Observation of Radon and Hot Spring Water with 2011 Tohoku Earthquake in Gifu Prefecture, Central Part of Japan

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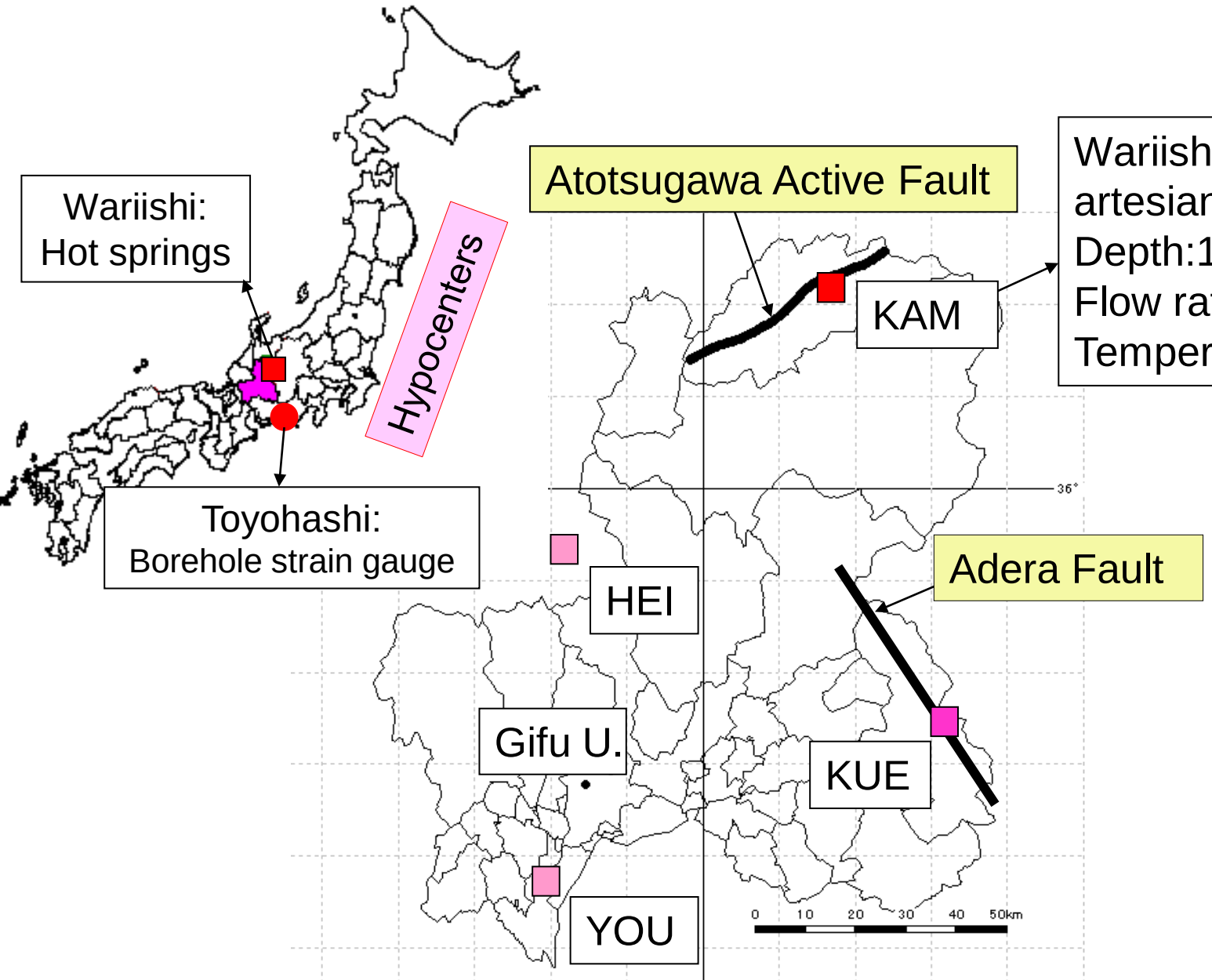
Location map of the observation in hot spring, Wariishi



Observation and Method

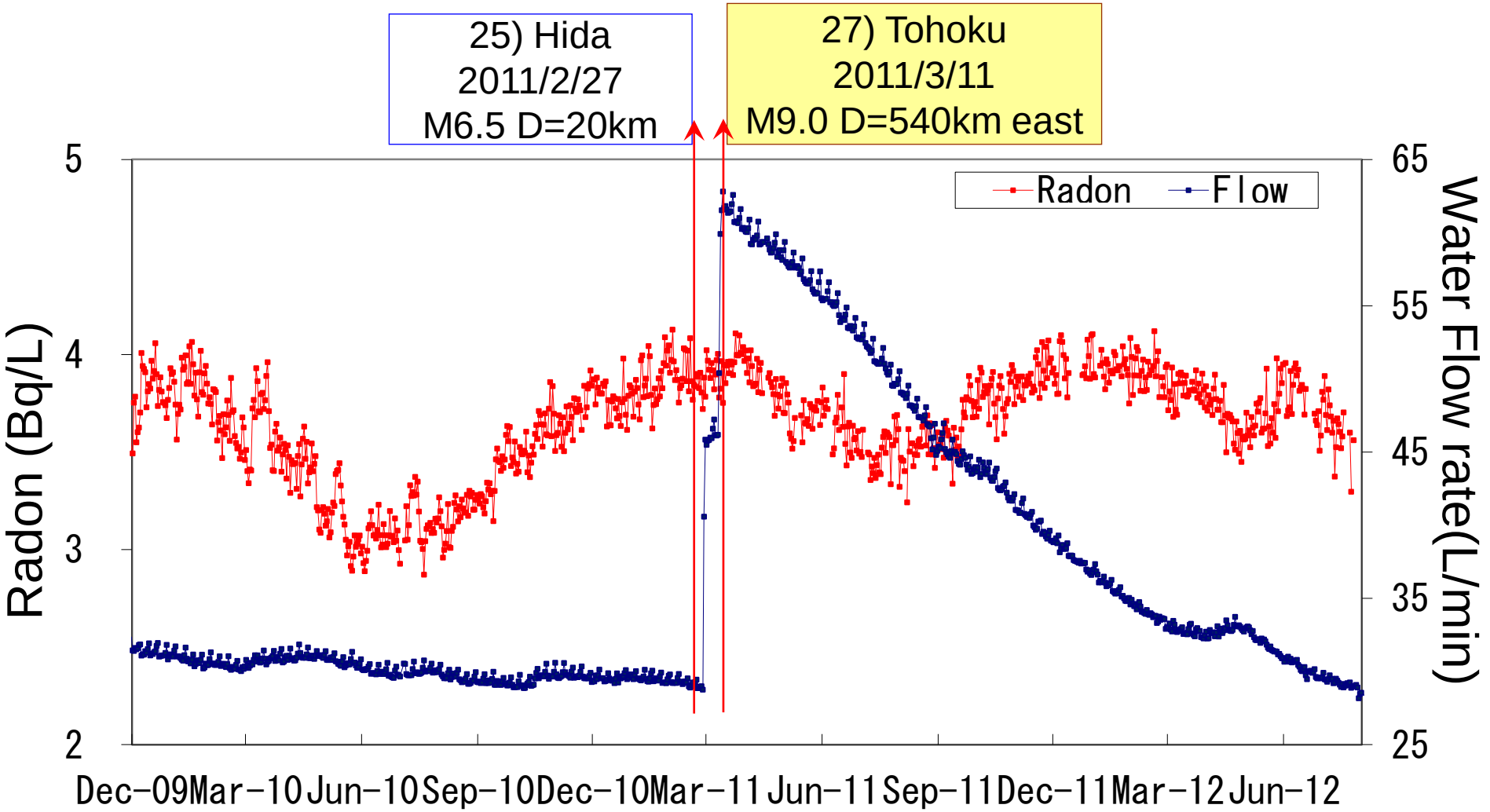
1) Radon, Helium isotope and dissolved gases

- Radon extract by using a gas-liquid mixer(2009-2012)
- Helium isotope ratio by Mass spectrometer(2011)
- Dissolved gases CO2, O2 and H2S by QMS(2011-2012)

2) Flow rate

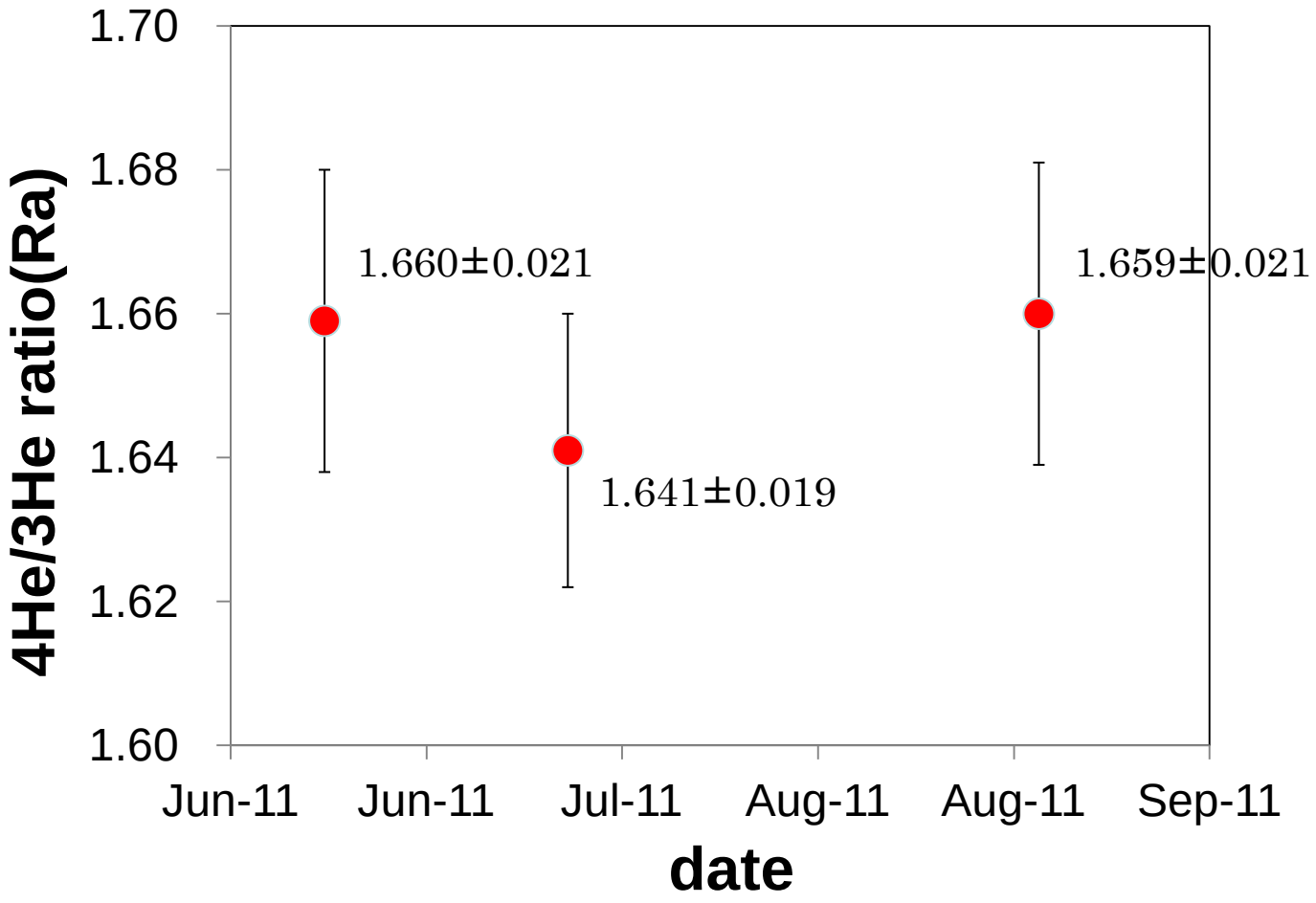
- Flow rate is continuously measured at intervals of a second by using an electromagnetic flow meter(2004-2012)
- 9 events of co-seismic changes were observed with Tohoku earthquakes of M>6.0(2011)
- Borehole strain data in Toyohashi observation by GSJ,AIST(2011)

Radon and Flow rate in Wariishi hot spring



Tohoku EQ：No changes for Radon Concentration
Flow rate Co-seismic changes with 2 EQ,
Hida28.8→46.2(L/min), Tohoku46.2→62.8(L/min)

Temporal variation Helium isotope 3He/4He in Wariishi

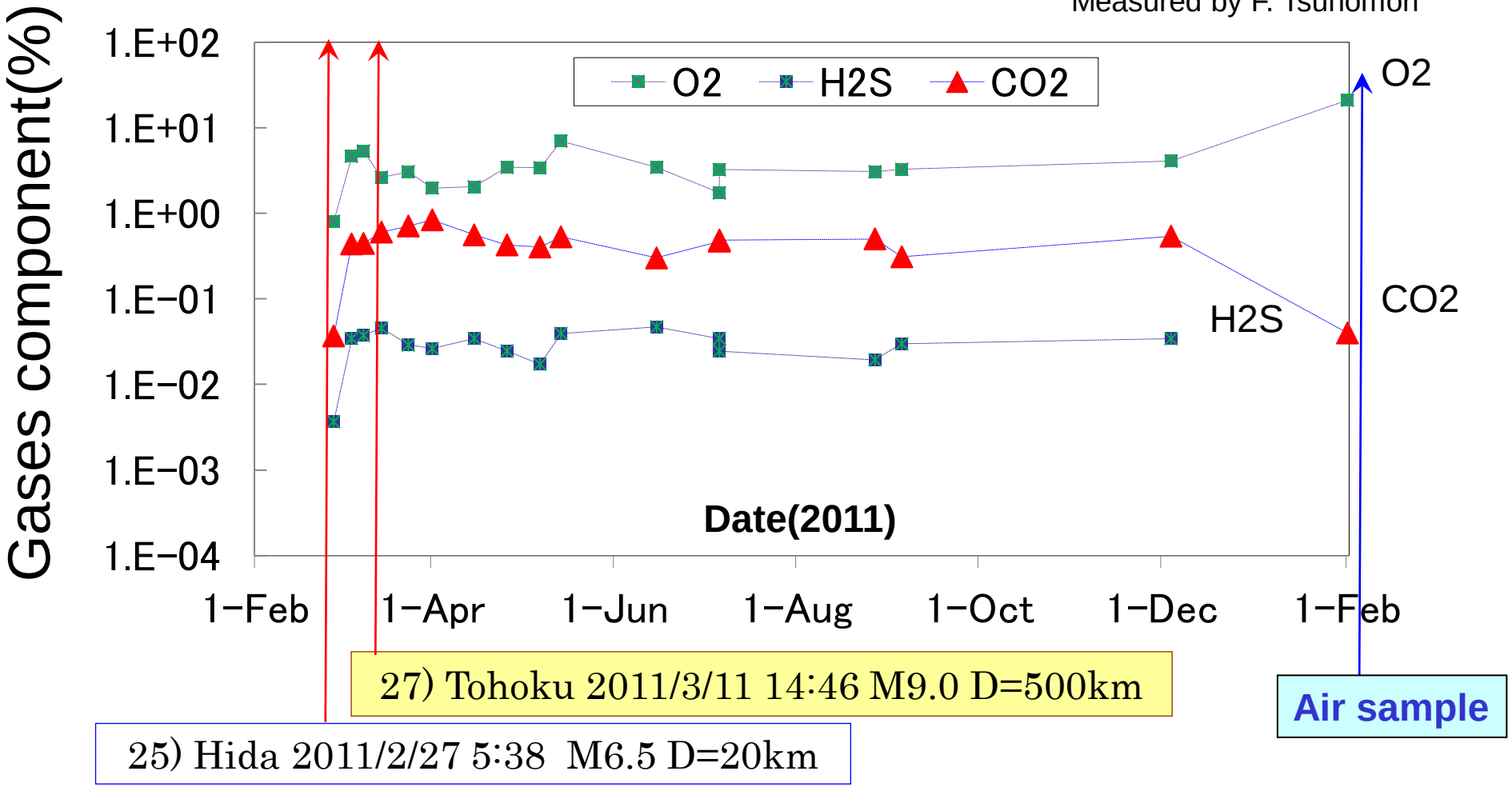


No change over time on Jun, Jul, Sep, 2011

3He/4He=1.65±0.01(Ra), air：Ra =1.4×10^{-6} , by K. Horiguchi

Gases CO2, O2 and H2S dissolved in Wariishi

Measured by F. Tsunomori



Gas Excess:CO2, Gas deficiency:O2
Changes after Hida EQ on 2012/2/27 15:22
No changes after Tohoku EQ for 2011/3/15 to 2011/12/4

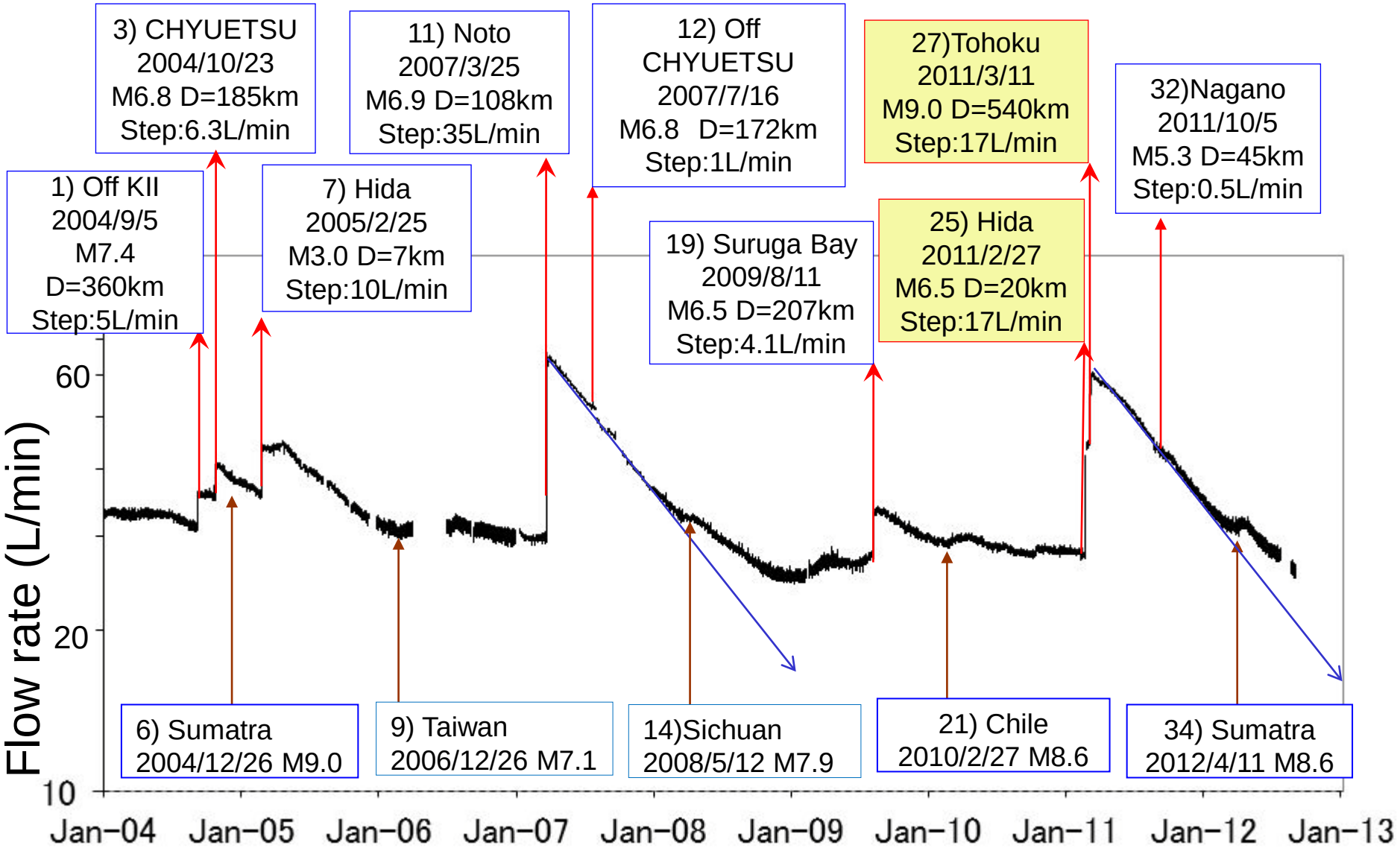
List of Co-seismic Changes of hot spring, Wariishi

No	date	epicenter	M	Amplitude +	Amplitude -	duration	Step increase	Initial decrease	comment
32)	2011/10/5 19:00	North Nagano	5.3	0.16	-0.16	25sec	0.5	*	D=45km
31)	2011/7/10 9:57	Off Iwate	7.1	0.7	-0.6	1.5min	none	*	After shock
30)	2011/4/12 8:08	Off Chiba	6.3	0.30	-0.25	1min	none	*	After shock
29)	2011/4/11 17:16	Fukushima	7.1	0.80	-0.90	3min	none	-0.1	After shock
28) ●	2011/4/7 23:32	Off Miyagi	7.2	1.80	-2.00	3min	none	-0.3	After shock
27-B)	2011/3/15 22:31	East Shizuoka	6.0	0.50	-0.50	2min	none	*	Induced?
27-A)	2011/3/12 3:59	North Nagano	6.7	0.30	-0.50	1min	none	*	Induced?
27-3)	2011/3/11 15:26	Off Miyagi	7.5	2.10	-1.60	6min	none	*	After shock
27-2) ●	2011/3/11 15:16	Off Ibaraki	7.7	13.00	-13.00	2min	none	*	After shock
27-1)	2011/3/11 15:08	Off Iwate	7.4	4.50	-5.00	3min	none	-0.3	After shock
27) ●	2011/3/11 14:46	Tohoku	9.0	30.00	-45.00	10min	17.0	-5.0	Main shock
26) ●	2011/3/9 11:45	Off Miyagi	7.3	-2.30	-2.00	3min	none	-0.3	Fore shock
25)	2011/2/27 5:38	Hida	5.4	*	*	*	15.5	*	D=20km
24)	2011/2/27 2:19	Hida	4.9	*	*	*	1.5	*	D=20km

a fore shock, main shock, 7 after shocks in Tohoku EQ(2011)

● Borehole strain data（Toyohashi）(by Geological Survey of Japan, AIST)

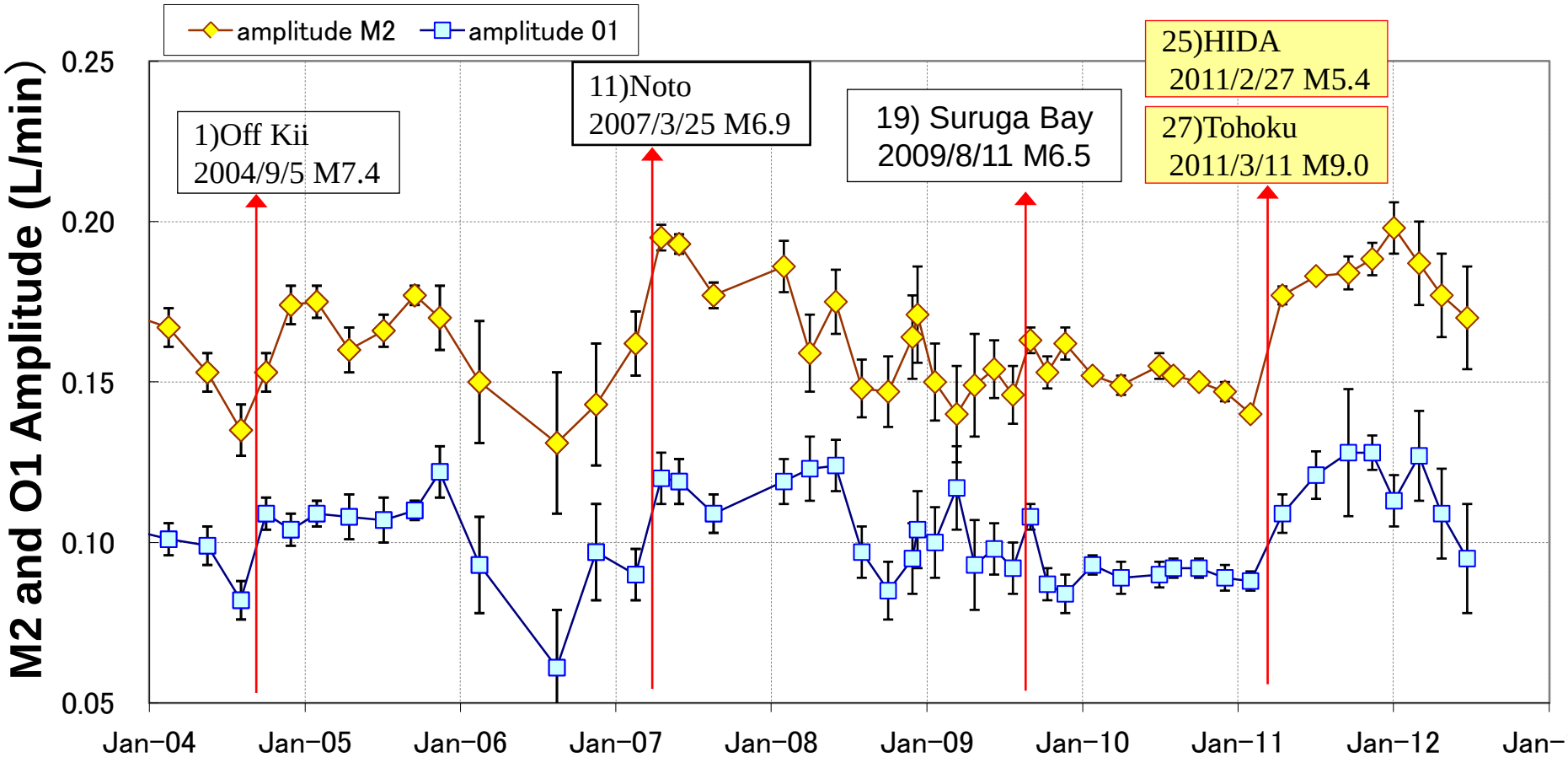
Flow rate Observations in hot spring(2004-2012)



Coseismic-changes:Hida28.8→46.2(L/min),Tohoku46.2→62.8(L/min)

Attenuation Curves: $F(t)=F_0EXP(-at)$, $T_{half}=LN(2)/a=340day$

Time Variation of tidal M2 and O1 amplitudes for earth tide

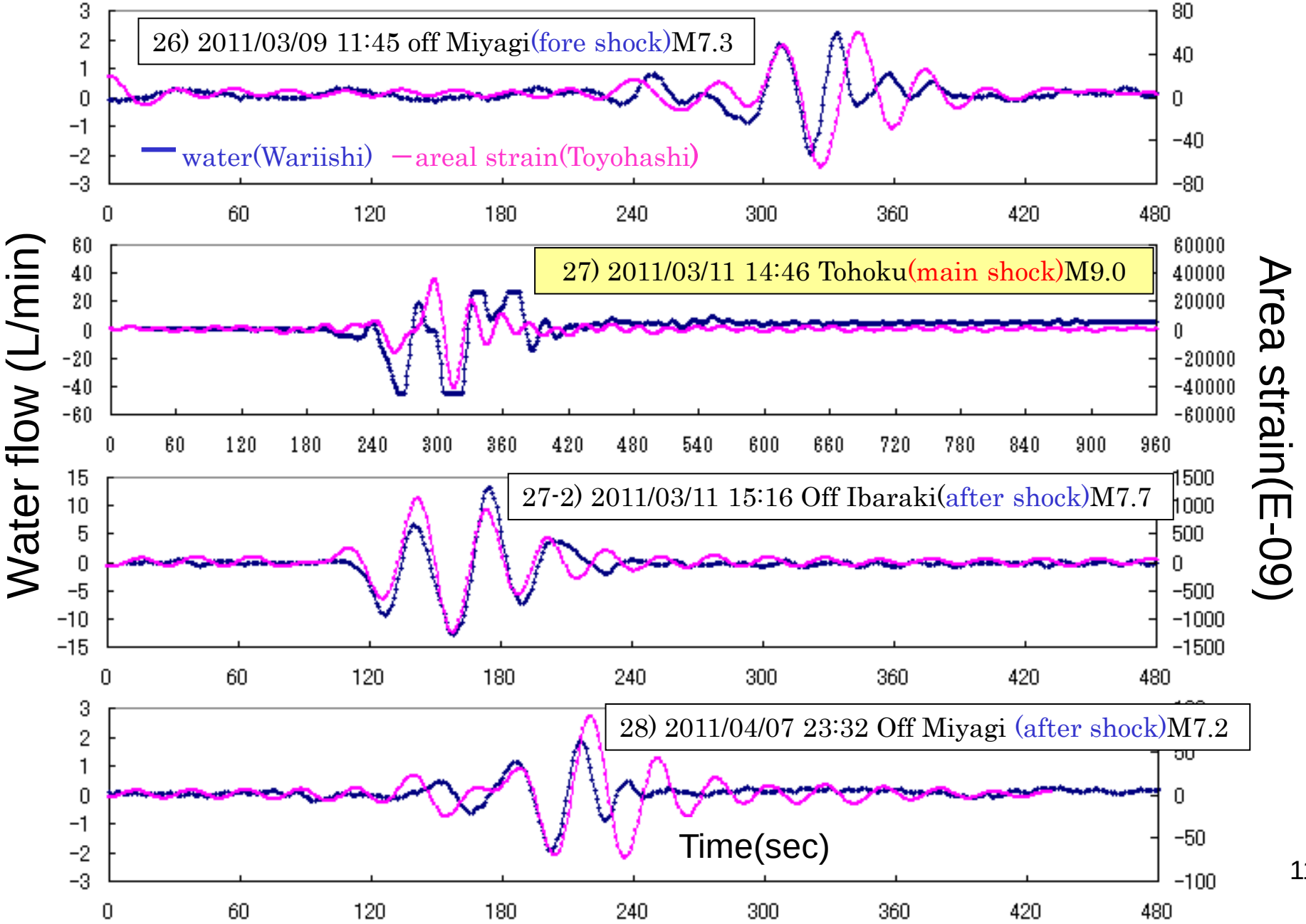


Water analysis by BAYTAP-G in 2004-2012
Tidal strain by GOTIC2,M2:0.997,O1:0.671(E-08)
Sensitivity of discharge water for the tidal strain(L/min)/(E-08)
M2(12.4h): 0.16±0.02, O1(25.8h): 0.15±0.02

Co-seismic change: sensitivity for tidal strain before/after Hida/Tohoku EQ
M2: 0.15→0.19±0.01, O1: 0.13→0.18±0.01 (L/min)/(E-08)

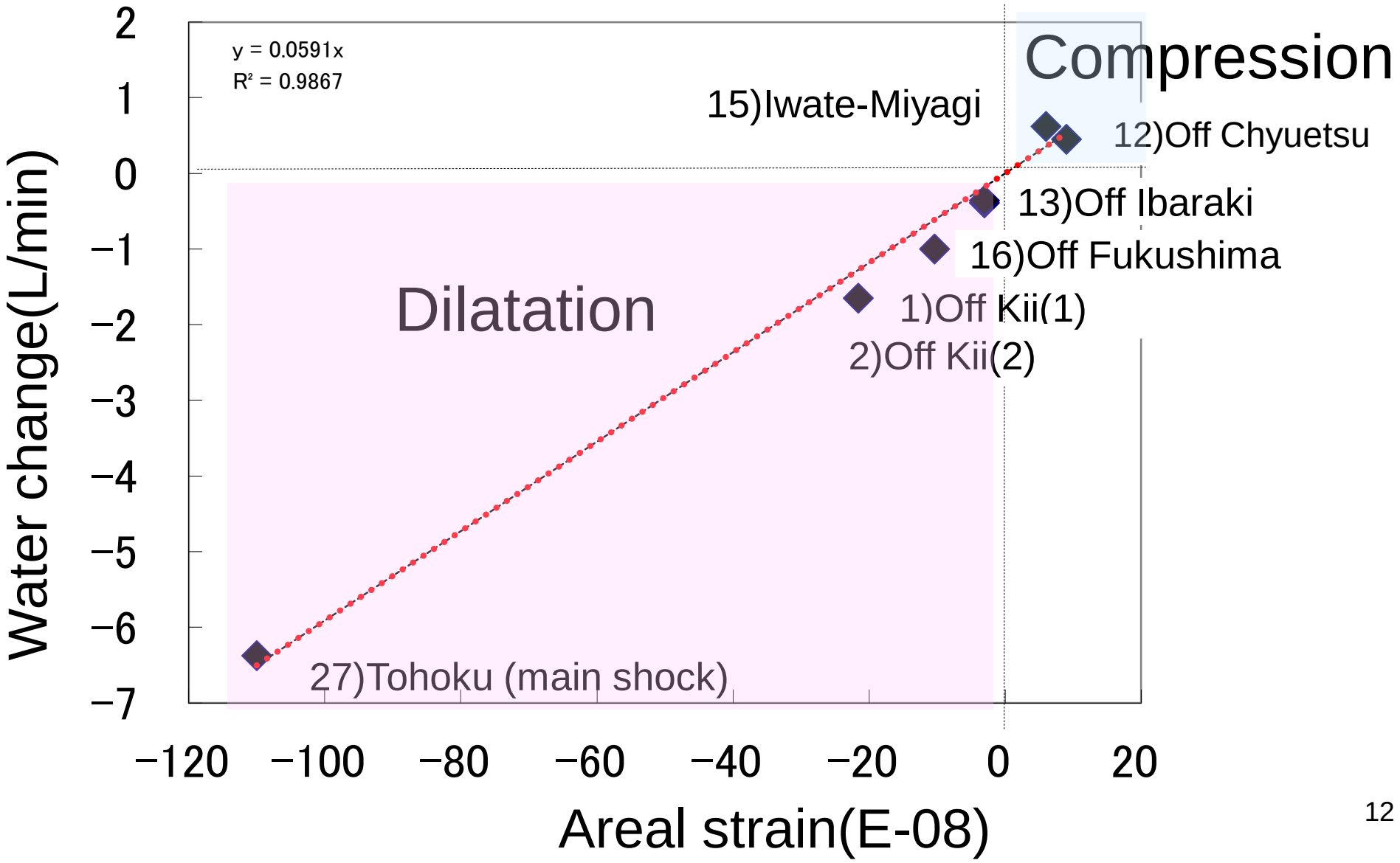
Seismic Changes of Water and Area Strain (2011)

Strain data with Band Pass Filter(High:0.01Hz-Low:0.04Hz)



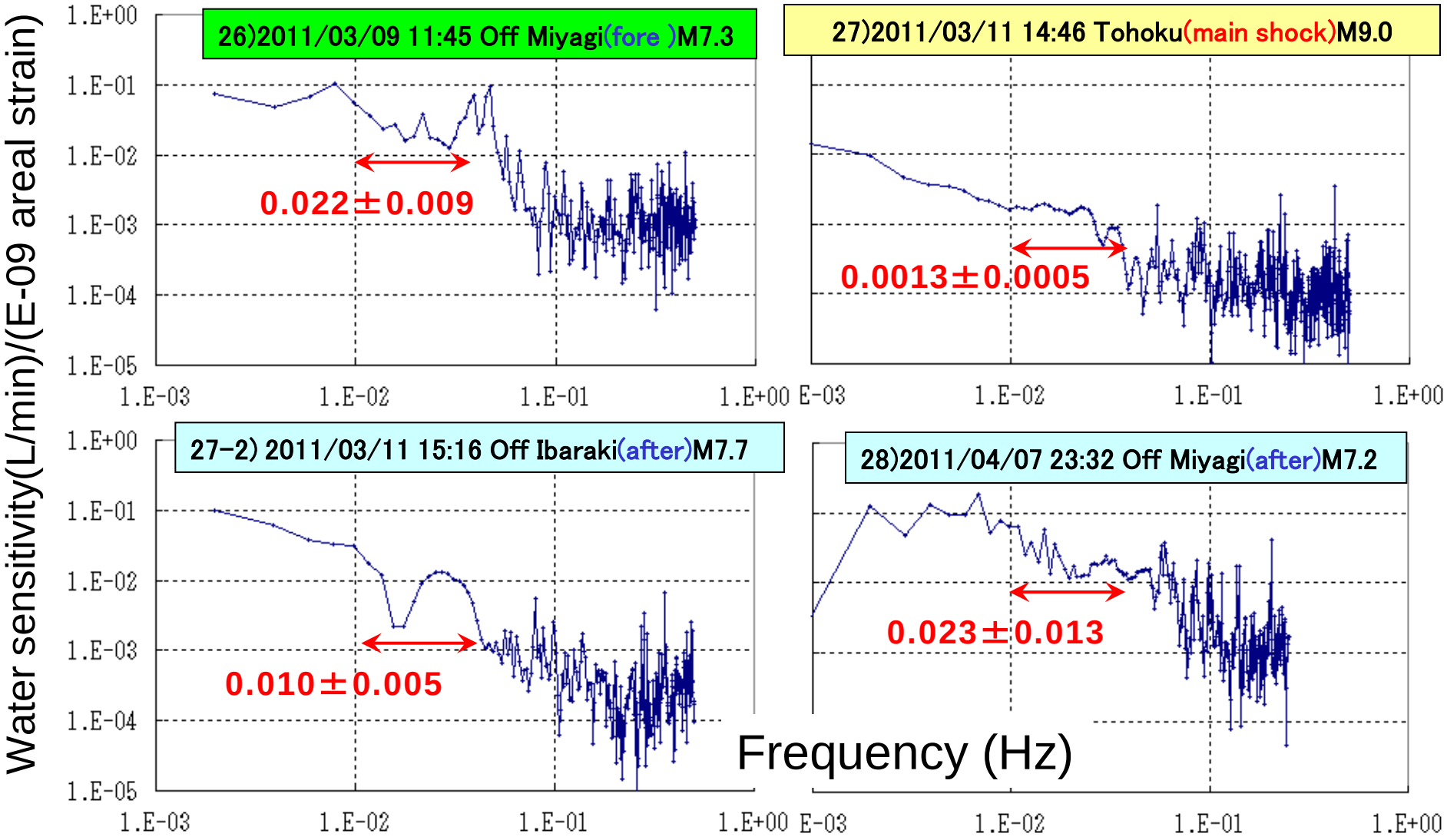
Initial water changes for areal strain

sensitivity: 0.06±0.02(L/min)/(E-08 area strain)



Water sensitivity for areal strain(2011Tohoku EQ)

Sensitivity[(L/min)/(E-09 areal strain)] Frequency:0.010-0.035Hz

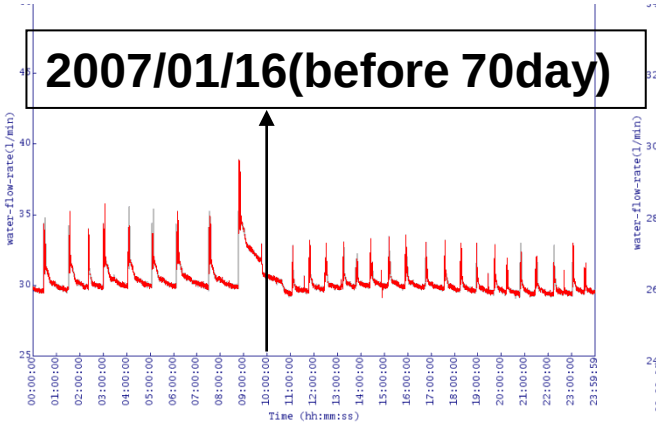


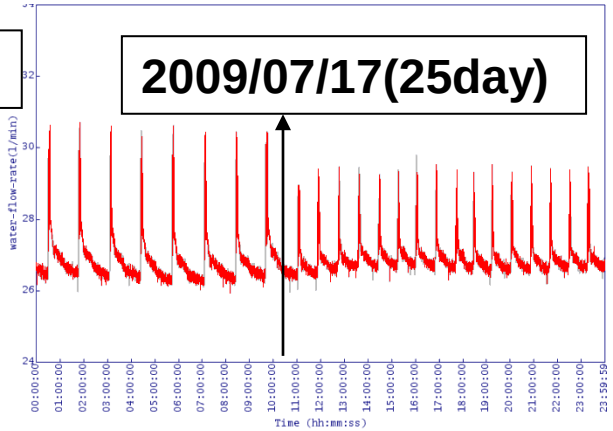
Co-seismic changes: 03/09(fore)→03/11(main)→03/11(after)→04/07(after)

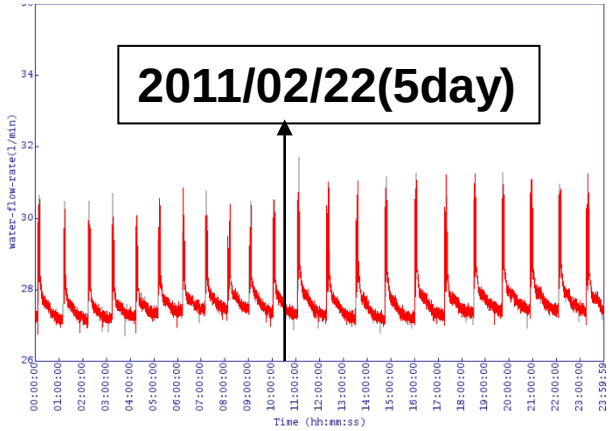
Water sensitivity : 0.022 →0.0013 →0.010 →0.023

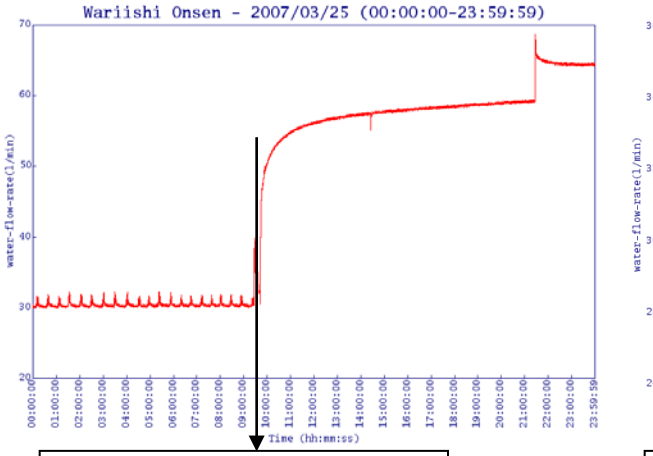
Periodic intermittent hot spring(geyser)

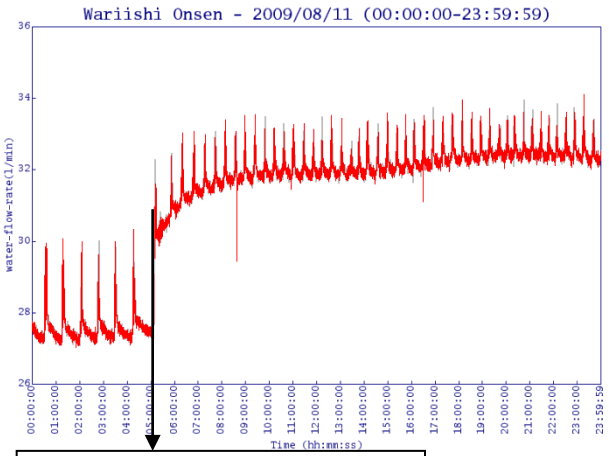
Period and amplitude of the geyser changes 5 days before Hida earthquake. Geyser disappeared after the earthquake.

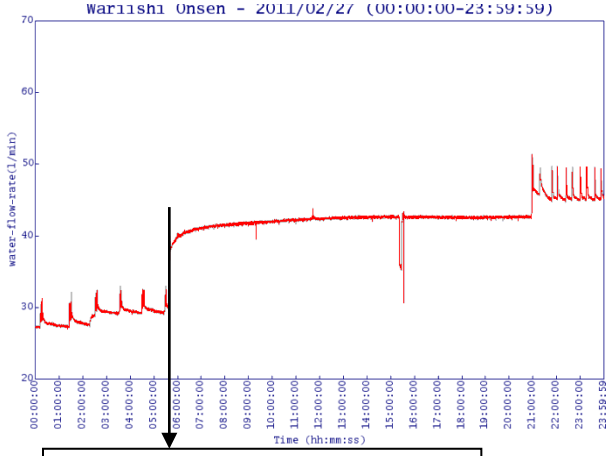










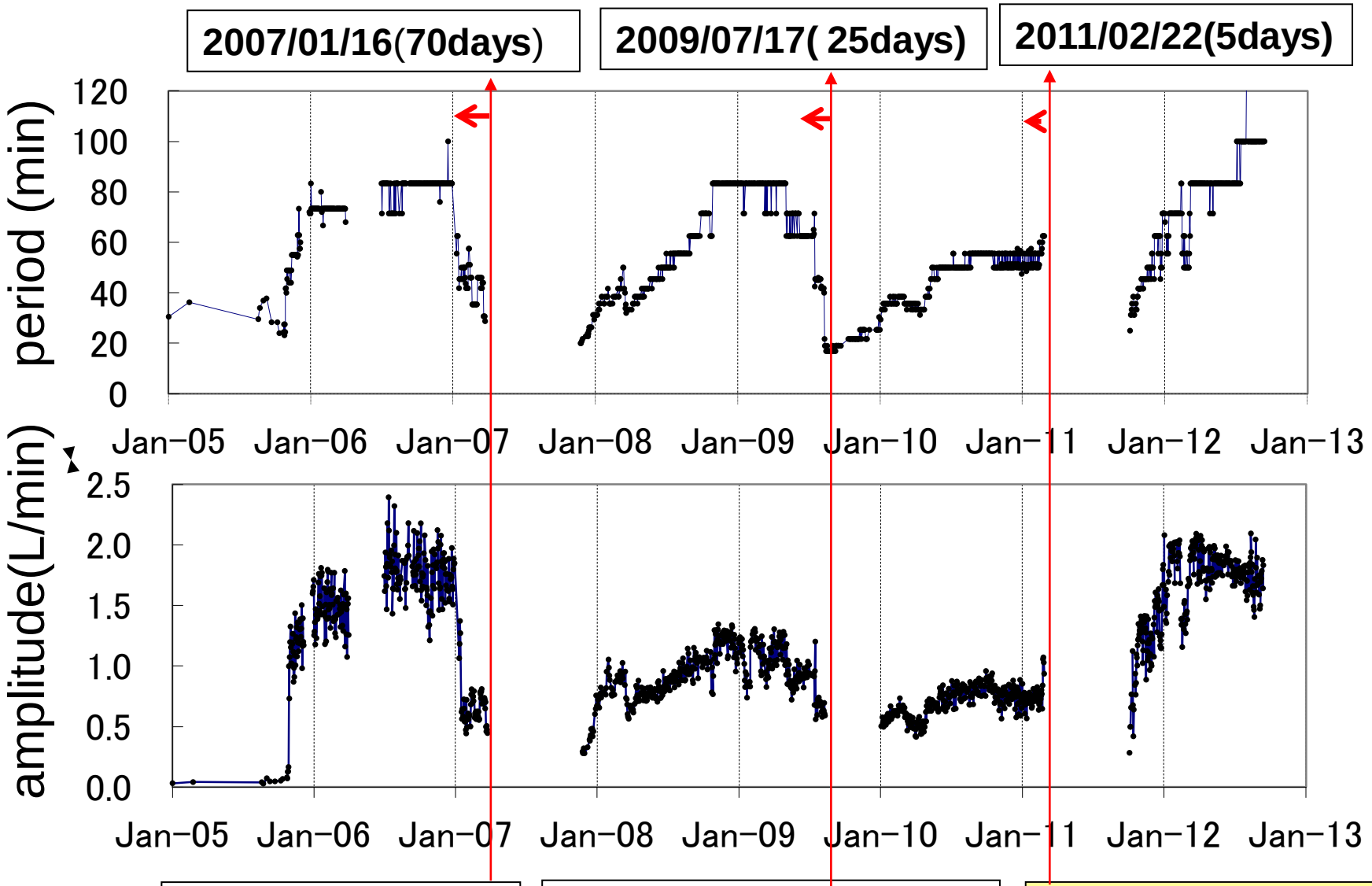


10) Noto
2007/03/25 9:42
M6.9 D=108km
Step:35L/min

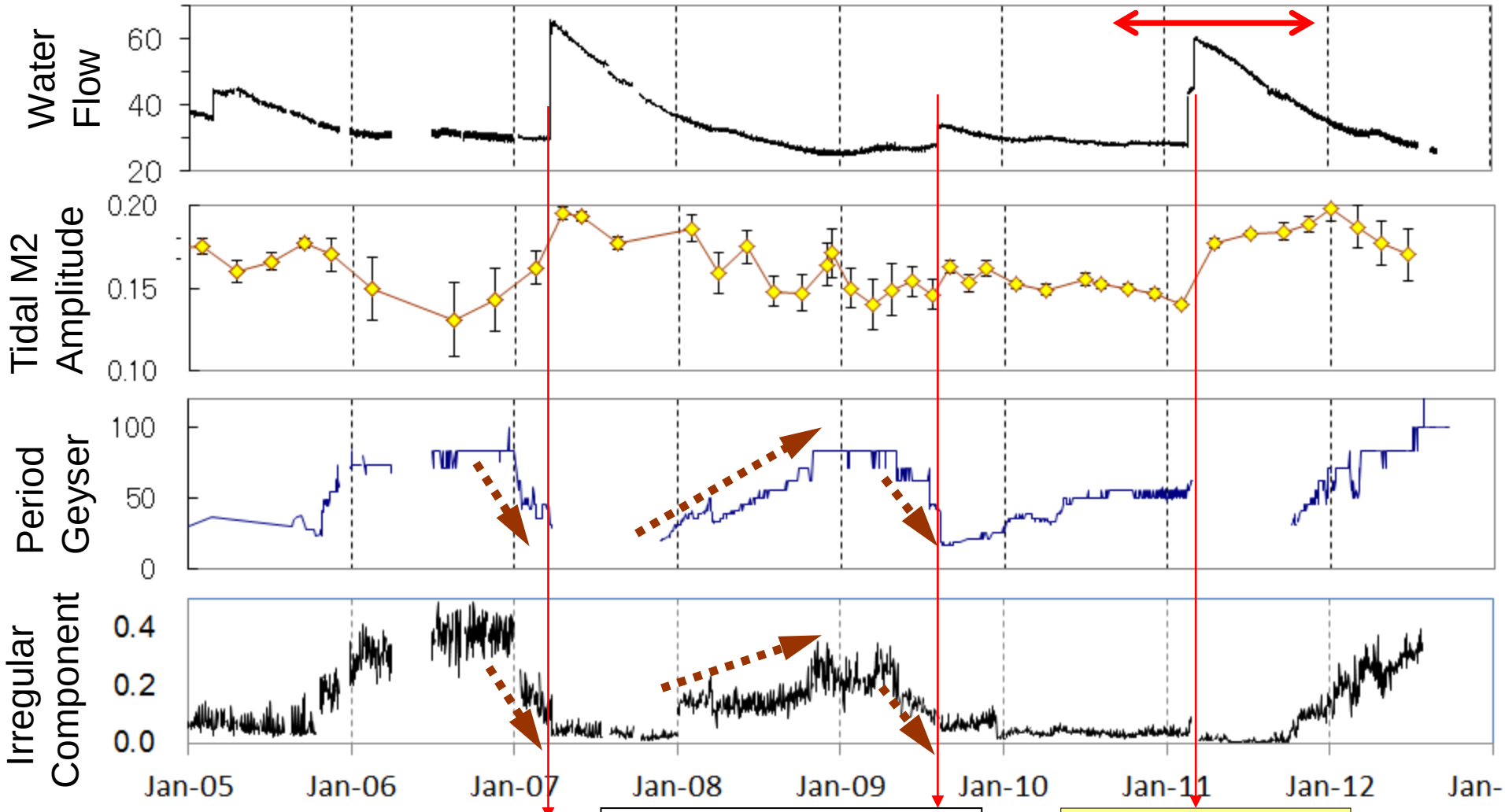
19) Suruga Bay
2009/08/11 5:07
M6.5 D=207km
Step:4.1L/min

25) Hida
2011/02/27 5:38
M6.5 D=20km
Step:17L/min

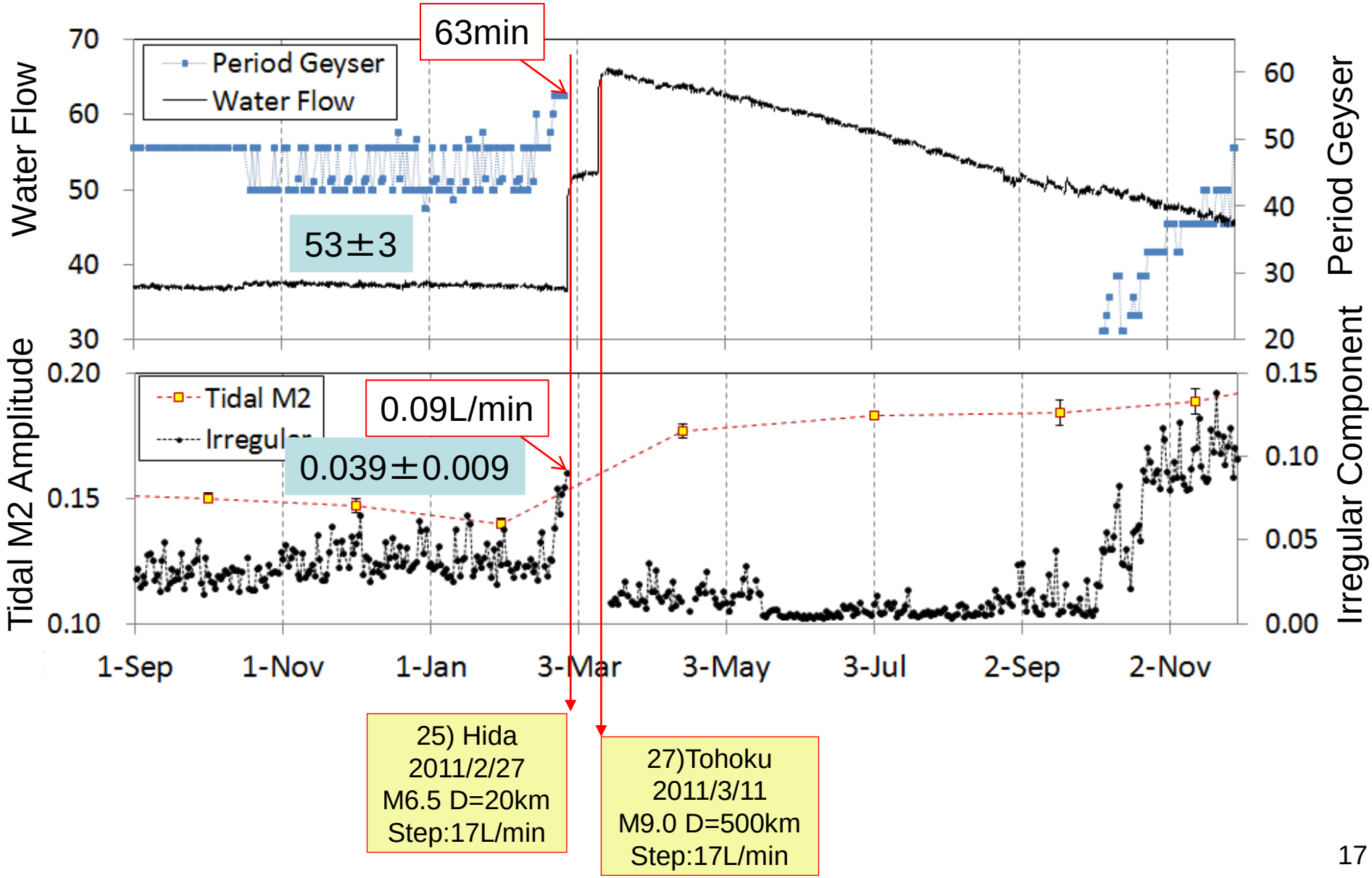
Pre-seismic changes of Amplitude and period of Geyser ?



Pre-seismic and Post-seismic Changes with Noto, Suruga and Hida EQ



Pre-seismic and Post-seismic Changes with Hida and Tohoku EQ (Sep,2010-Nov,2011)



Summary

1) Gases dissolved in Wari-ishi hot spring

- No changes for Radon with Tohoku EQ
- No change for Helium isotope ratio 3He/4He over time on Jun, Jul, Sep, 2011
- No changes for CO2,O2 and H2S with Tohoku EQ
- Change for CO2,O2 and H2S after Hida EQ on 2012/2/27

2) Water flow in Wari-ishi hot spring

- Co-seismic changes with Hida and Tohoku EQ.
- Tidal Strain sensitivity changes before and after EQ.
- Water sensitivity for the strain has changed with the foreshock, main shock and aftershocks.
- Pre-seismic changes for (1) and (2) last 3 earthquakes
  - (1)Amplitude and period of Geyser
  - (2)Irregular component of water flow