Groundwater changes related to the 2011 Off the Pacific Coast of Tohoku Earthquake (M9.0)

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Abstract

Geological Survey of Japan, AIST has groundwater observation network in and around Tokai, Kinki, Shikoku regions in Japan for earthquake prediction research. The 2011 off the Pacific Coast of Tohoku earthquake, whose moment magnitude was 9.0, occurred at 14:46 on March 11, 2011 (JST). Epicentral distances of our observation wells ranges from 300 km to 1100 km. There was no clear precursory groundwater change at the observation wells. However, there were many postseismic groundwater changes, which were changes in level, pressure and discharge rate. Most of the changes were drops and they were consistent with the static coseismic volumetric strain changes due to the fault slip of the earthquake. On the other hand, some of them were not consistent with the static strain changes. This suggests that those changes were caused by ground shaking.

1. INTRODUCTION

The 2011 off the Pacific Coast of Tohoku earthquake, whose moment magnitude was 9.0, occurred at 14:46 on March 11, 2011 (JST). According to analysis by Yoshida et al.(2011), it is inferred that plate boundary fault rupture began at the hypocenter off the coast of Miyagi Prefecture and propagated as far as off the coast of Iwate Prefecture to the north and off the coast of Ibaraki Prefecture to the south. Just after the earthquake, a giant tsunami attacked the coasts facing the Pacific (Fujii et al, 2011) and caused severe damages. Geological Survey of Japan, AIST has many groundwater observatories in Tokai, Kinki and Shikoku. At many of the observatories, coseismic and/or postseismic changes in groundwater level, groundwater pressure or discharge rate were observed although there was no clear precursory change. In this paper, we will report the observation results and organize the characteristics of the postseismic groundwater changes.

2. OBSERVATIONS

For forecasting the Tokai, Tonankai and Nankai earthquakes, Geological Survey of Japan, AIST has a network composed of approximately 50 groundwater observatories mainly in and around the Tokai, Kinki, and Shikoku regions in Japan (Koizumi et al., 2009; Itaba et al.2010)(Fig. 1 and 2). Crustal deformation and ground motion are also observed at some of the observatories. Many of the observatories have only one observation well. However some of them have two or three wells with different depths. The depths of screens of the wells range from 10 to 1200 meters. At the observatories with two or three wells, the wells are numbered in order of depth from the deepest to the shallowest (Table 1). Unconfined groundwater, which is usually shallower than 50 m, is not sensitive to the volumetric strain changes (Bredehoeft, 1967). Therefore the groundwater data in 72 wells at 53 observatories, whose screen depths are deeper than 50 m, were examined in this paper (Table 1, Figs.1 and 2). Note that the epicentral distances in Table 1, which are distances between the wells and the epicenter of the 2011 Off the Pacific Coast of Tohoku Earthquake(Fig.1), are shown just for reference because the source region of the earthquake was about 200 km x 500 km (Yoshida et al., 2011).

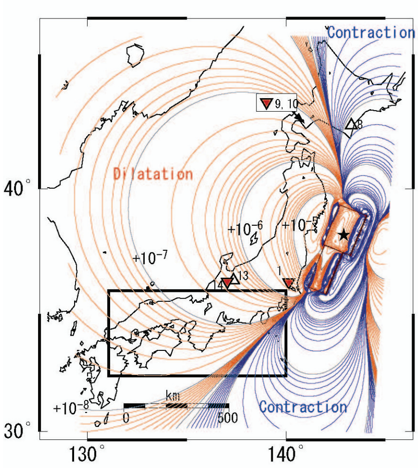

Fig. 1: Distribution of the static coseismic volumetric strain changes due to the fault slip of the earthquake.and the postseismic groundwater changes. The star shows the epicenter determined by Japan Meteorological Agency. △ : Rise (>=10mm or 10 cm^3/min), ▼ : Drop(<=-10mm or -10 cm^3/min). As to the groundwater changes in the rectangle, refer to Fig.2.

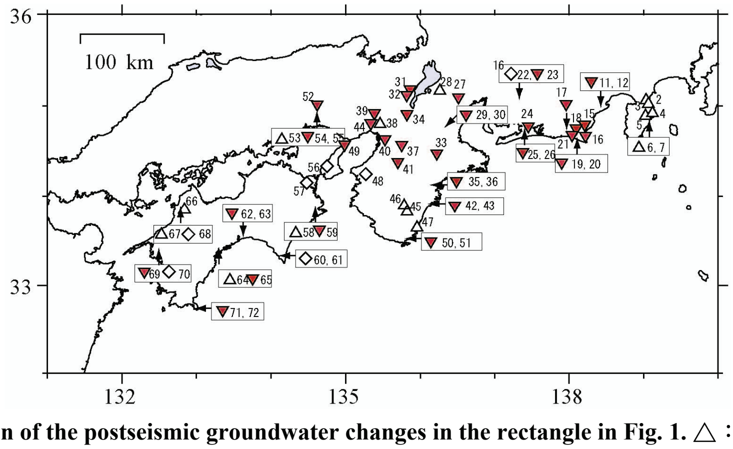

Fig. 2: Distribution of the postseismic groundwater changes in the rectangle in Fig. 1. △ : Rise (>=10mm or 10 cm^3/min), ▼ : Drop(<=-10mm or -10 cm^3/min), ◇: No change.

Table 1: List of the observation wells.

No.	Name	Depth of Screen*1 m	ED*2 km	PC*3 mm or L/min
1	TKB	565-582	331	<-20
2	174	deeper than 50	484	76
3	EDY	deeper than 50	484	288
4	OMR	130-146	489	15
5	HKW	130-147	491	105
6	AKZ1	620-779	494	36
7	AKZ6	584-620	494	111
8	CRI	871-1190	497	21
9	DTE1	136-175	514	-97
10	DTE2	80-114	514	-53
11	KNG1	309-320	525	-328
12	KNG2	224-235	525	-927
13	ATS	645-676	525	185
14	SGR	257-268	539	-30
15	HAI	71-154	556	-165
16	OMZ	104-164	569	No Change
17	KKZ1	95-128	570	-21
18	OGS	128-145	570	-57
19	HMO	154-265	571	-21
20	HMZ1	156-200	571	-33
21	DIT	145-222	575	-103
22	TYS1	405-427	597	No Change
23	TYS2	149-154	597	-255
24	TYE	186-208	608	-184
25	TYH1	182-198	608	-327
26	TYH2	134-150	608	-216
27	HKS	429-439	656	-69
28	HTS	338-360	674	212
29	ANO1	503-514	685	-397
30	ANO2	198-209	685	-355
31	HNO	235-246	703	-151
32	OHR	256-267	710	-349
33	ITA1	548-559	713	-49
34	OBK1	357-374	722	-125
35	MYM1	419-430	745	-382
36	MYM2	140-151	745	-137
37	KRY	412-434	747	-140
38	IKD	540-561	757	83
39	ING	700-823	758	-31
40	TNN	447-464	760	-30
41	GOJ	313-330	762	-67
42	ICU1	523-533	763	-25
43	ICU2	96-107	763	-260
44	TKZ	188-210	765	-113
45	HNG	794-997	794	117
46	HGM2	181-192	795	150
47	KTU	deeper than 50	796	211
48	NGR	402-446	797	-8
49	HRB	630-650	807	-183
50	KST1	509-520	812	-202
51	KST2	133-144	812	-68
52	YSK	132-137	812	-113
53	YST1	254-265	814	109
54	YST2	144-150	814	-189
55	YST3	144-150	814	-14
56	SED	210-225	840	No Change
57	BND	419-430	868	No Change
58	ANK1	489-516	878	149
59	ANK2	90-101	878	-121
60	MUR1	408-418	950	No Change
61	MUR2	130-141	950	No Change
62	KOC1	486-507	975	-88
63	KOC2	169-174	975	-80
64	SSK1	356-372	1006	48
65	SSK2	91-102	1006	-248
66	ODG	deeper than 50	1019	403
67	MAT1	512-529	1025	No Change
68	MAT2	170-181	1025	No Change
69	UWA1	446-457	1072	-192
70	UWA2	69-80	1072	No Change
71	TSS2	239-244	1075	-144
72	TSS3	129-135	1075	-23

*1: Screen: Casing pipe with holes where groundwater can move in and out.

*2 ED: Epicentral Distance

*3 PC: Postseismic Change(Value-A).

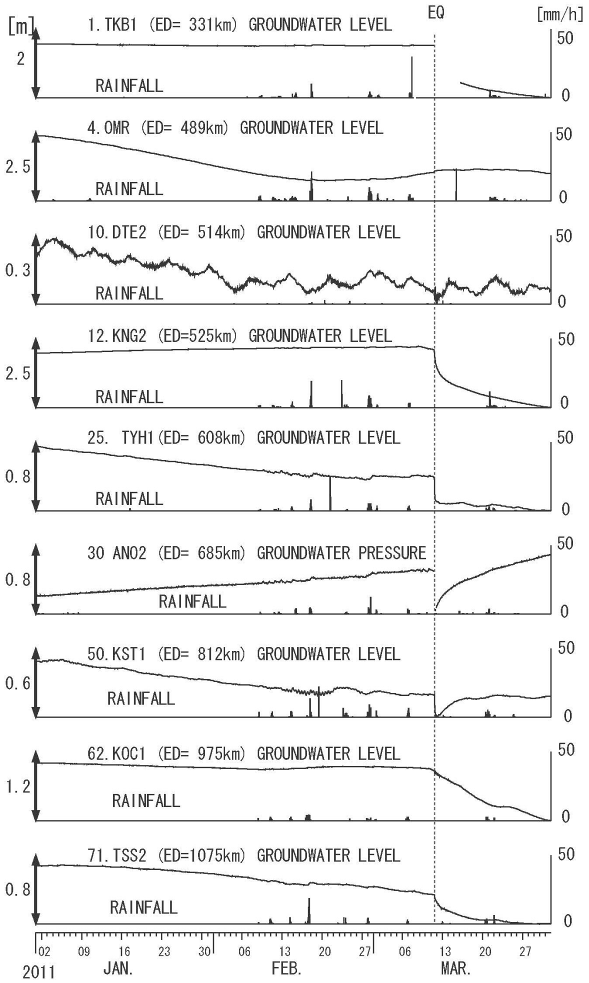

Fig. 3: Temporal change in groundwater level or pressure and rainfall at some of the observation wells in order of the epicentral distances in Table 1 during the period from January to March in 2011. The smpling interval is 1 hour. Tidal changes and the effect of the barometric pressure were deleted from the original groundwater data and the residuals or the corrected data were shown. EQ and a dotted line show the occurrence of the 2011 off the Pacific Coast of Tohoku earthquake

At the wells, groundwater level or groundwater pressure is mainly measured. The groundwater pressure data are converted into dimension of the groundwater level, that is, in meters. At a few of the wells, discharge rate is measured. Data are mainly recorded at sampling rates of 1 second or 2 minutes. At a few of the wells, data are recorded at sampling rates of 20 Hz. In the following analysis, the data with a sampling rate of 1 second or 20 Hz were re-sampled at 1 minute without averaging. We also used hourly data which were re-sampled at 1 hour without averaging.

3. RESULTS

3.1 Groundwater changes before the earthquake

Figs.3 shows the groundwater changes at some of the observation wells in order of the epicentral distances in Table 1 during the period from January to March in 2011.. There had been some changes in groundwater or pressure at a few of the wells since the middle of February ,2011. However those changes, which seem independent of the epicentral distances, are considered to be caused by rainfall. Therefore we judged that there were no clear precursory groundwater changes.

3.2 Groundwater changes after the earthquake

Associated with the seismic wave of the 2011 off the Pacific Coast of Tohoku earthquake (M9.0), the dynamic oscillations of the groundwater levels and the rest were observed at most of the wells. At many of the wells persistent changes in the groundwater level and the rest were observed during or after the dynamic oscillations. At some of the wells in coastal areas, the fluctuations of the groundwater level and the rest due to the tsunami were observed . For example, the groundwater level at DTE2, KOC1 and TSS2 in Fig.4 showed tsunami-induced changes a few hours after the earthquake occurrence.

There was almost no rainfall on March 11 and 12, 2011 (Fig.4). Because of the dynamic oscillations, it is difficult to estimate the coseismic persistent changes. Therefore we calculated the postseismic persistent changes in the following way. First, we calculated the mean value from 14:35 to 14:45 on March 11, 2011. Next, we calculated the mean value from 14:35 to 14:45 on March 12, 2011 as the value a day after the earthquake. Then the value-A is defined as the difference between the two values. The value-A was calculated from the original data whose sampling interval is 1minute or 2minutes. Therefore it included the effect of barometric pressure and tide. Using the program of BAYTAP-G, which can delete the effect of them from the original hourly groundwater data, we made hourly corrected data. Therefore we calculated the value-B which is the difference between the value at 14:00 on March 11, 2011 and that at 14:00 on March 12, 2011 in the corrected hourly data. If the sense of the value-A was different from that of value-B, and if the value-A or value-B was smaller than 10 mm in groundwater level (pressure) or 10 cm^3/min in discharge rate at a certain well, we judged there was no postseismic change at the well in this paper. If the sense of the value-A was the same as that of value-B, and if both of the value-A and the value-B are larger than 10 mm in groundwater level (pressure) or 10 cm^3/min in discharge rate, we judged there was the postseismic change. As to TKB, which is the nearest well, groundwater observation was stopped 2minutes after the earthquake because of power failure. Therefore we just inferred the postseismic change was drop and the amplitude was larger than 20 mm from Figs.3 and 4 (Table 1).

Figs.1and 2 show the distribution of the postseismic changes. There were rises at 17 of the wells, drops at 45 of the wells and no change at 10 of the wells.

Using the preliminary fault model by Geospatial Information Authority of Japan (Geospatial Information Authority of Japan , 2011), which was estimated from GPS data, we calculated static coseismic volumetric strain changes (Fig.1) due to the fault slip of the earthquake by a program of MICAP-G (Naito and Yoshikawa, 1999), which uses programs of Okada (1992). All of the wells except CRI were in the dilatation area (Fig.1). The 45 drops and 1 rise can be explained by the static volumetric strain changes although the 16 rises cannot (Figs.1 and 2).

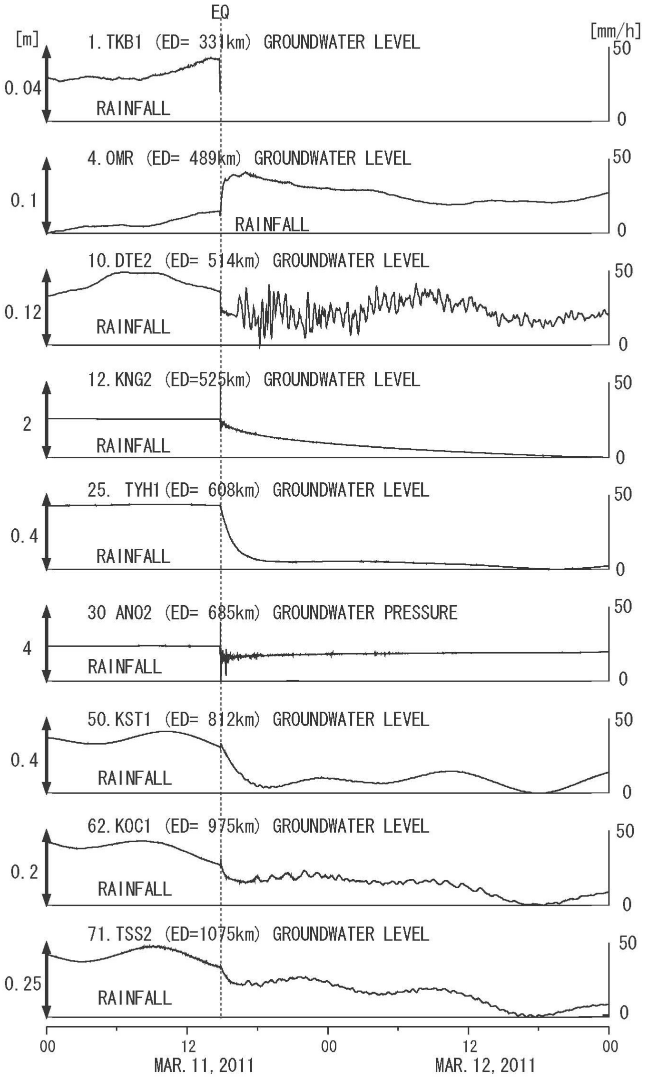

Fig. 4: Changes in groundwater level or pressure in the same observation wells as shown in Fig.3 just before and after the 2011 off the Pacific Coast of Tohoku earthquake. The original data with the sampling of 1 or 2 minutes are shown.

4. DISCUSSIONS

46 of the postseismic changes can be explained by the static coseismic volumetric strain changes due to the fault slip of the 2011 off the Pacific Coast of Tohoku earthquake. However most of the rises can not be explained by the stratic volumetric strain changes.

The rises in Izu Peninsula are opposite in sign to static volumetric strain change due to the fault slip of the earthquake. In the past, groundwater level changes at OMR were consistent with volumetric strain changes related to earthquake swarms off the east coast of Izu Peninsula (Koizumi et al., 2004). However, the rise at OMR did not agree with the dilatation in this case. In addition, there are 10 wells where postseismic rises occurred in the dilatation areas expect for Izu Peninsula. At several observatories with two or three wells in the dilatation area, the deepest well tends to have the postseismic rise although it is generally thought that deep aquifers are well confined and their strain sensitivities are large.

There are the other reasons which cause postseismic persistent groundwater changes. Liquefaction is one of them but does not tend to occur in the deep aquifer. Another reason is the removal of the temporary deposition barrier in a fracture due to groundwater flow by seismic wave or ground shaking (Brodsky et al., 2003). It can cause persistent groundwater changes due to distant earthquakes in the deep aquifer.

5. CONCLUSIONS

Before and after the 2011 off the Pacific Coast of Tohoku earthquake, we examined changes in confined groundwater at 72 observation wells of Geological Survey of Japan, AIST, whose epicentral distances range from 300km to 1100km. There was no clear precursory groundwater change although there were 62 postseismic persistent changes. 45 postseismic drops and one postseismic rise can be explained by the static volumetric strain changes due to the fault slip of the earthquake. However 16 postseismic rises cannot be explained by it. Probably ground shaking caused the 16 postseismic rises.

6. ACKNOWLEDGEMENTS

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