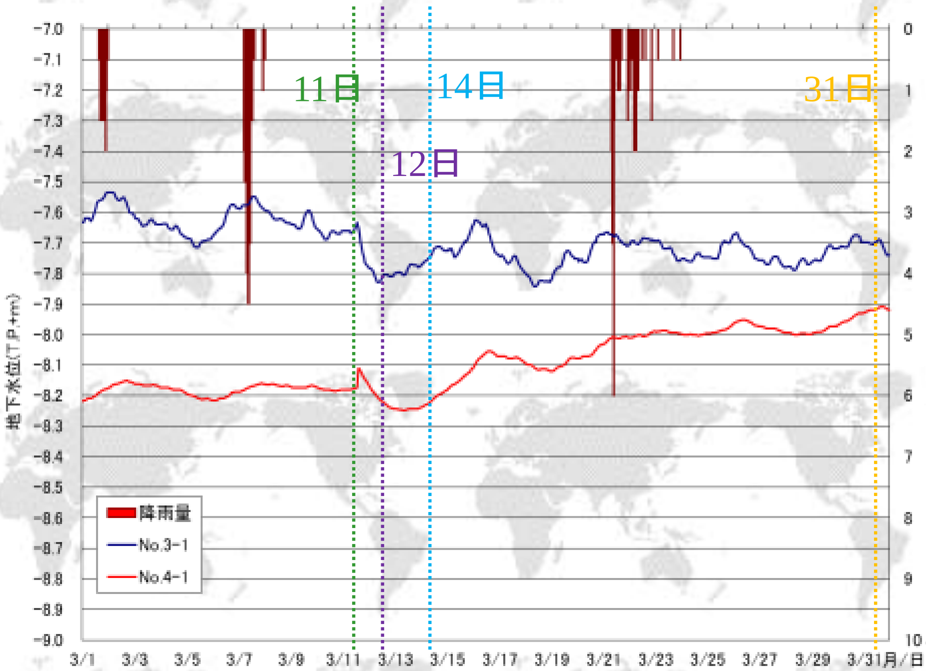
ストレーナ深度



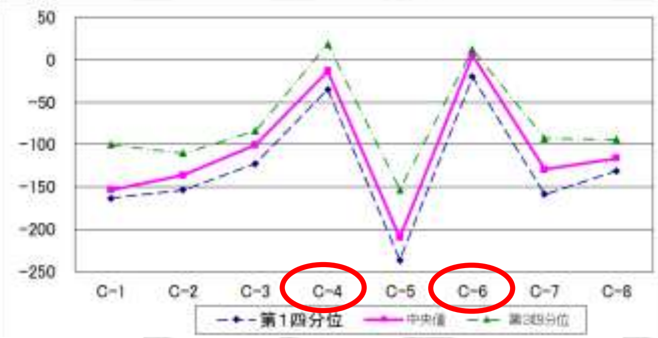


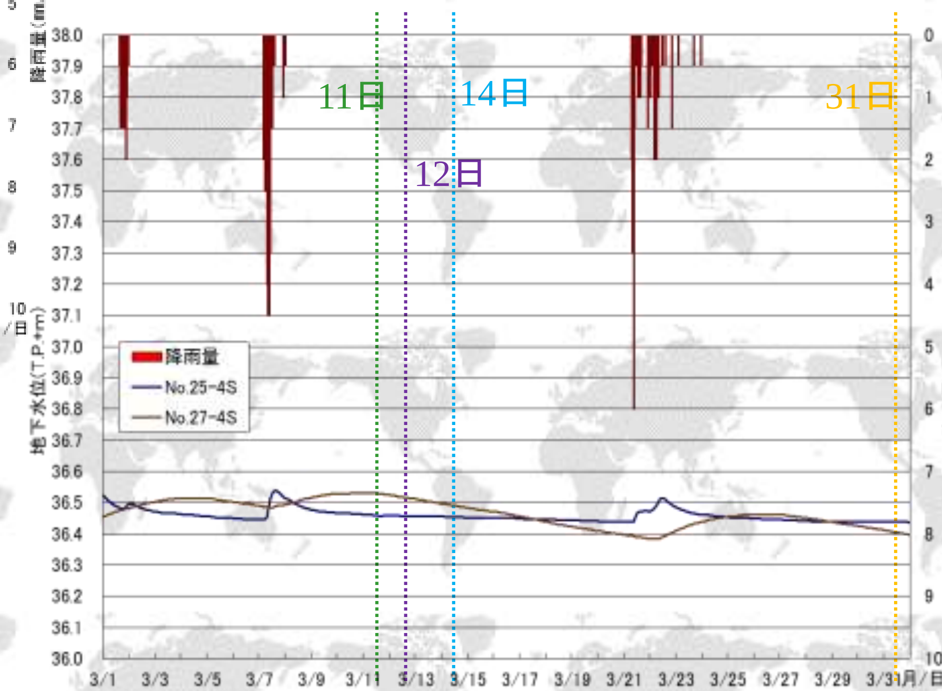
3-3　　Group-3の分布特性

・Cluster-4，Cluster-6



ストレーナ深度





・Group-3：直後に若干の水位上昇，または大きな変動なし

その後も大きな変動なし，深度はかなり浅い