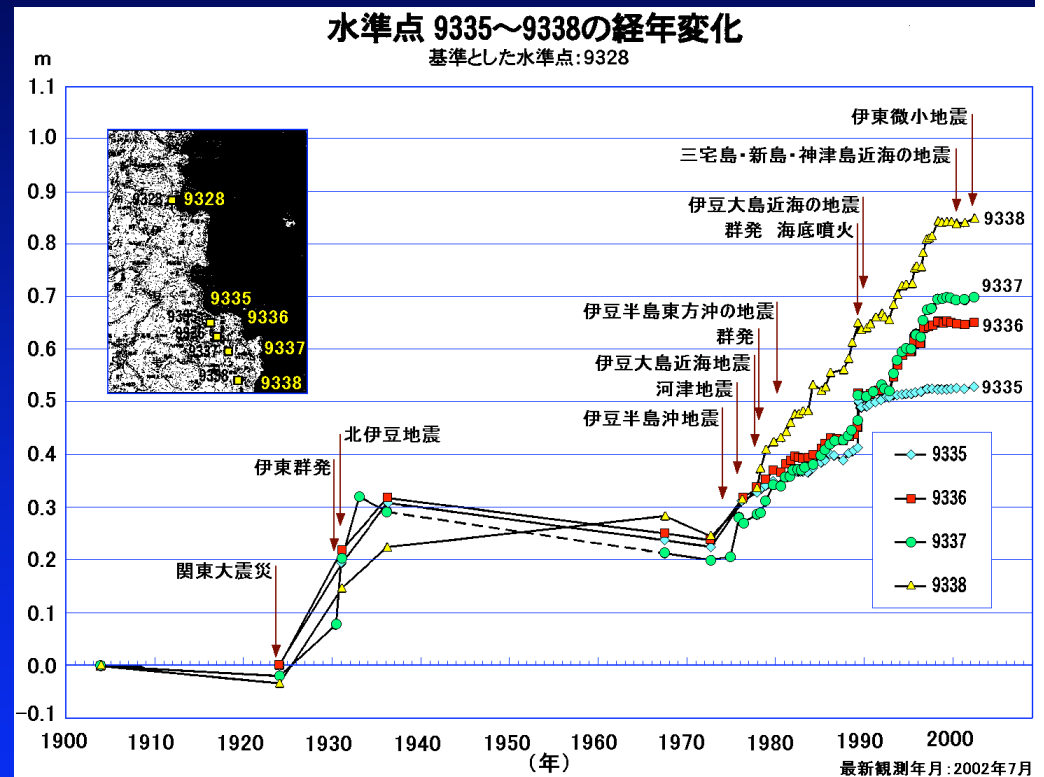
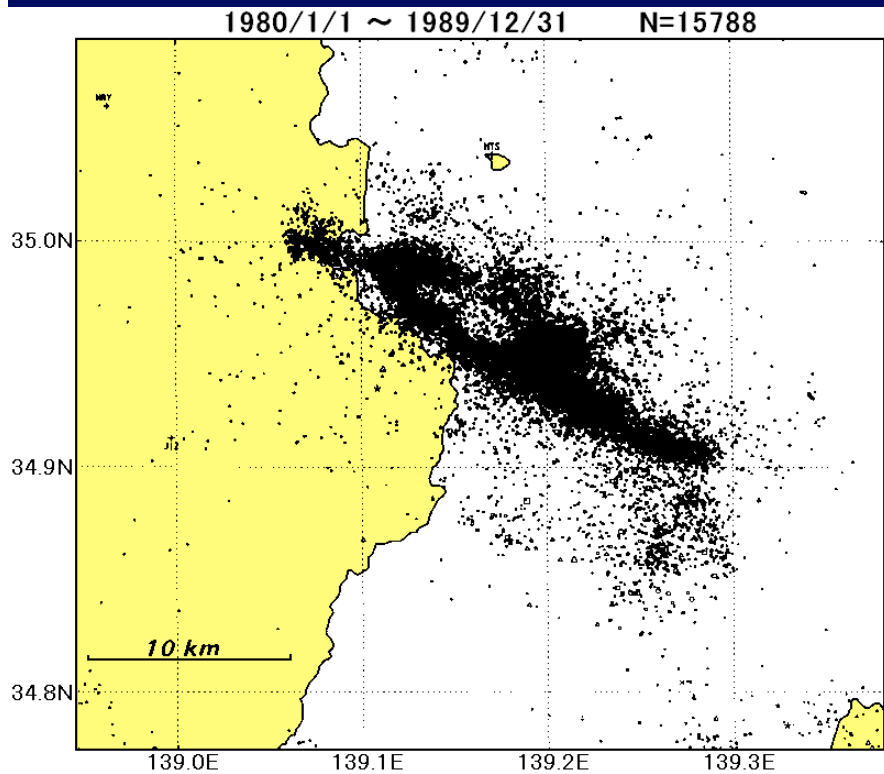


# Recurrence of earthquake swarms off eastern Izu Peninsula, central Japan

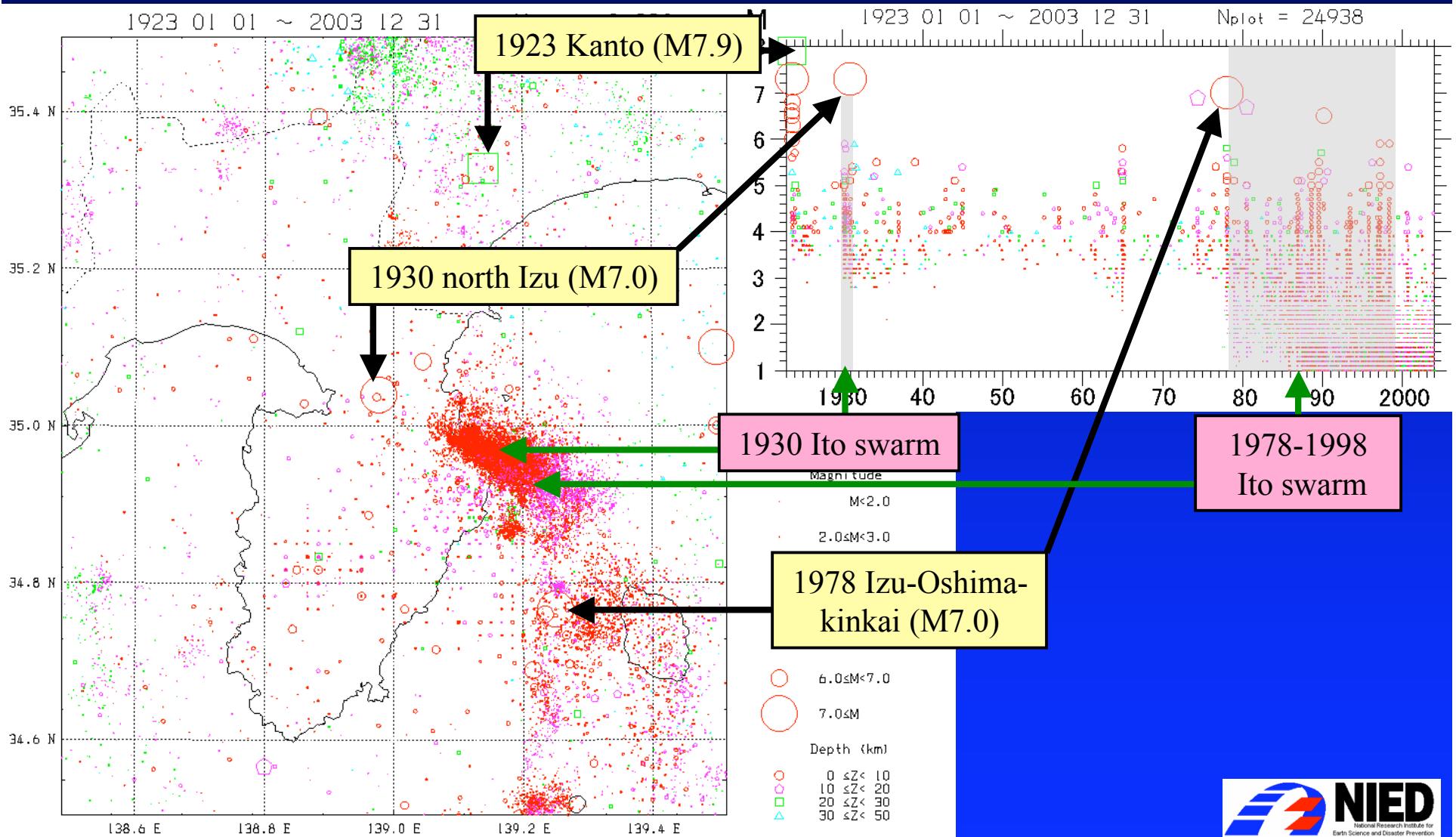


Yoshimitsu Okada

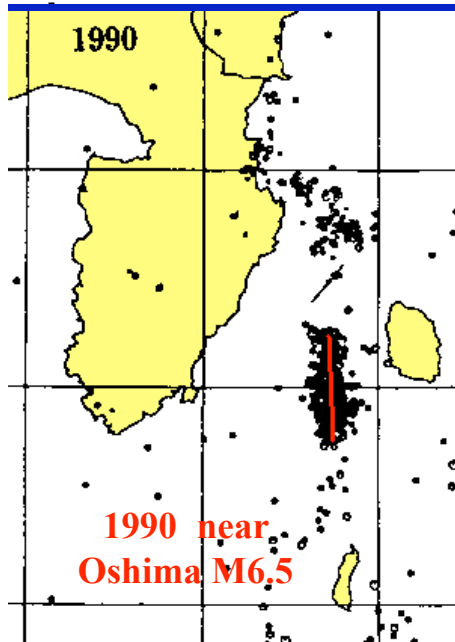
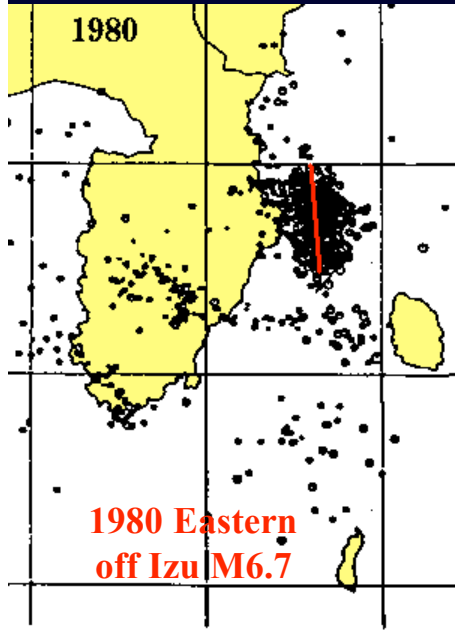
(National Research Institute for Earth Science and Disaster Prevention, Japan)

# Long term seismic activity around Izu Peninsula

1923 ~ 2003 (JMA)

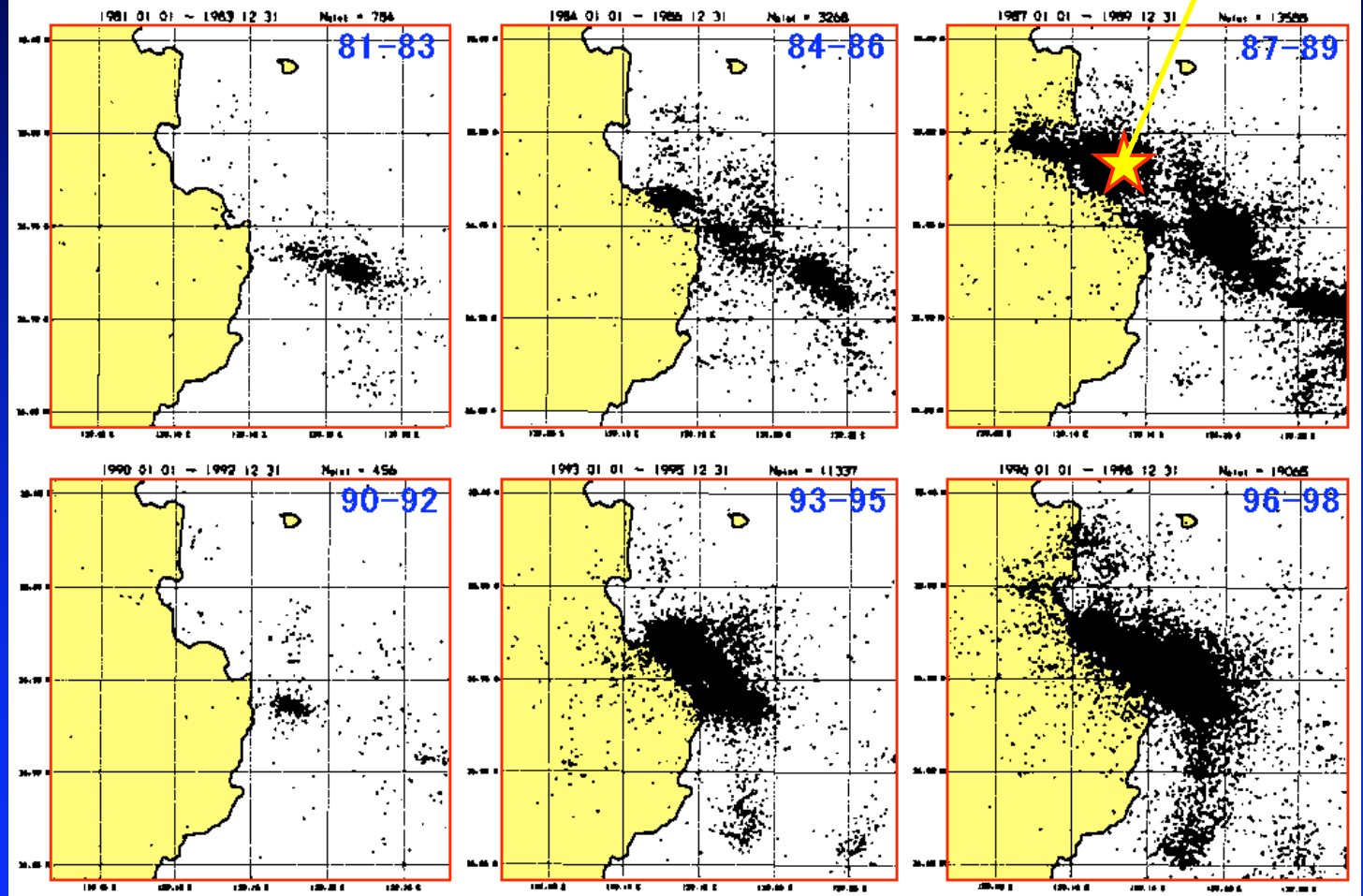


# Seismic activity in 1980-1998



## Swarms at eastern off Izu Peninsula

*submarine eruption*



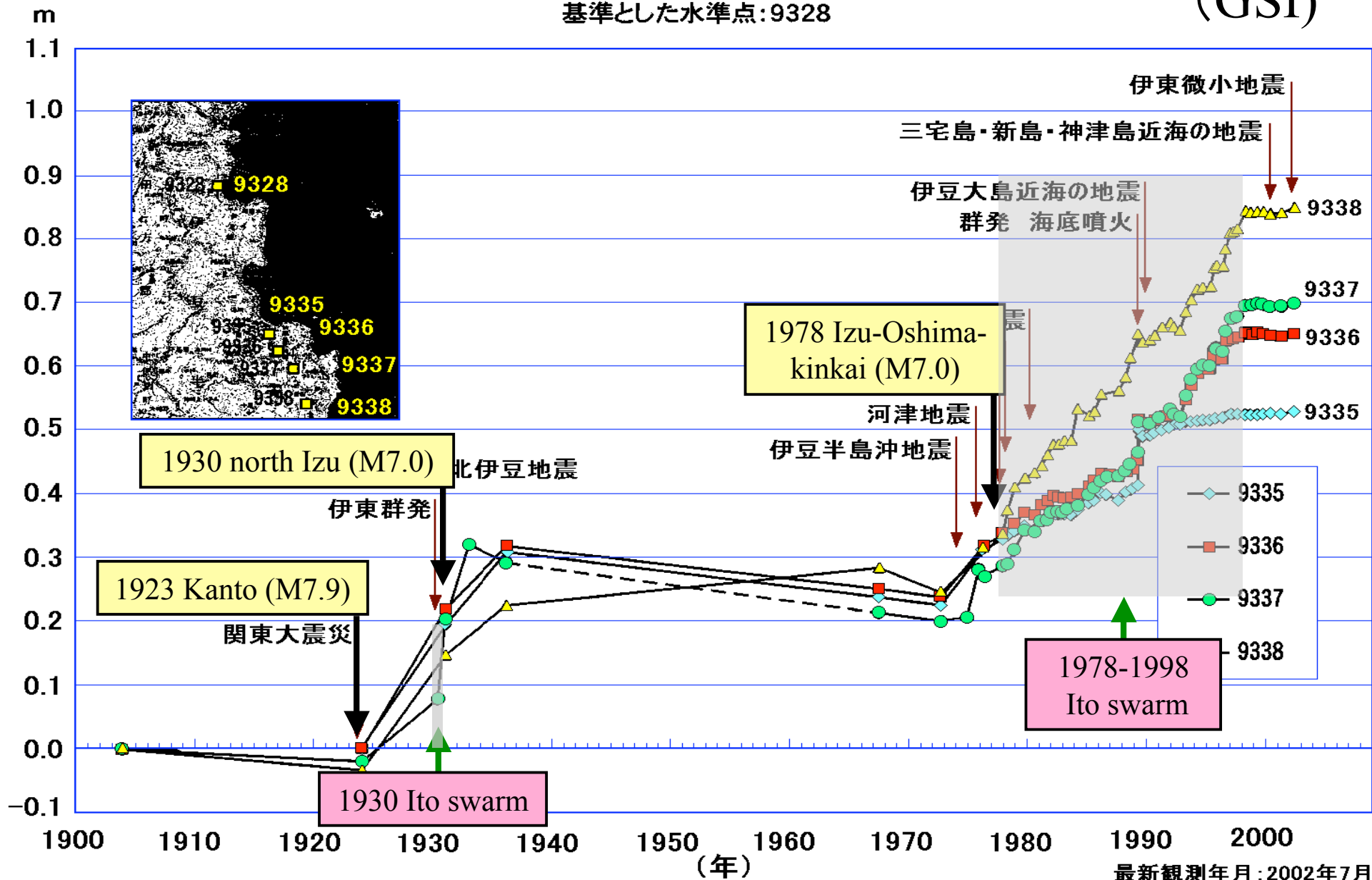
(Okada and Ishii, 2000)

# Long term crustal deformation around Ito (leveling)

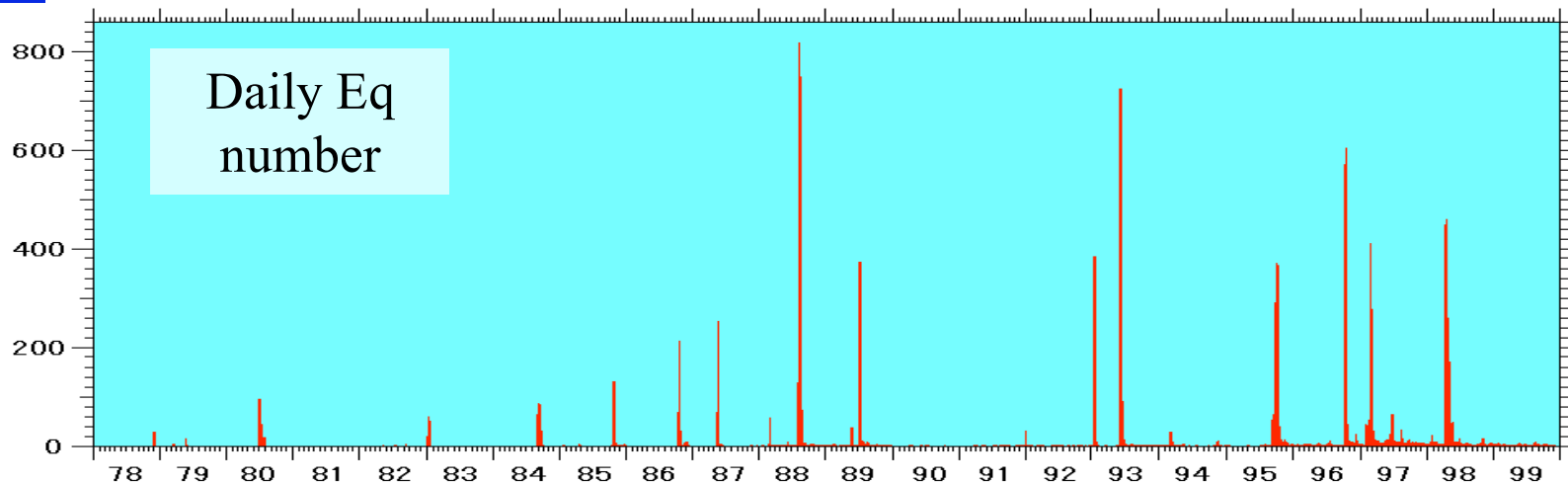
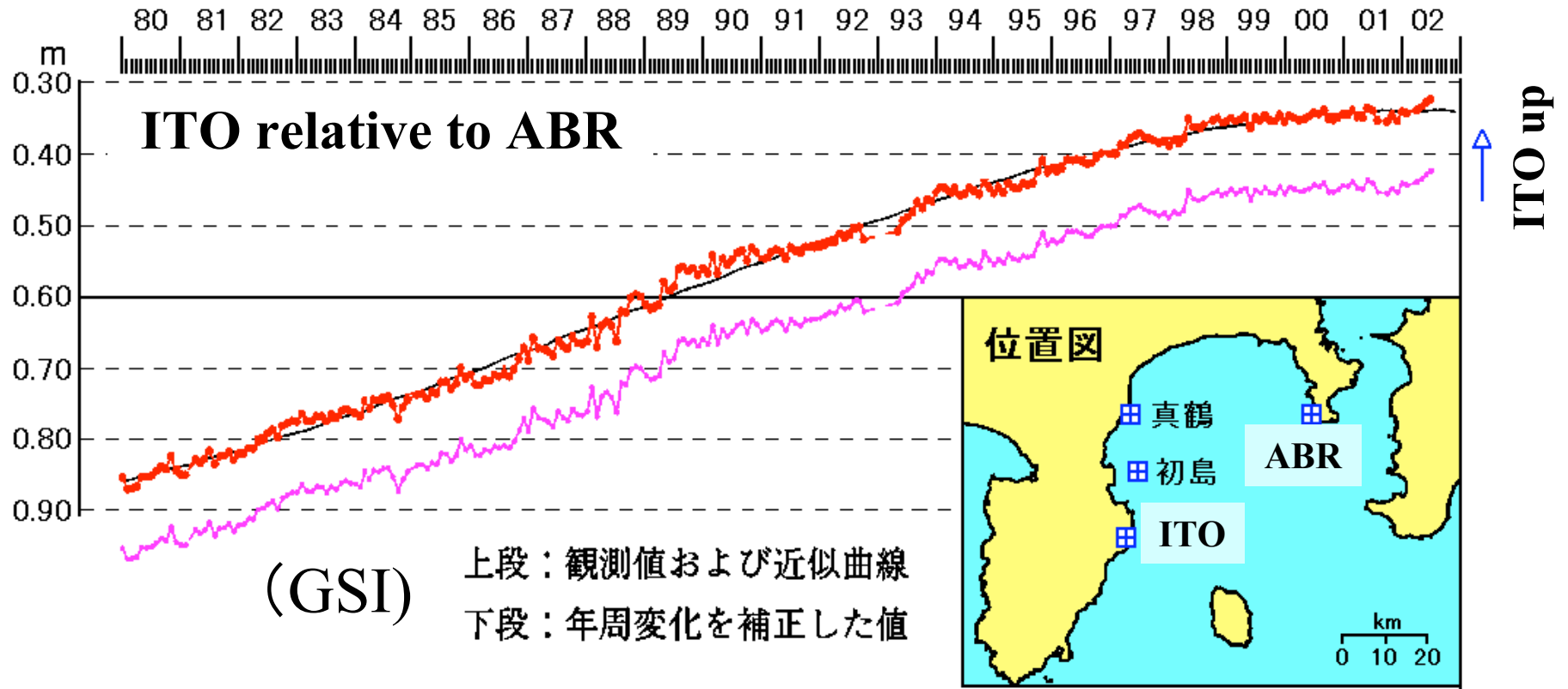
## 水準点 9335~9338の経年変化

基準とした水準点: 9328

(GSI)



# Crustal deformation in 1980-2002 (tidal observation)



# Crustal deformation associated to swarm

Observation item	Earthq. Number counted at $N \geq 5000$															Epoch	Station Name	Agency												
	11,443	1,905	14,081	392	1,308	676	2,183	5,976	2,745	4,212	981	6,125	2,635	579	204				17,171	1,173	24,989	315	6,005	9,334	446	11,033	Kamata			
	781	790	800	820	820	820	830	840	850	851	851	861	870	880	880	880	890	890	911	930	930	930	940	950	960	980				
Continuous	Strain (volume)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Ajiro(AJR)	JMA		
	Strain (3comp.)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Ajiro2(AJR2)	JMA	
	Tilt (borehole)	● clear change																											Higashiizu(HIG)	JMA
		- no change																											Ito(ARA)	ERI
		? No report																											Ito(KWN)	NIED
																													Tokunaga(TNG)	NIED
																													Oka(OKA)	NIED
	Tilt (vaultPEN)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Osaki(OSK)	JMA	
	Tilt (vaultWTT)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Ito(ARA)	ERI	
	Radon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Nakaizu(JIZ)	NIED	
	Discharge rate	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	Ajiro (AJI)	ERI	
	Water temperature	●	-	●	●	?	?	-	●	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Nakaizu(RHB,SKE)	TKY	
	Water level	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Himenoyu(HMN)	GSJ	
	Semi-continuous	Continuous EDM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Himenoyu(HMN)	GSJ	
		Continuous GPS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Akazawa(ITO6)	GSJ	
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Akazawa(ITO6,ITO1)	GSJ		
Discrete	EDM survey	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	Usami-24(USM)	ERI		
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Akazawa(ITO6,ITO1)	GSJ		
		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Hirono(HRN)	TKY		
	Leveling	●	○	○	○	○	-	-	-	●	●	-	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	Edoya(EDY)	TKY	
		○	○	○	○	○	-	-	-	●	●	-	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	Matsubara174(MBR)	GSJ	

Submarine eruption

continuous crustal deformation

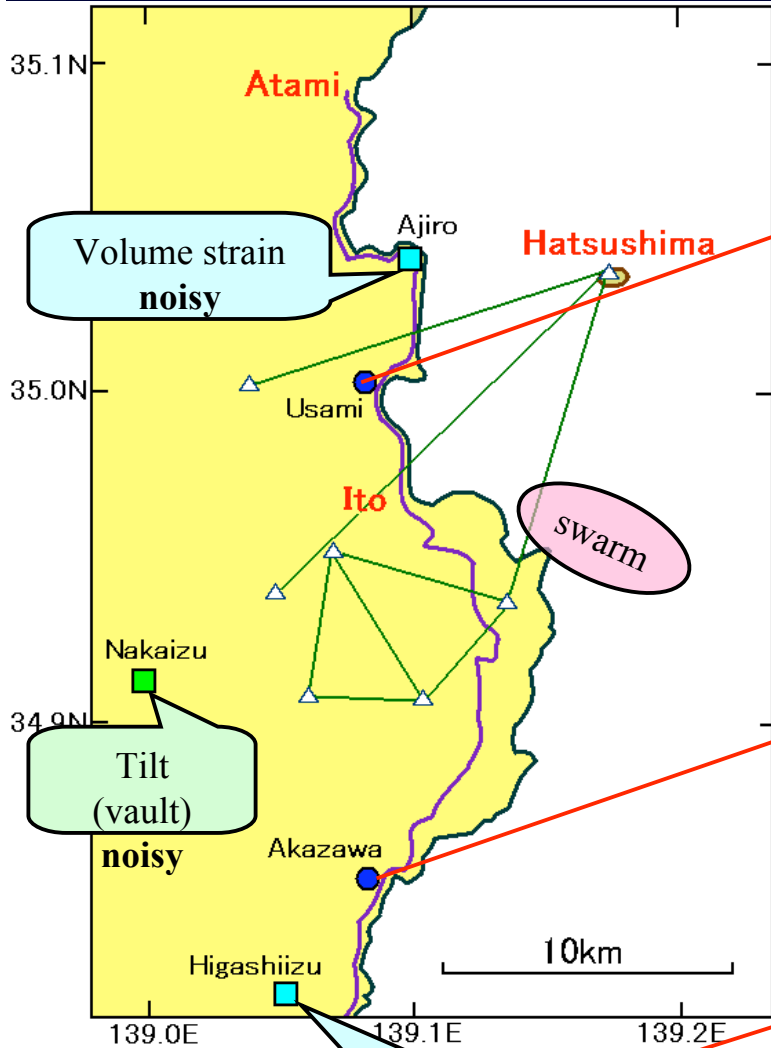
groundwater

continuous or step-wise?

no time-resolution

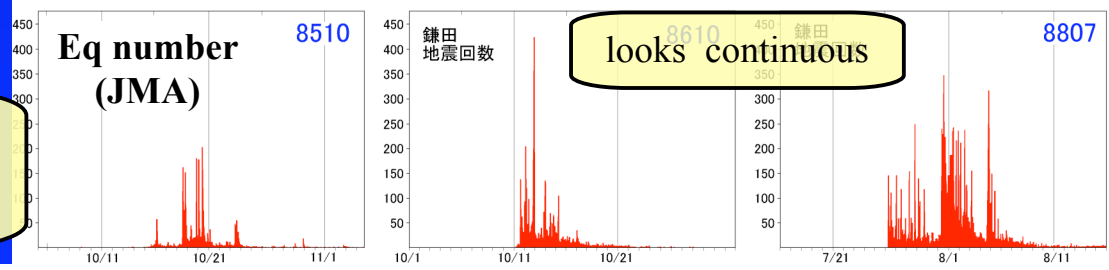
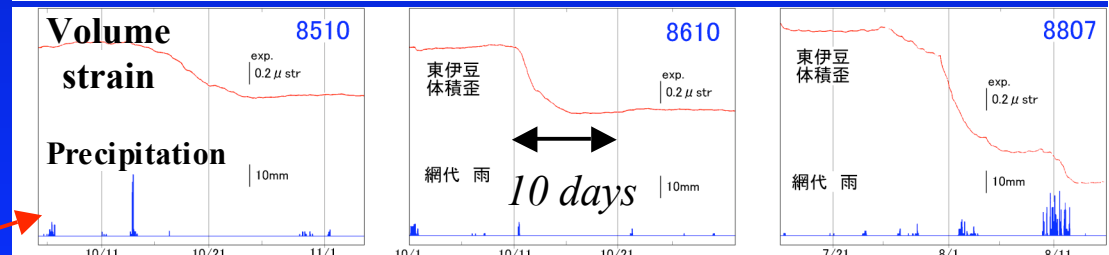
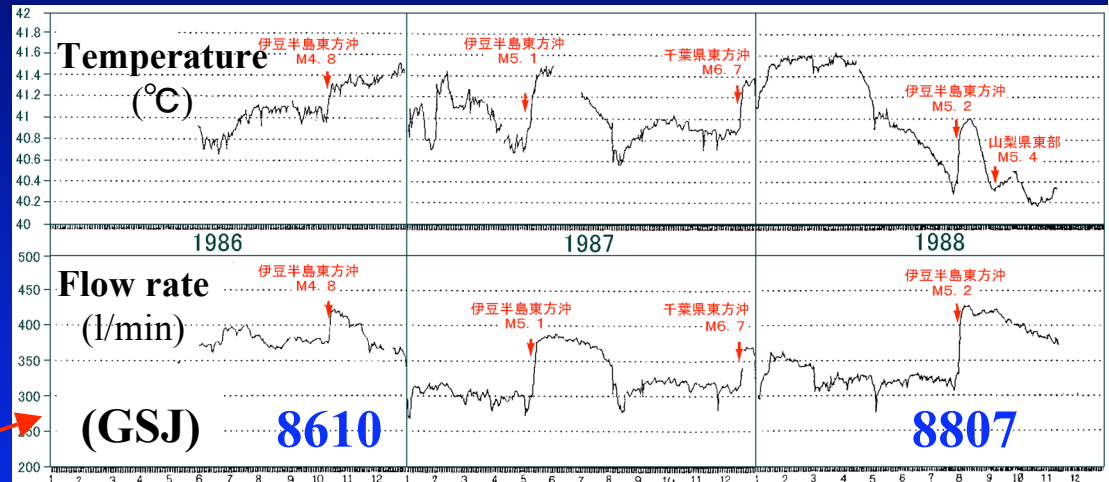
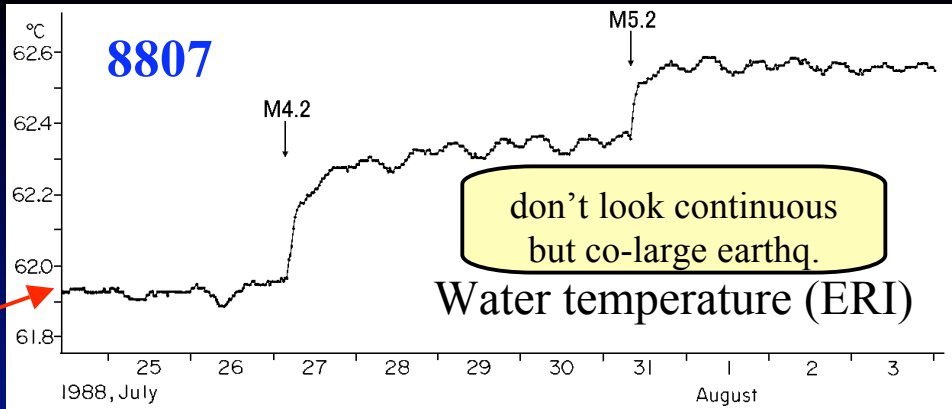
● clear change  
 - no change  
 ? No report

# Before 1989

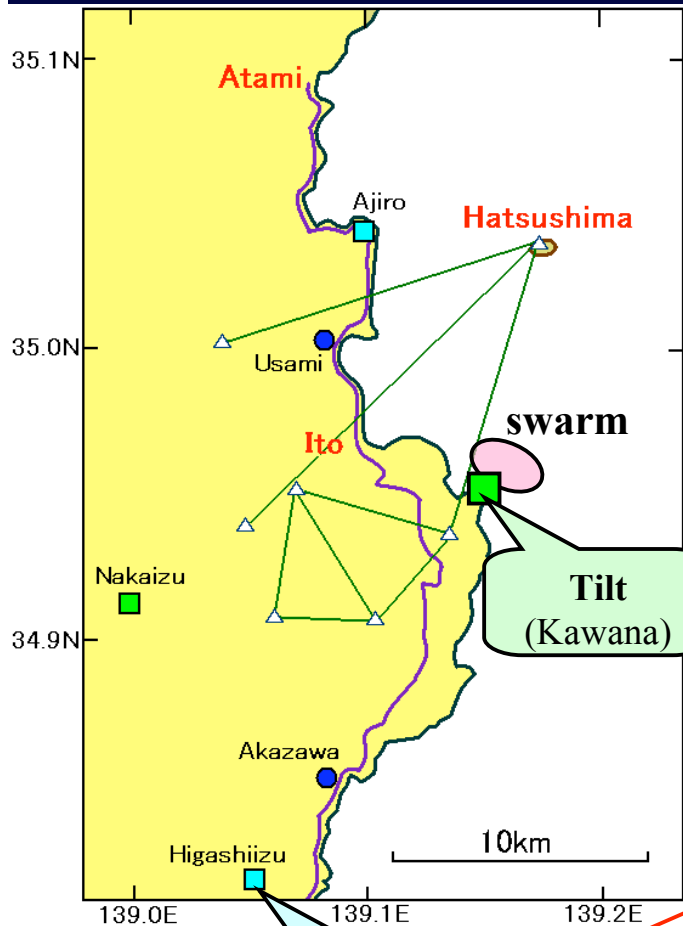


Volume strain

- (?) only 1-station, 1-component
- (?) contaminates with rainfall effect
- (?) large signal compared to distance

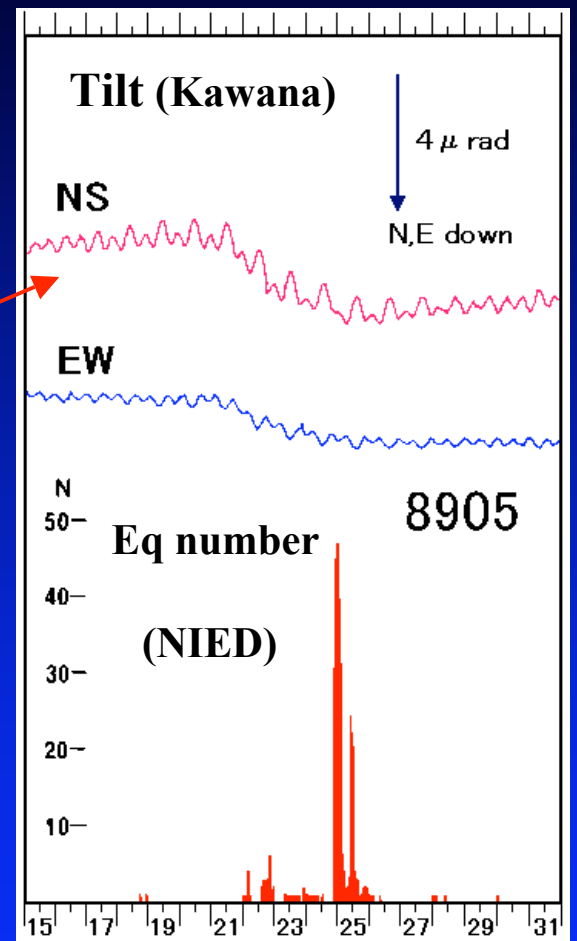
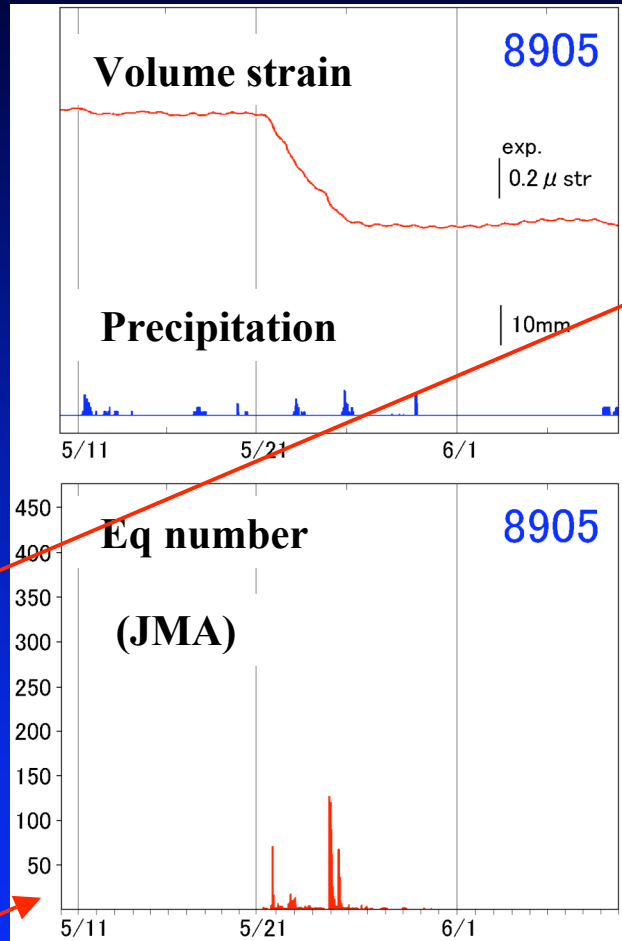


# A minor swarm in May 1989



**Volume strain**  
(Higashiizu)

**Tilt**  
(Kawana)



- 2-stations, multi-components  
- changed simultaneously  
⇒ **real co-swarm signal**



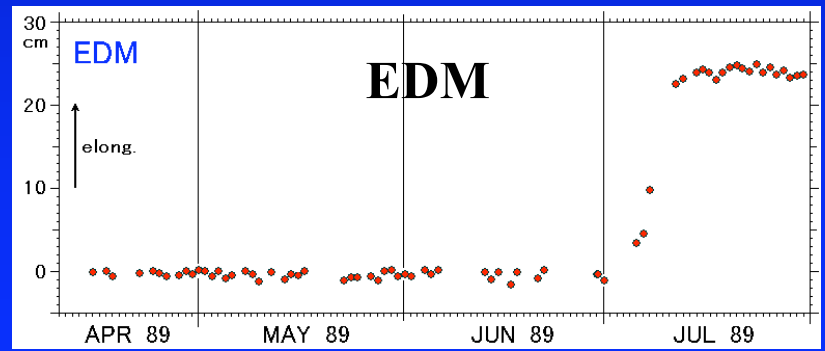
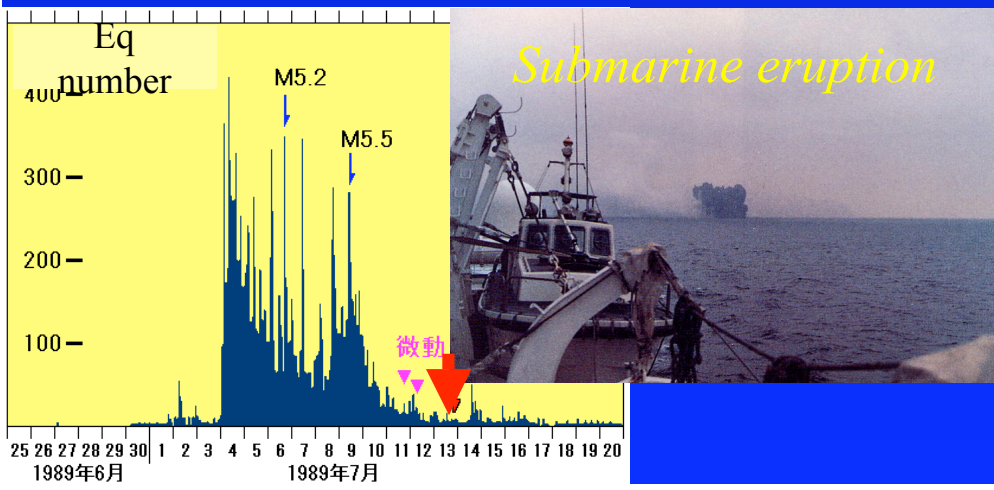
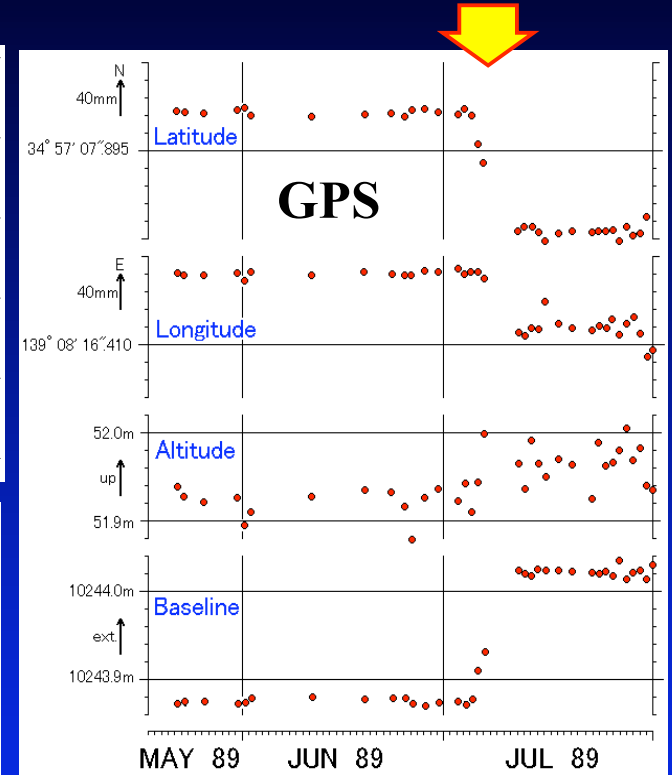
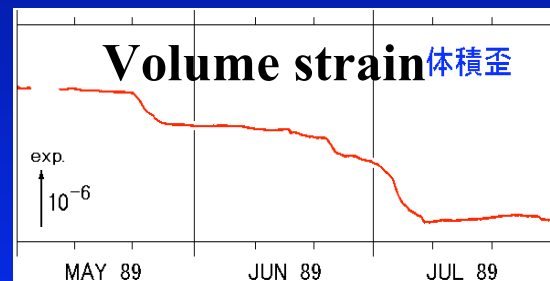
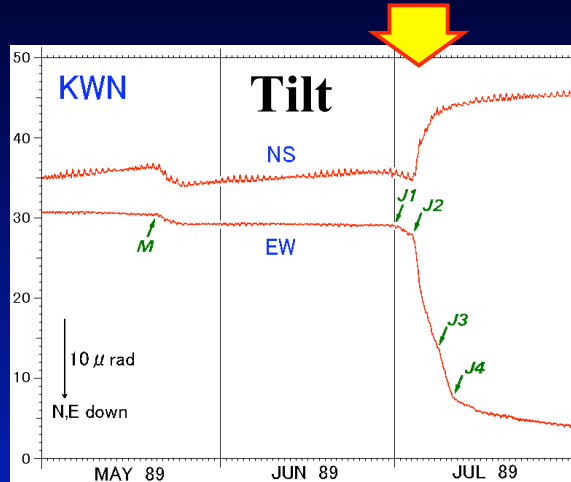
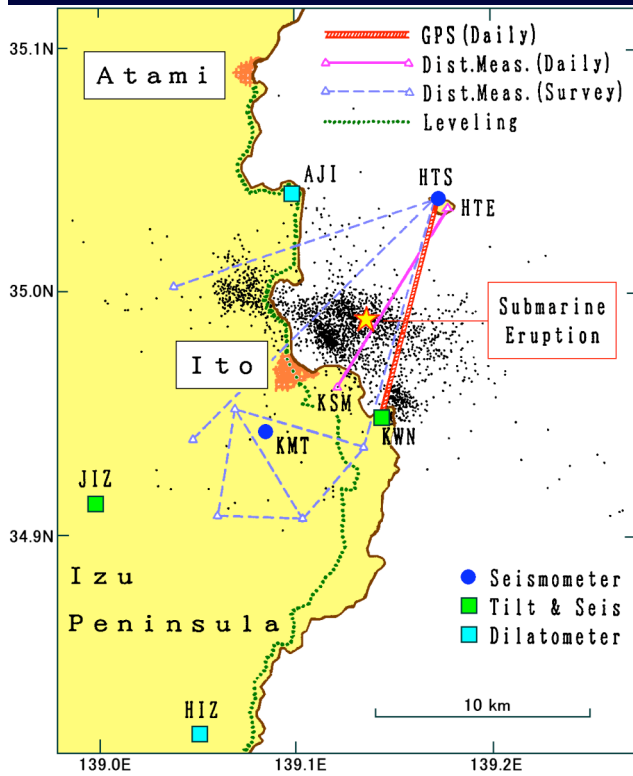
# Co-swarm crustal deformation

		Earthq. Number counted at Kamata Epoch															N ≥ 5000																		
Observation item		11,033	446	9,334	6,005	315	9,469	300	-	9,567	2,064	354	24,989	1,173	17,171	204	579	2,635	6,125	981	4,212	2,745	5,976	2,183	676	1,308	392	14,081	1,905	2,585	11,443	781			
		980	970	970	961	960	950	940	930	930	930	911	890	890	880	880	880	870	861	851	851	850	840	830	820	820	820	800	790	790	781				
Continuous	Strain (volume)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
	Strain (3comp.)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
	Tilt (borehole)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Tilt (vaultPEN)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Tilt (vaultWTT)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Radon	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Discharge rate	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Water temperature	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Water level	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Semi-continuous	Continuous EDM	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Continuous GPS		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Discrete	EDM survey	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Leveling	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

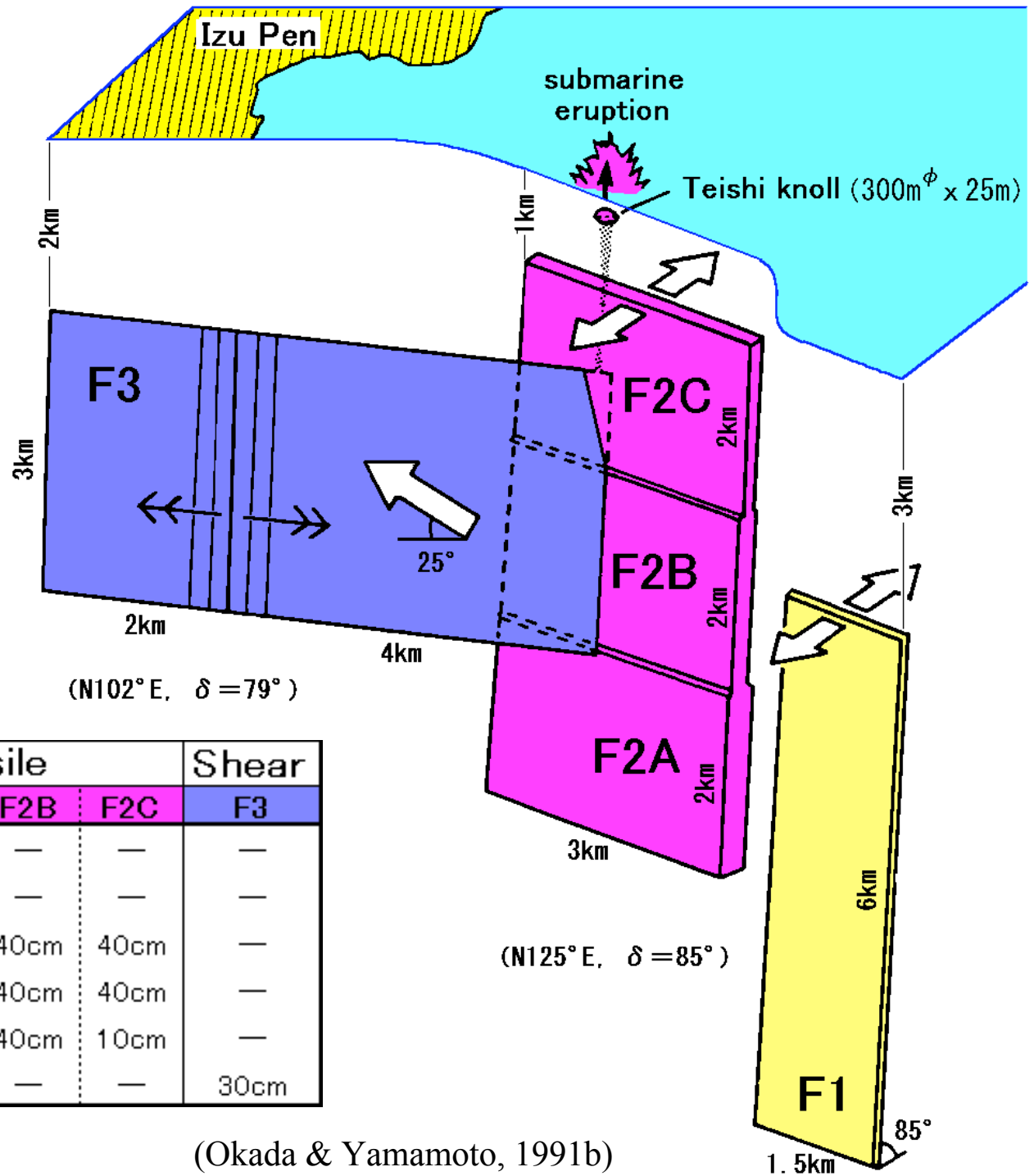
● clear change  
 - no change  
 ? No report



# A major swarm in July 1989



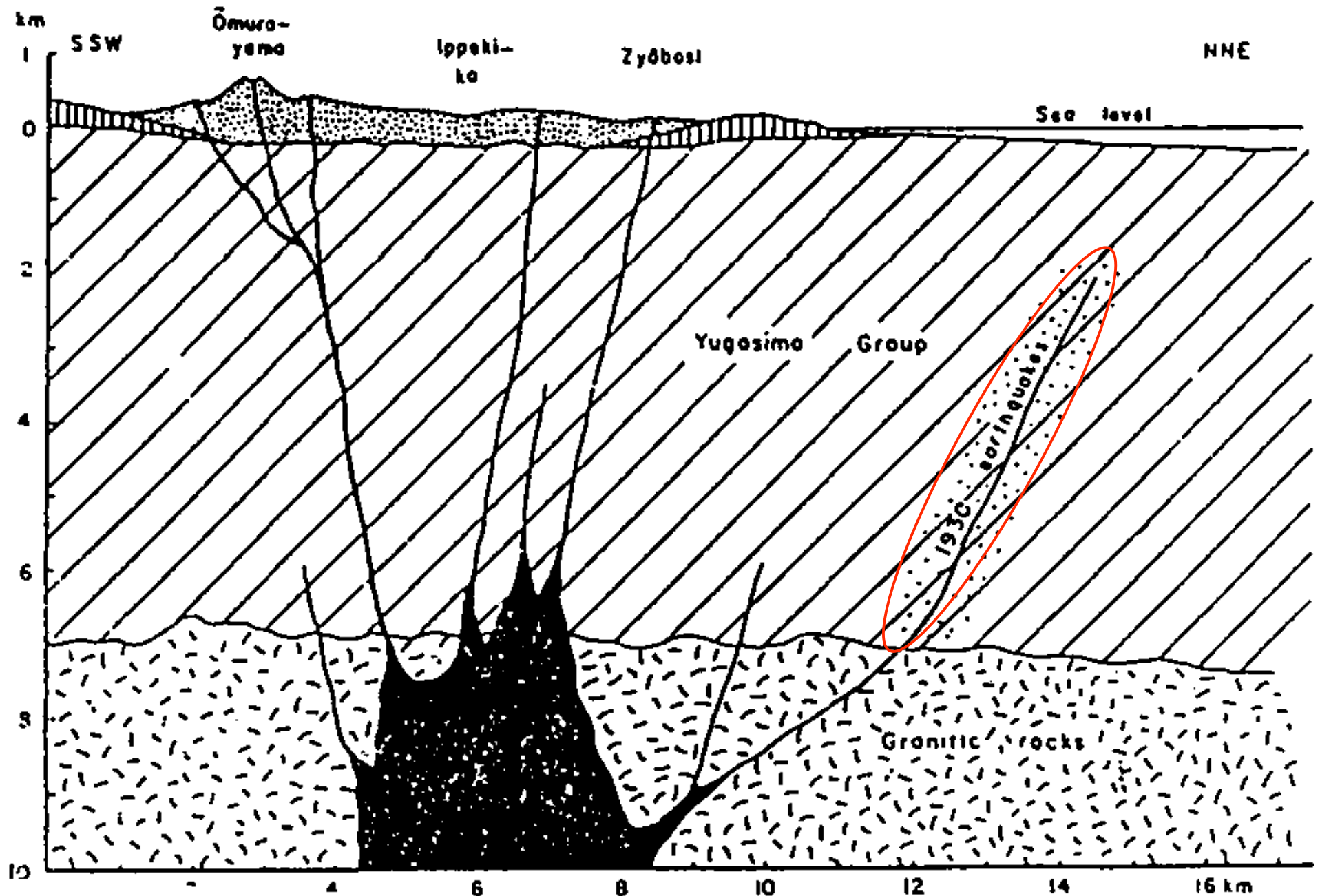
# Dyke intrusion model for 1989 seismo-volcanic activity



Period	Tensile				Shear
	F1	F2A	F2B	F2C	F3
1989年 5/21 - 25	25cm	—	—	—	—
7/1 - 7/4 08h	—	25cm	—	—	—
7/4 08h - 7/5 11h	—	40cm	40cm	40cm	—
7/5 11h - 7/8 20h	—	40cm	40cm	40cm	—
7/8 20h - 7/11 03h	—	40cm	40cm	10cm	—
7/9 11h09m	—	—	—	—	30cm

(Okada & Yamamoto, 1991b)

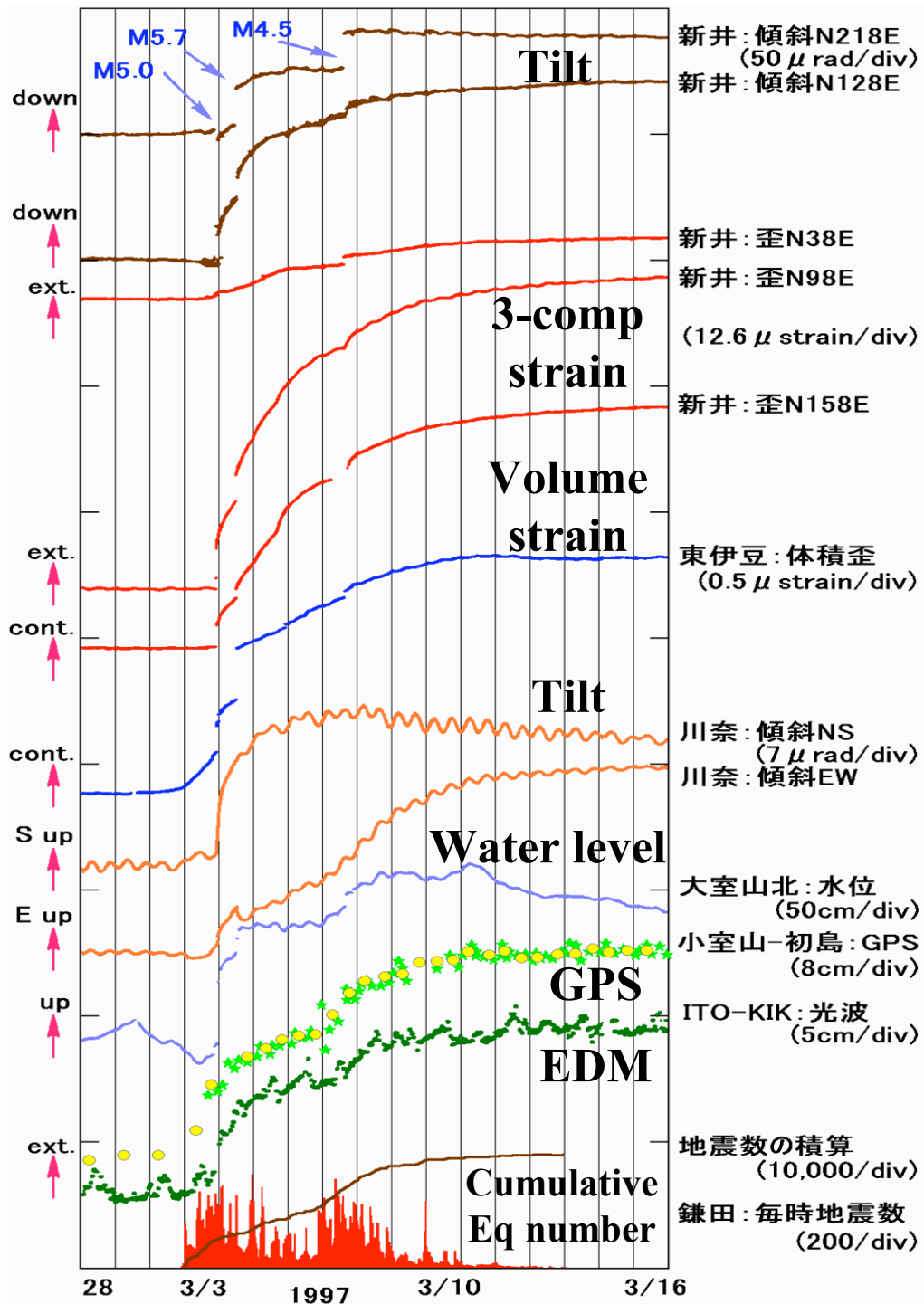
# Swarm in 1930 and its magma source (Kuno, 1954)



# Co-swarm crustal deformation

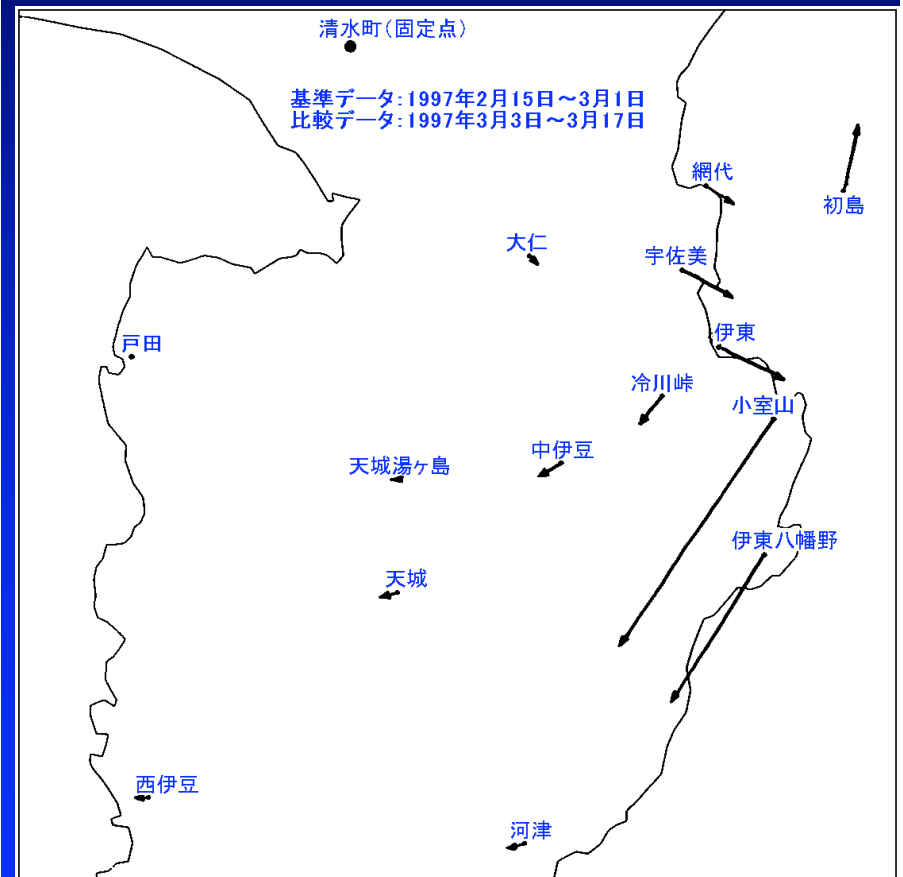
		Earthq. Number counted at Kamata Epoch															N ≥ 5000																					
Observation item		11,033	446	9,334	6,005	315	9,469	300	-	9,567	2,064	354	24,989	1,173	17,171	204	579	2,635	6,125	981	4,212	2,745	5,976	2,183	676	1,308	392	14,081	1,905	2,585	11,443	781						
		980	970	970	961	960	950	940	930	930	930	911	890	890	880	880	880	870	861	851	850	840	830	820	820	820	800	790	790	790	781							
Continuous	Strain (volume)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●						
	Strain (3comp.)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●					
	Tilt (borehole)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
	Tilt (vaultPEN)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				
	Tilt (vaultWTT)	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
	Radon	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
	Discharge rate	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
	Water temperature	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
	Water level	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		
	Semi-continuous	Continuous EDM	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Continuous GPS		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Discrete	EDM survey	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Leveling	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

● clear change  
 - no change  
 ? No report



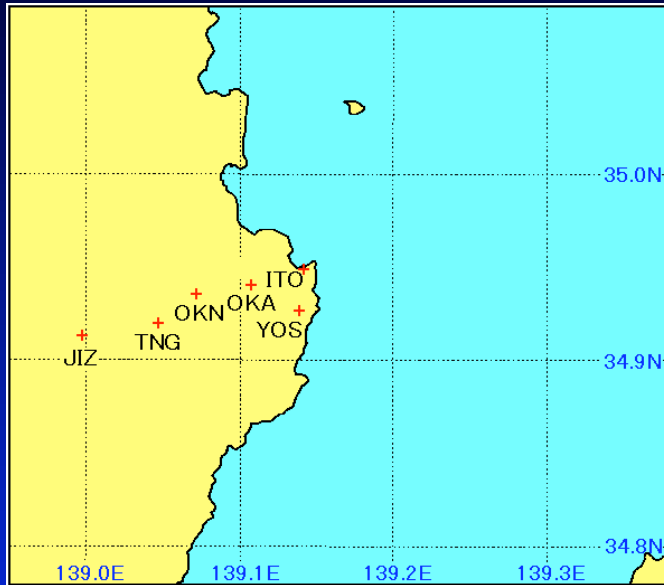
# A major swarm in March 1997

## GPS observation (GSI)

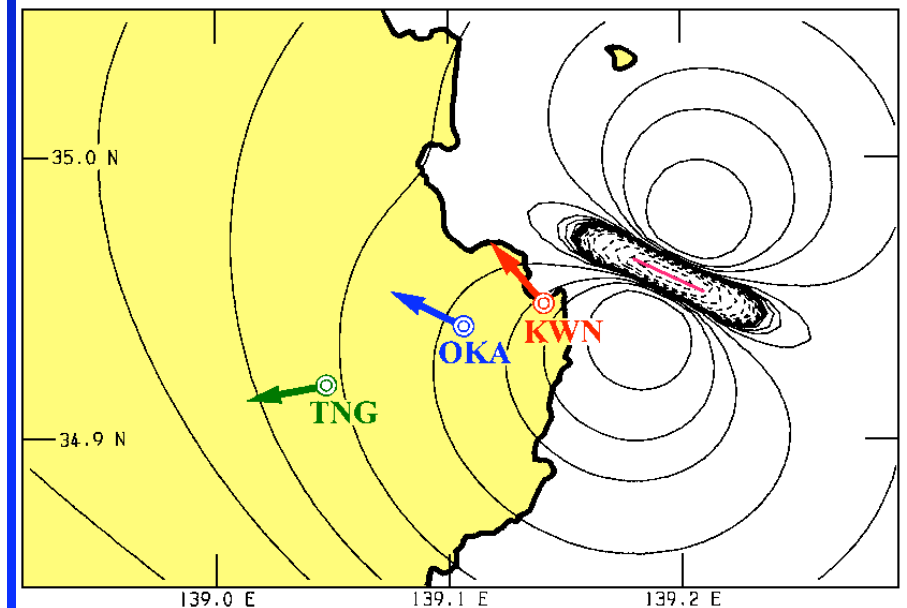
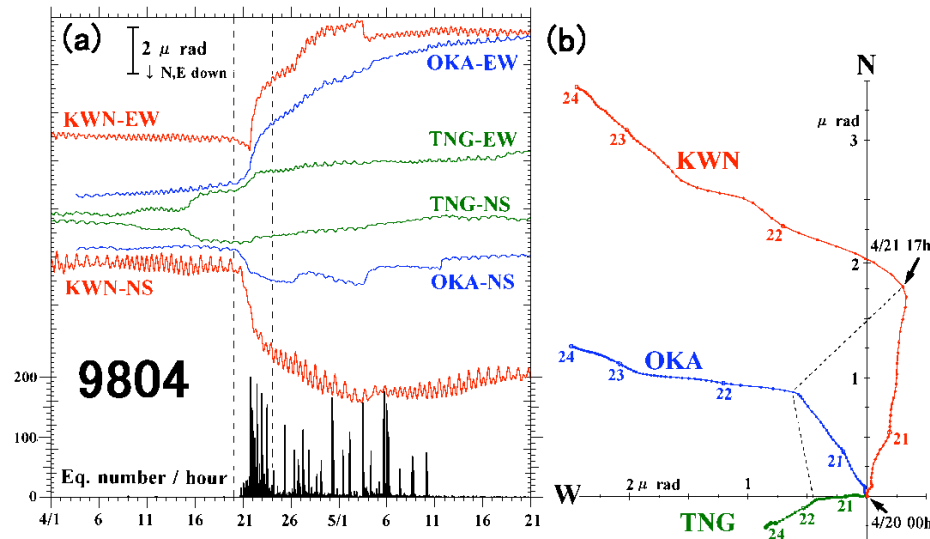
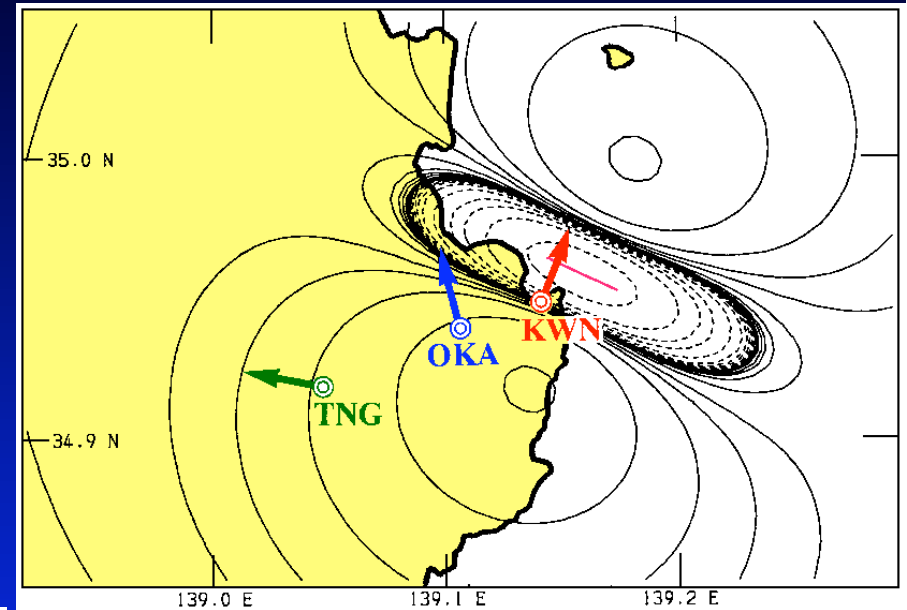


# Co-swarm tilt associated to a swarm in April 1998

*Tiltmeter array*

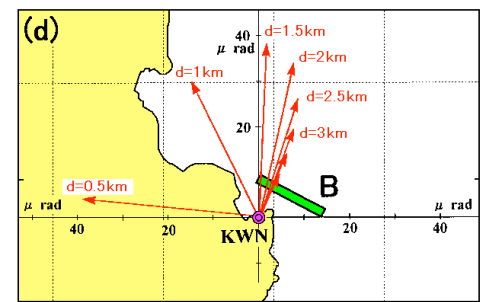
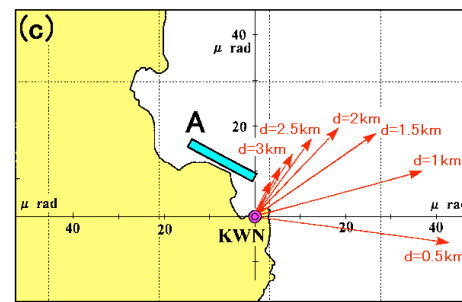
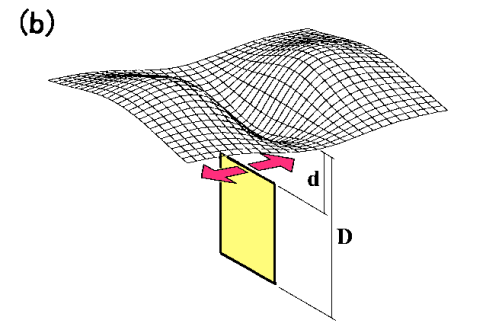
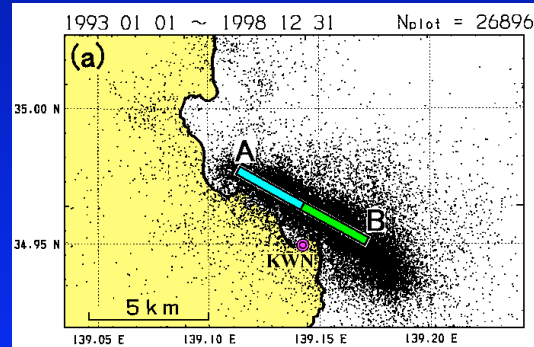
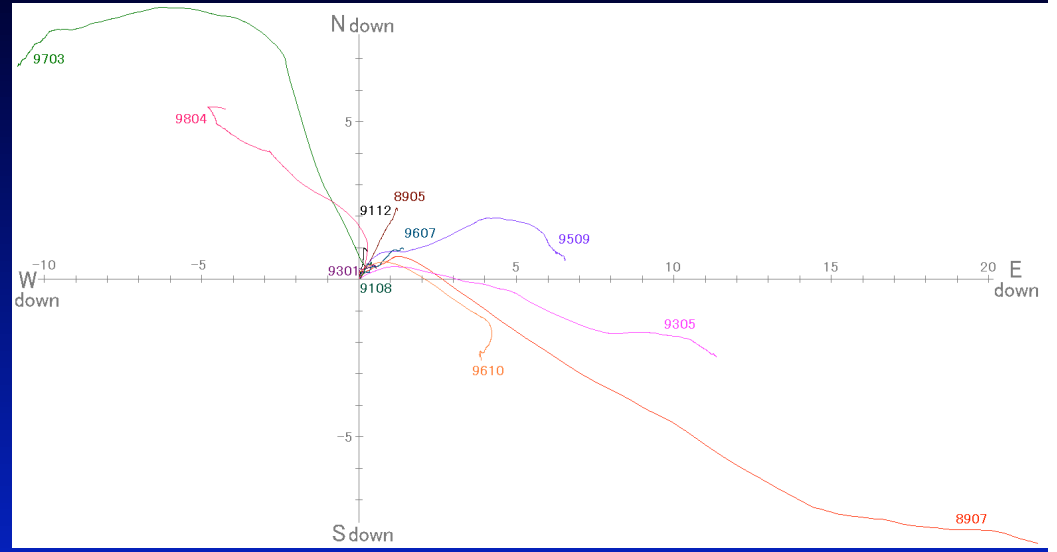
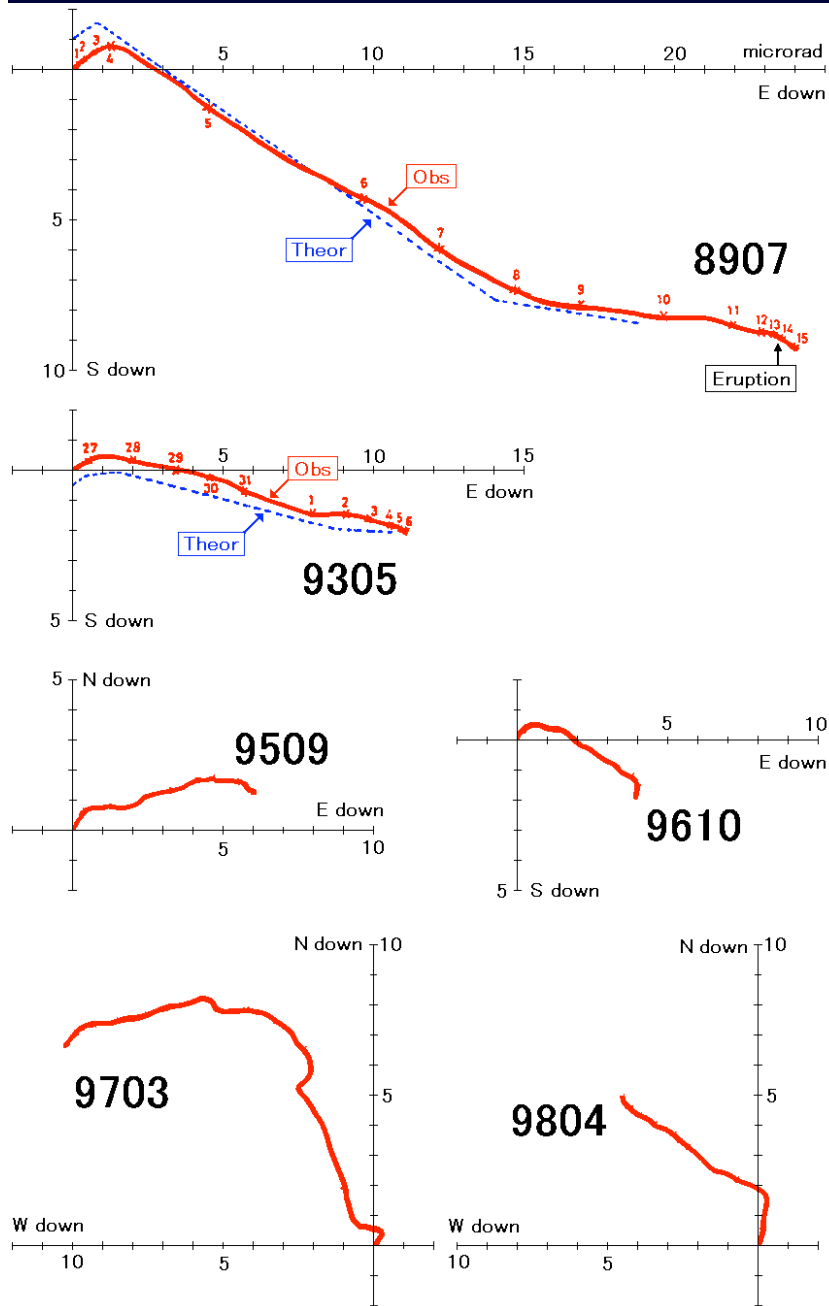


*Dyke intrusion model*



**Figure 6.** (a) Tiltmeter records at KWN, OKA, and TNG for the period April 1 to May 21, 1998, compared with the hourly numbers of the located earthquake. All coseismic steps are eliminated. (b) Tide-removed tilt-down vector diagrams at the three stations within 4 days, April 20–23, which corresponds to the period between the dashed lines in Figure 6a.

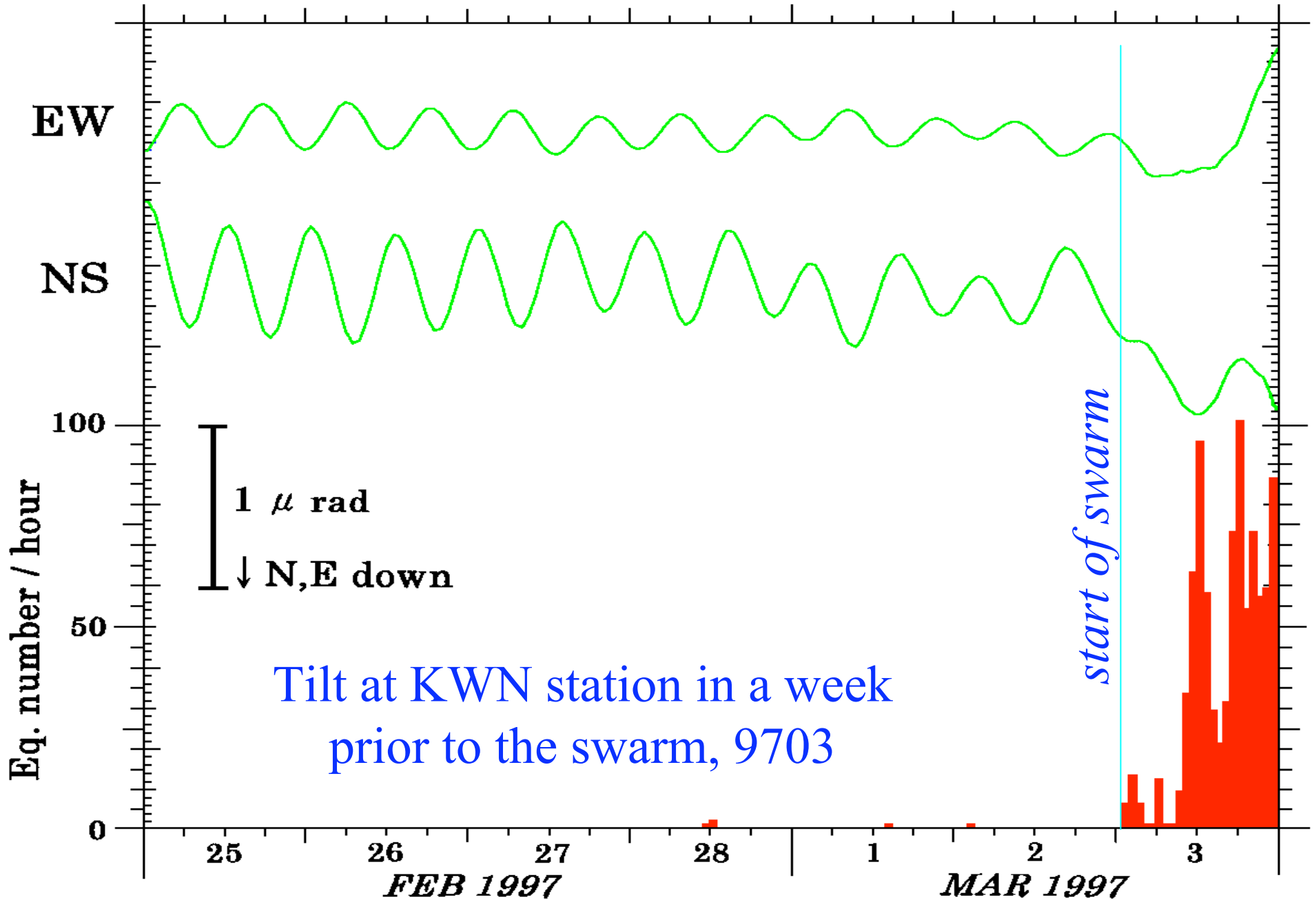
# Tilt down vector change at KWN station



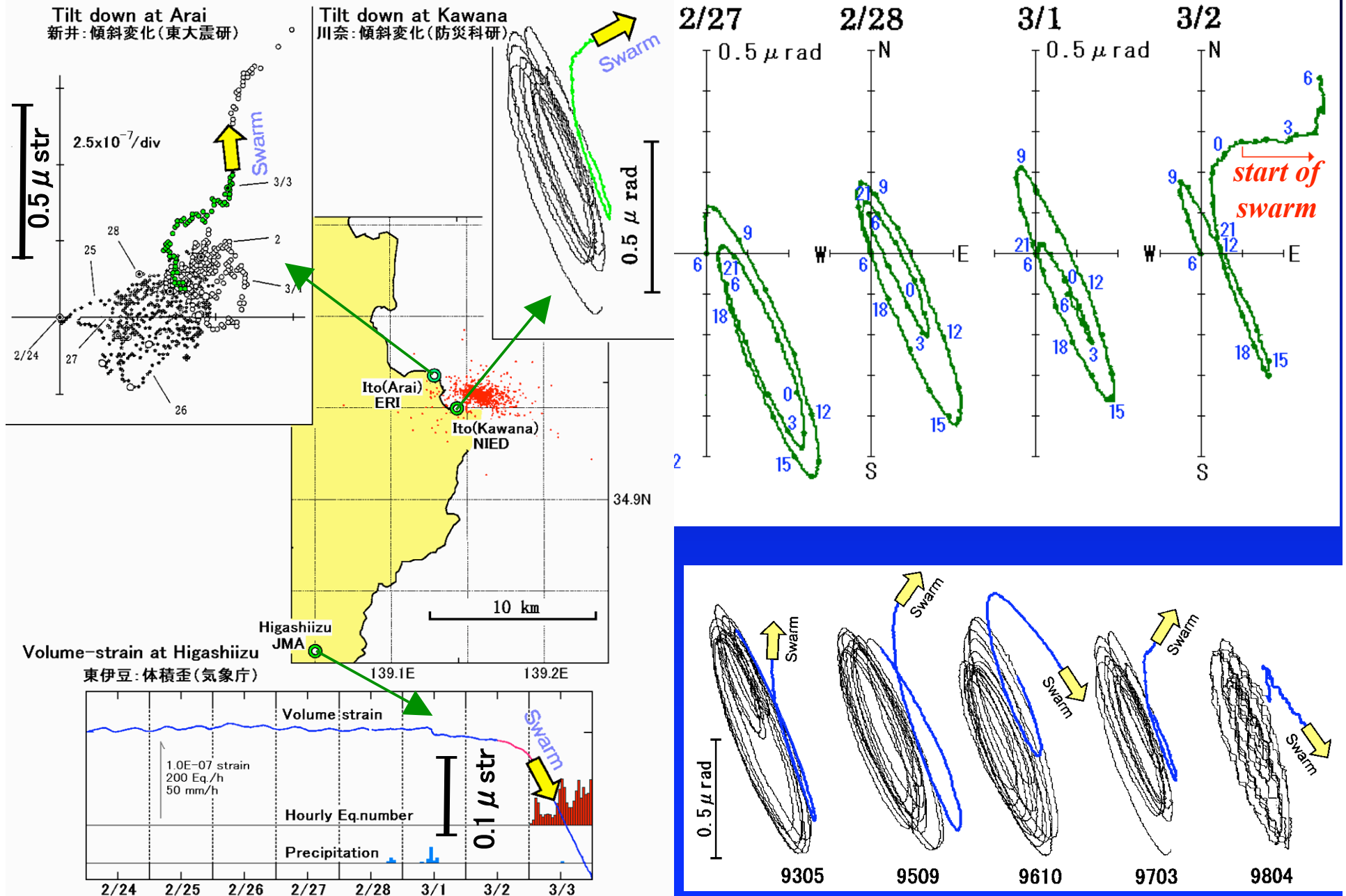
**Figure 5.** (a) Two vertical tensile fault models, A and B, along the swarm zone. (b) Schematic surface elevation change due to a buried tensile fault, whose top and bottom depths are  $d$  and  $D$ , respectively. (c) Expected tilt-down vectors at KWN for model A. (d) Expected tilt-down vectors at KWN for model B.



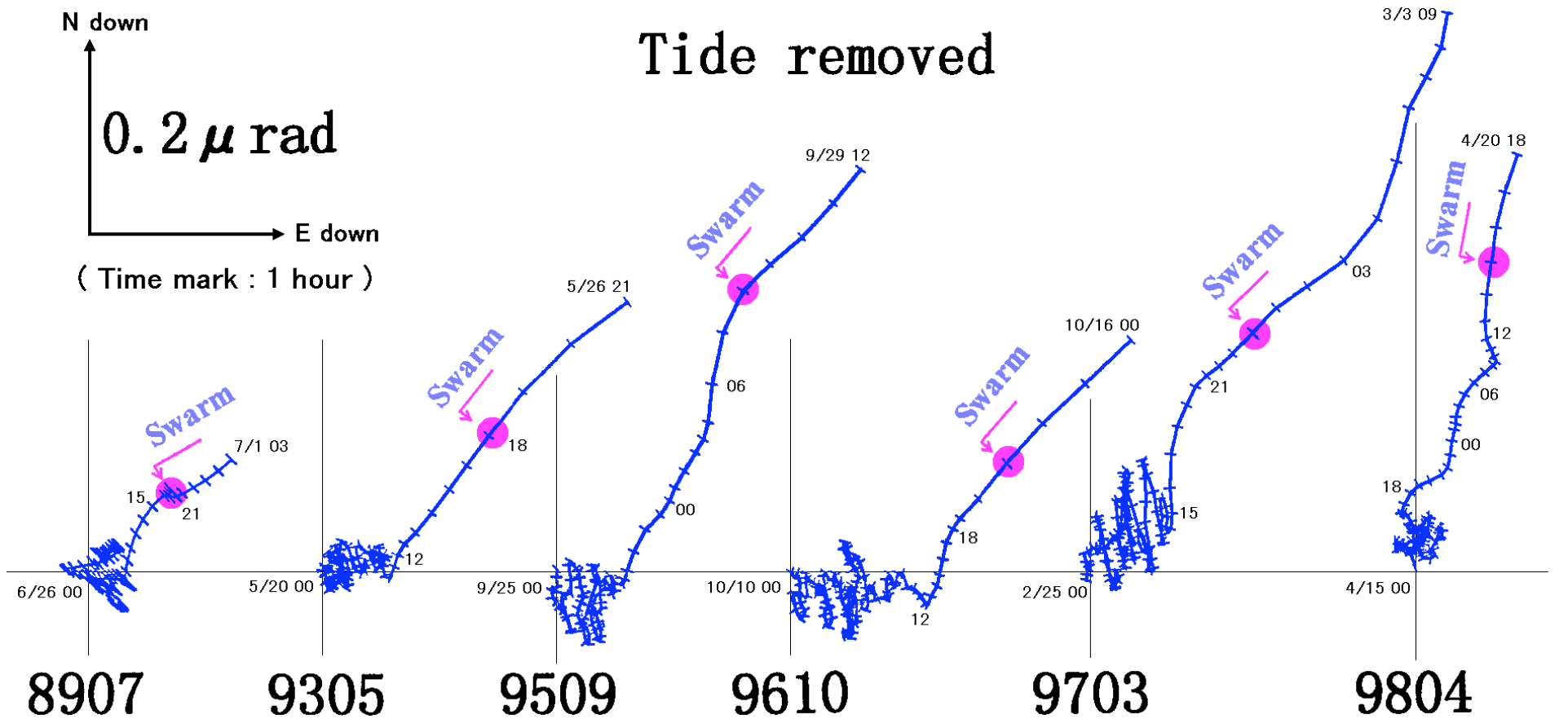
# Pre-swarm crustal deformation



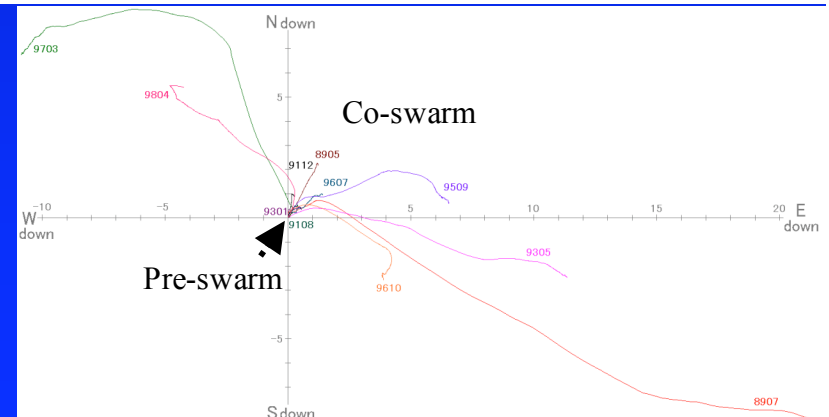
# Daily tilt vector change at KWN



# Pre-swarm tilt vector change (tide removed)



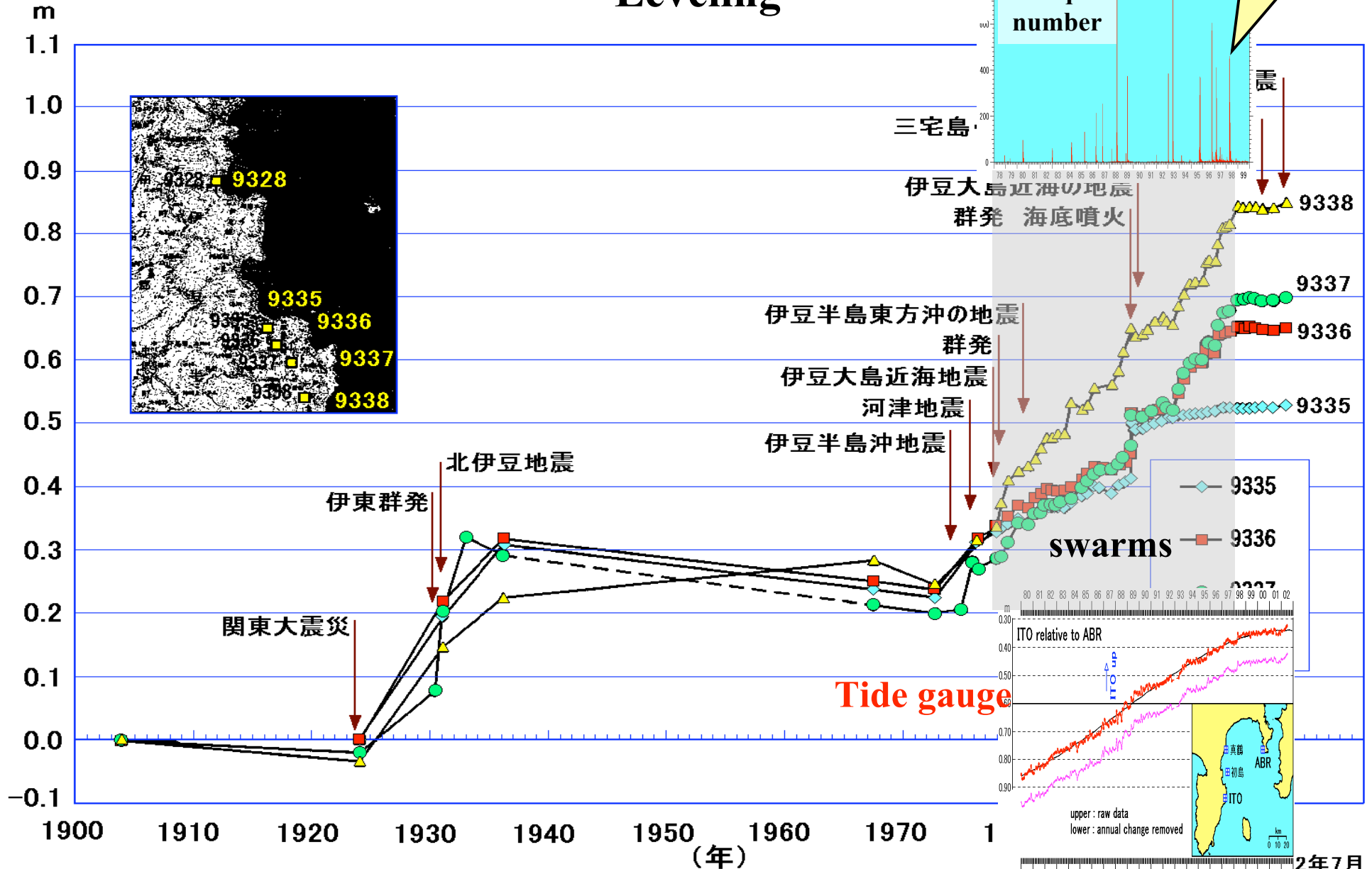
- 1) Clear only for major swarms
- 2) Precede several hour to half a day
- 3) Signal level is order of  $0.1 \mu\text{rad}$
- 4) Always NE down and smoothly connect to co-swarm change  $\Rightarrow$  **deep intrusion**



# Did crustal deformation stop? (leveling)

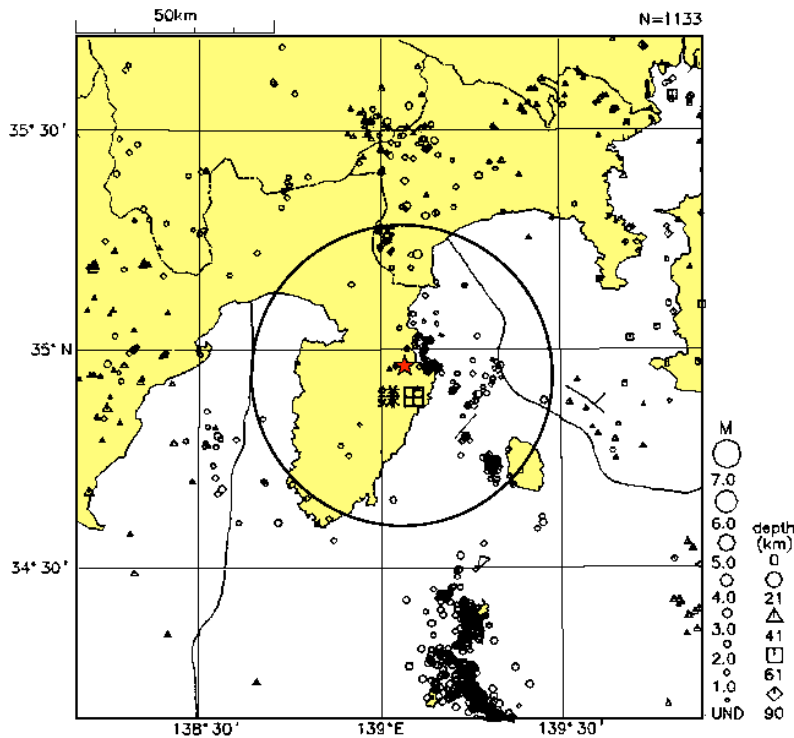
Last swarm on Apr 1998

## Leveling



# Recurrence of earthquake swarm

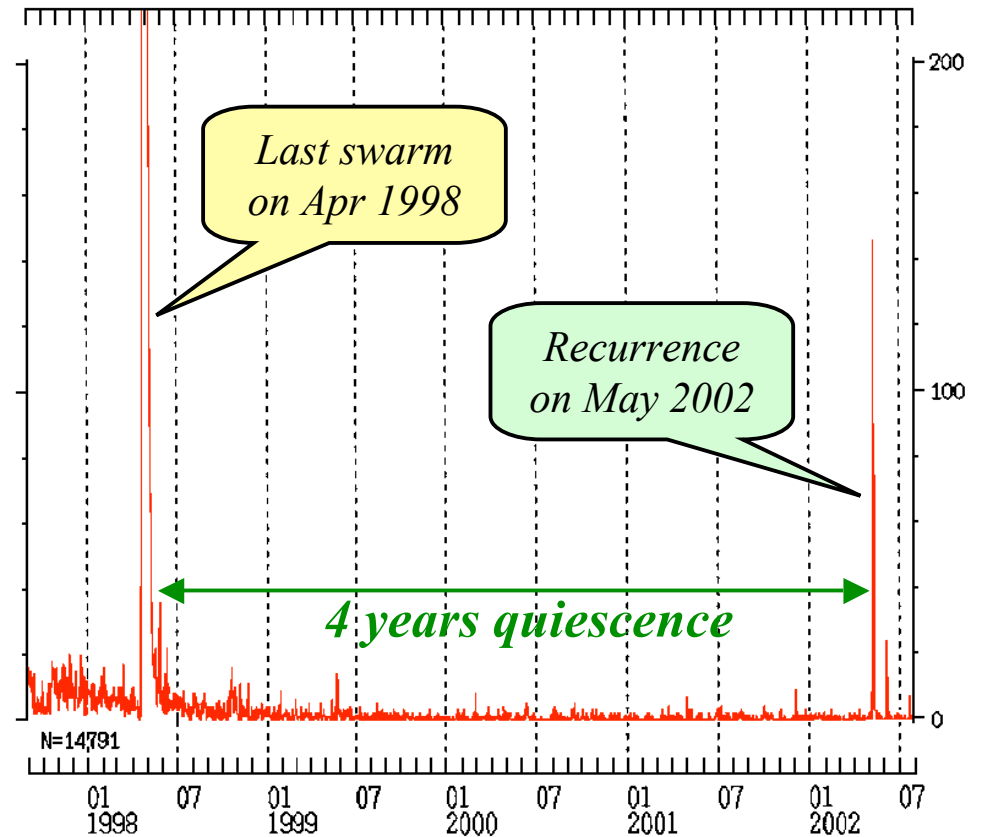
## Epicentral distribution during 5/1 – 7/31, 2002



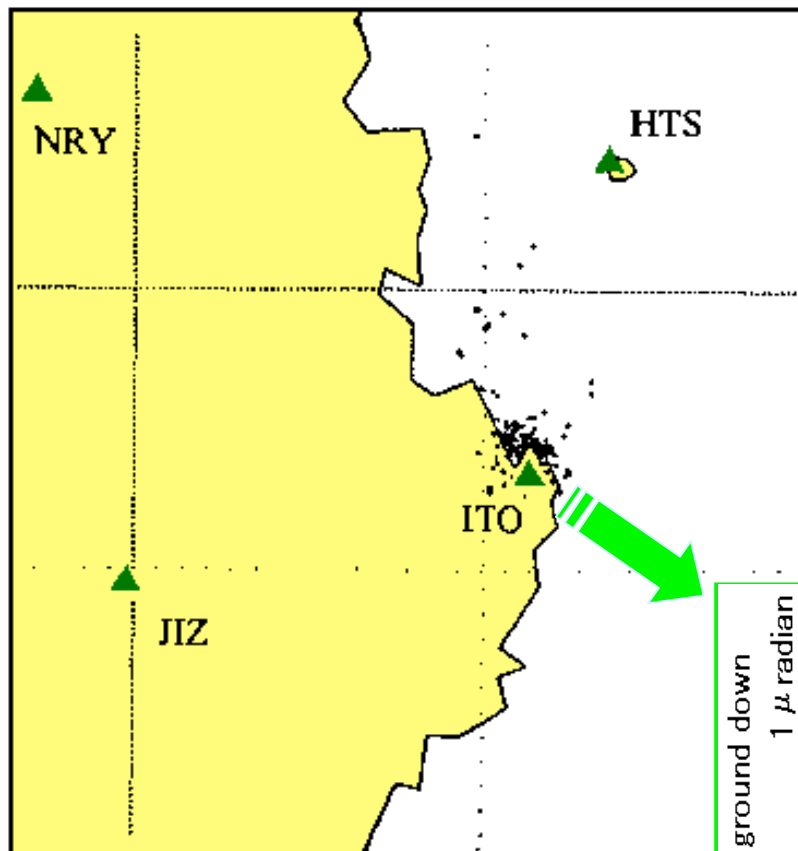
0 ≤ 深さ ≤ 90 km  
図の円内は鎌田における S-P ≤ 6sec の範囲を示す。

## Daily Eq number at KMT station

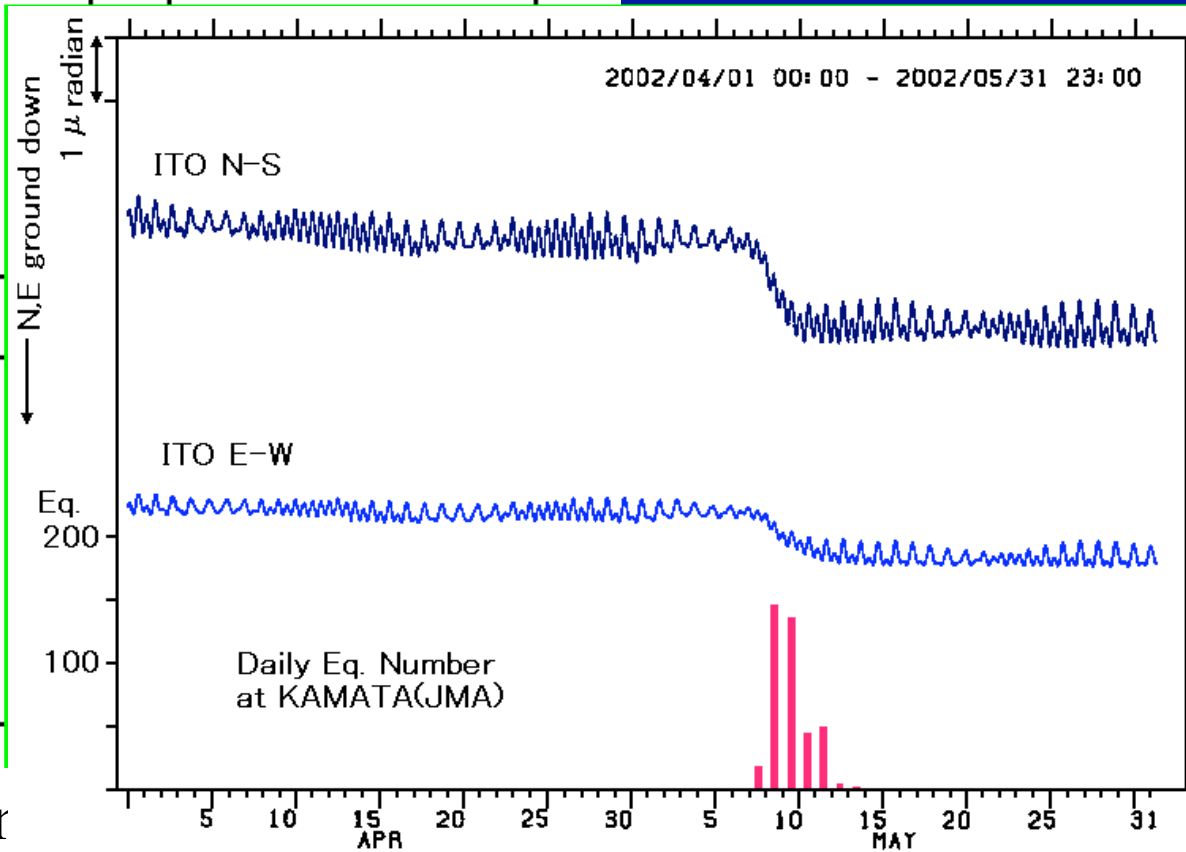
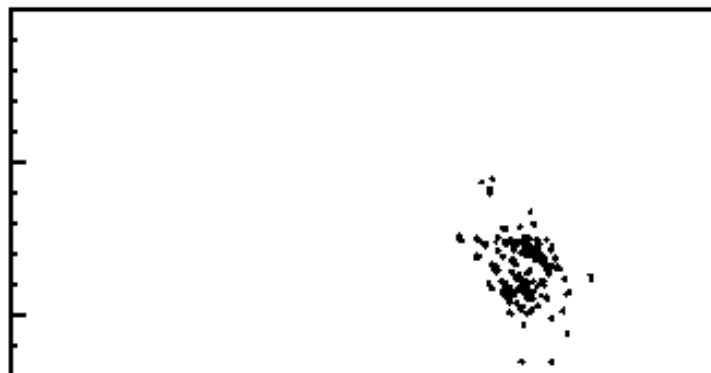
1997年9月1日~2002年7月31日 (S-P ≤ 6sec)



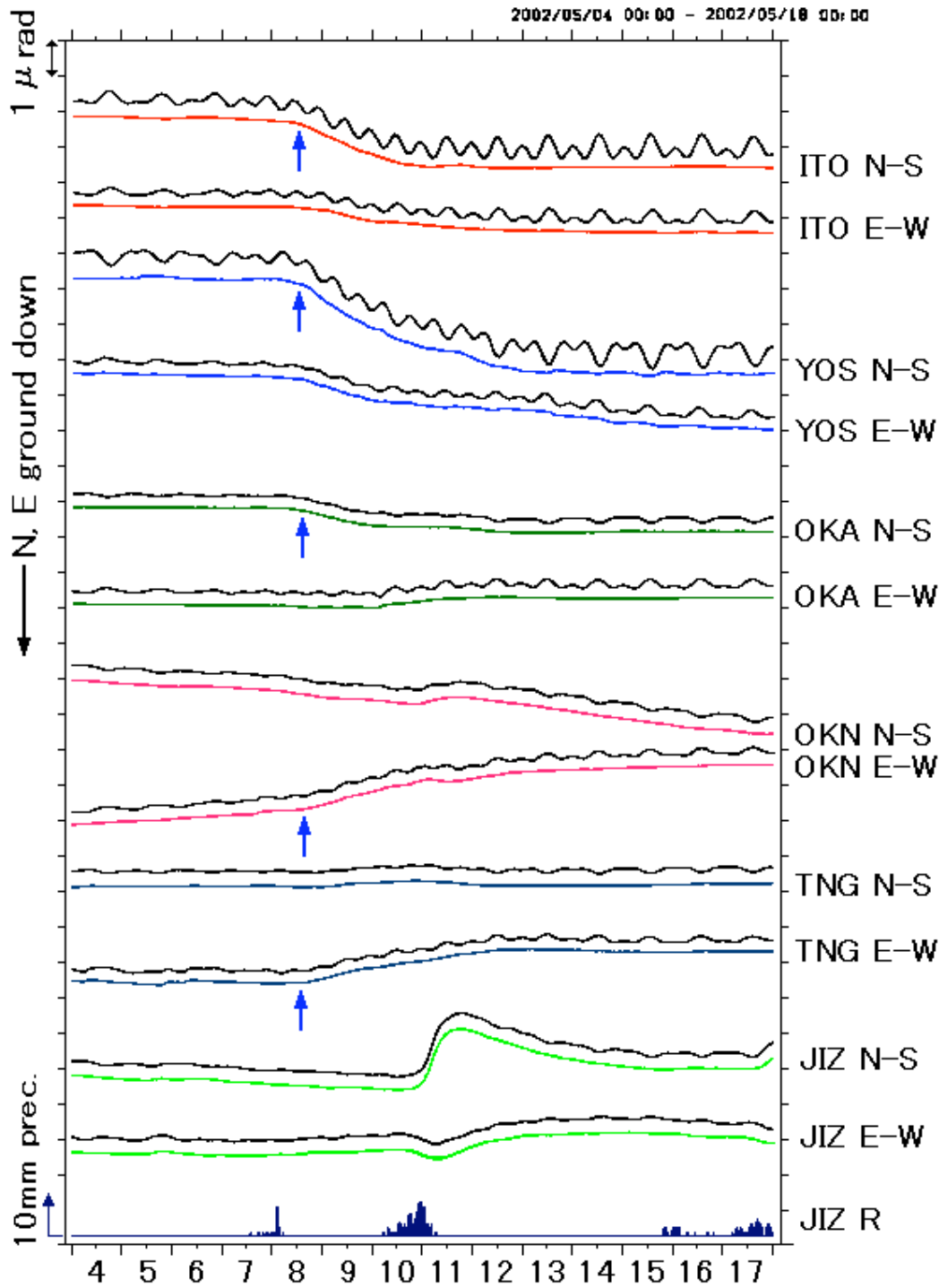
本年5月8日から15日にかけての伊豆半島東方沖の活動以降、静かな状態に戻っている。



Swarm on  
May 2002

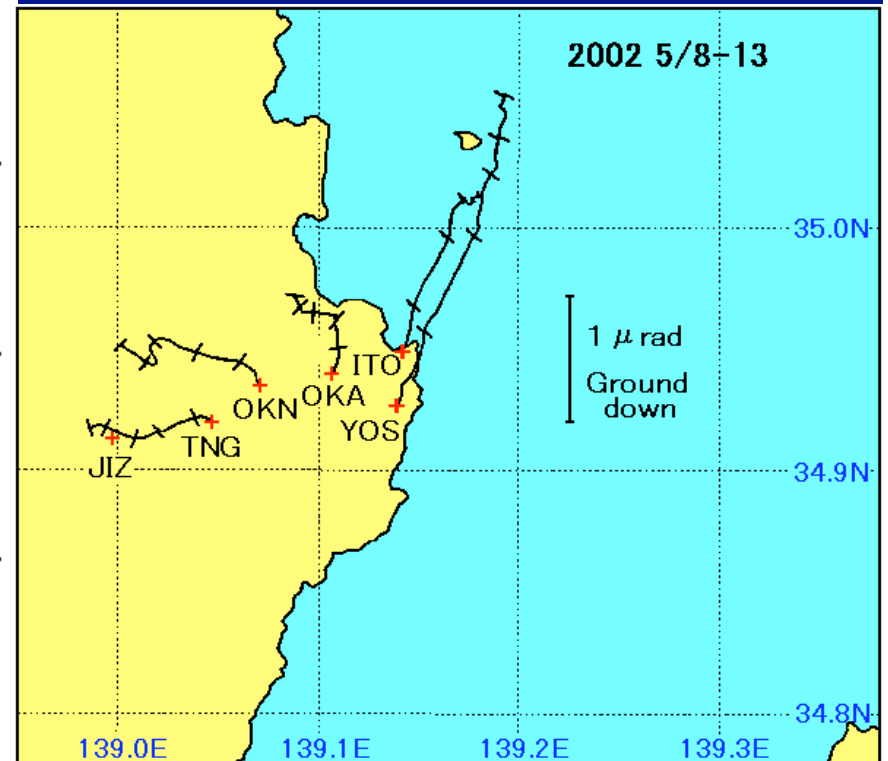


Hypocentral distributor



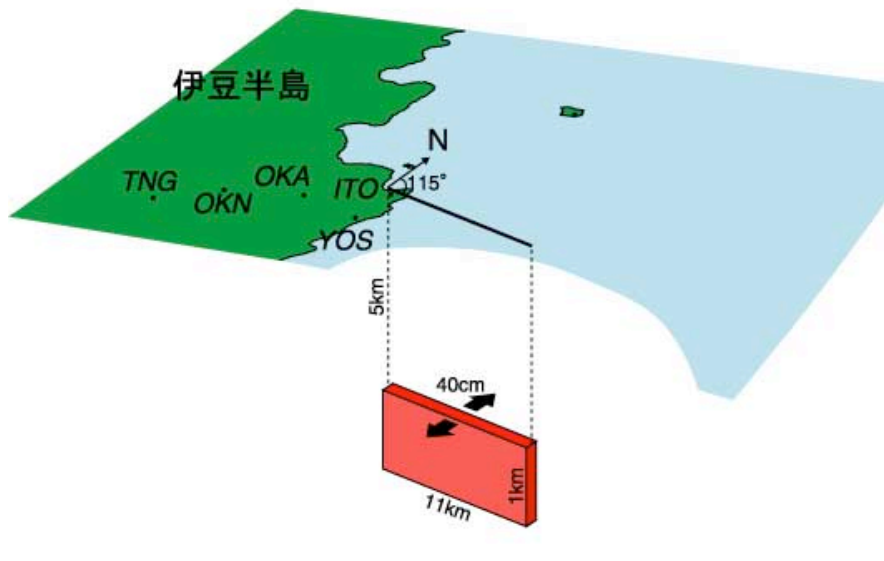
# Tilt changes associated to the swarm 0205

*Tilt vector change*

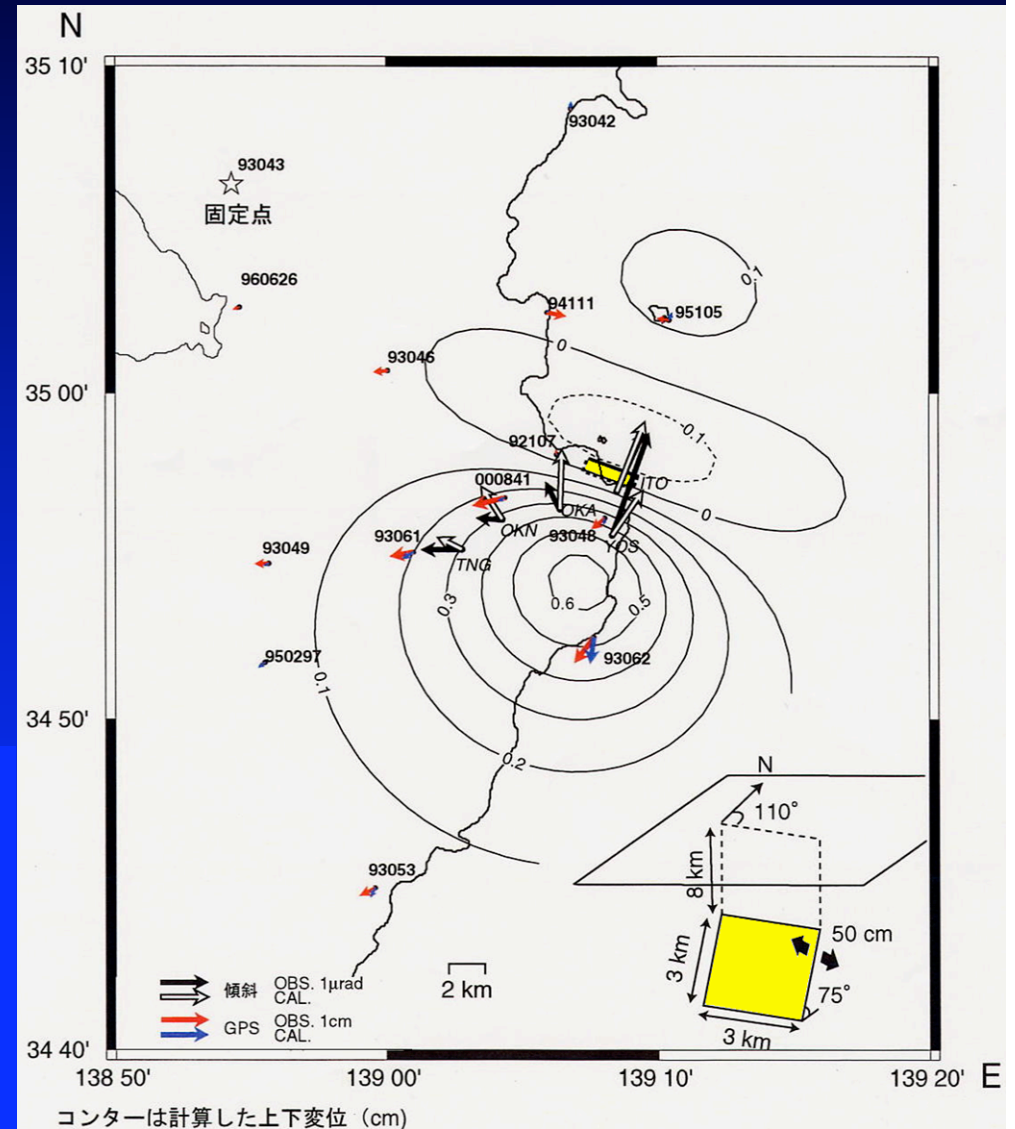


# Dyke intrusion model for the swarm 0205

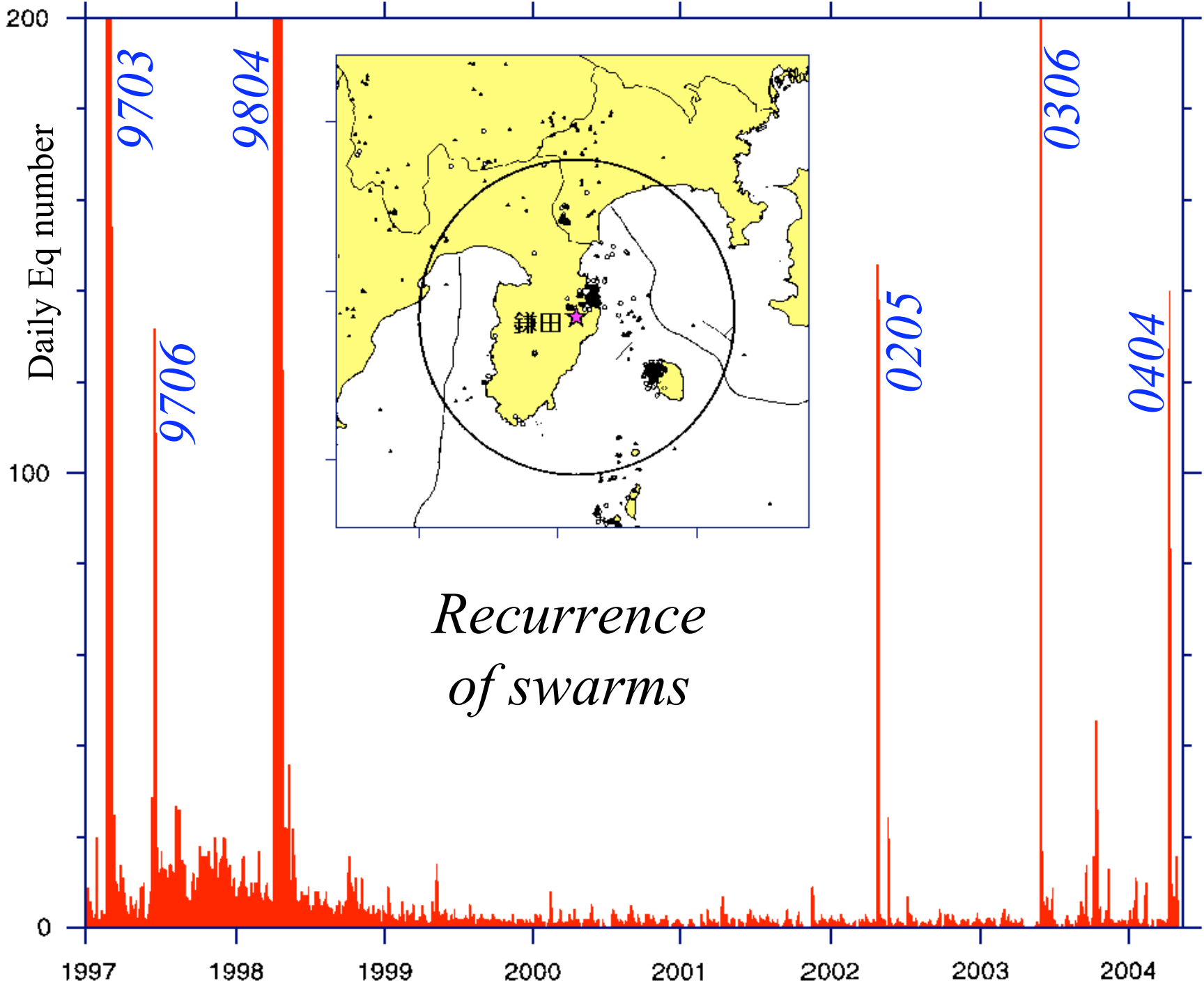
*1<sup>st</sup> approximation model using tilt data*



*2<sup>nd</sup> approximation model using tilt and GPS data*

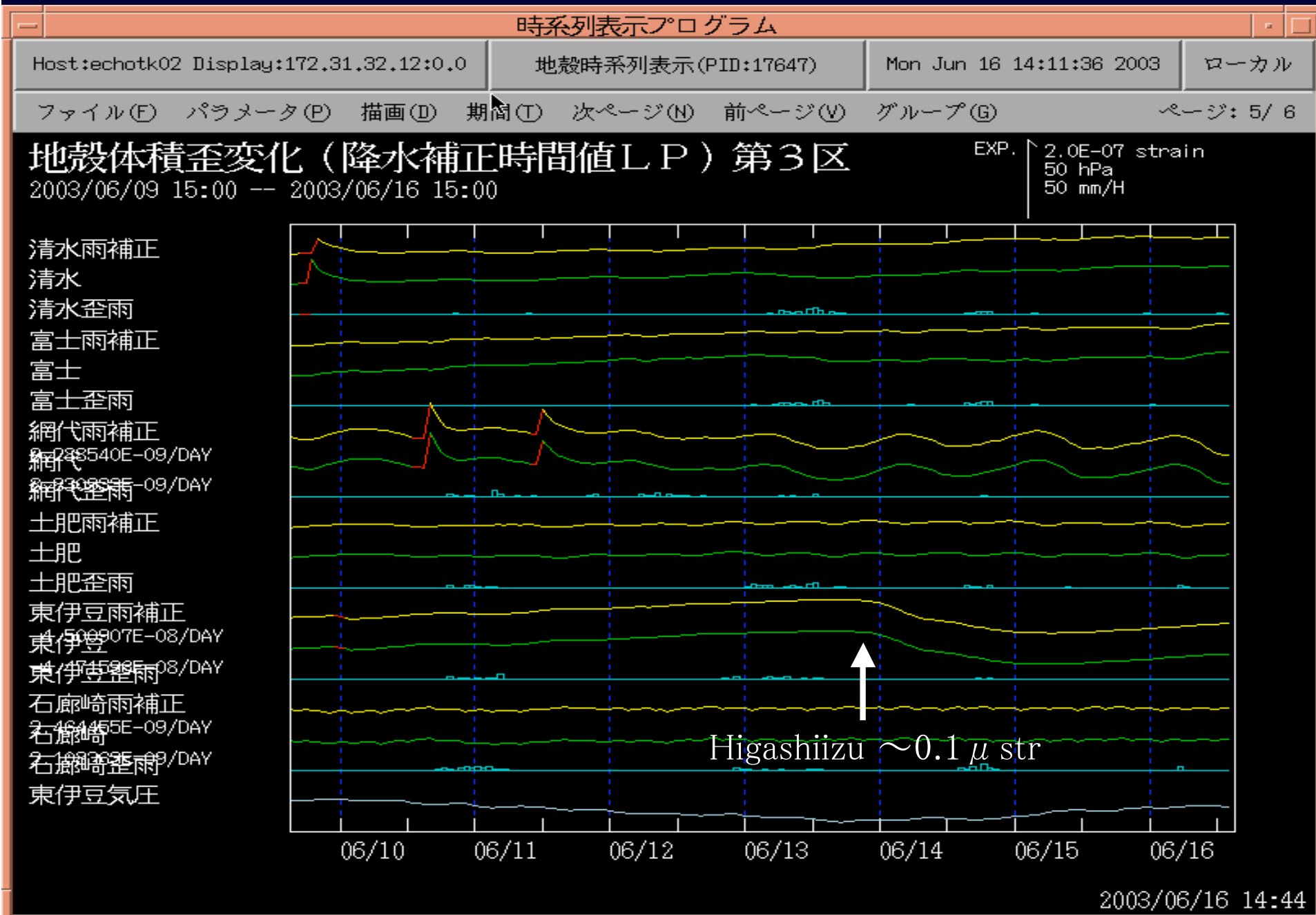






*Recurrence  
of swarms*

# Volume strain associated to the swarm 0306



# Tilt changes associated to the swarm 0306

時系列表示プログラム

Host:echotk02 Display:172.31.32.12:0.0

地殻時系列表示 (PID:9209)

Mon Jun 16 15:28:36 2003

ローカル

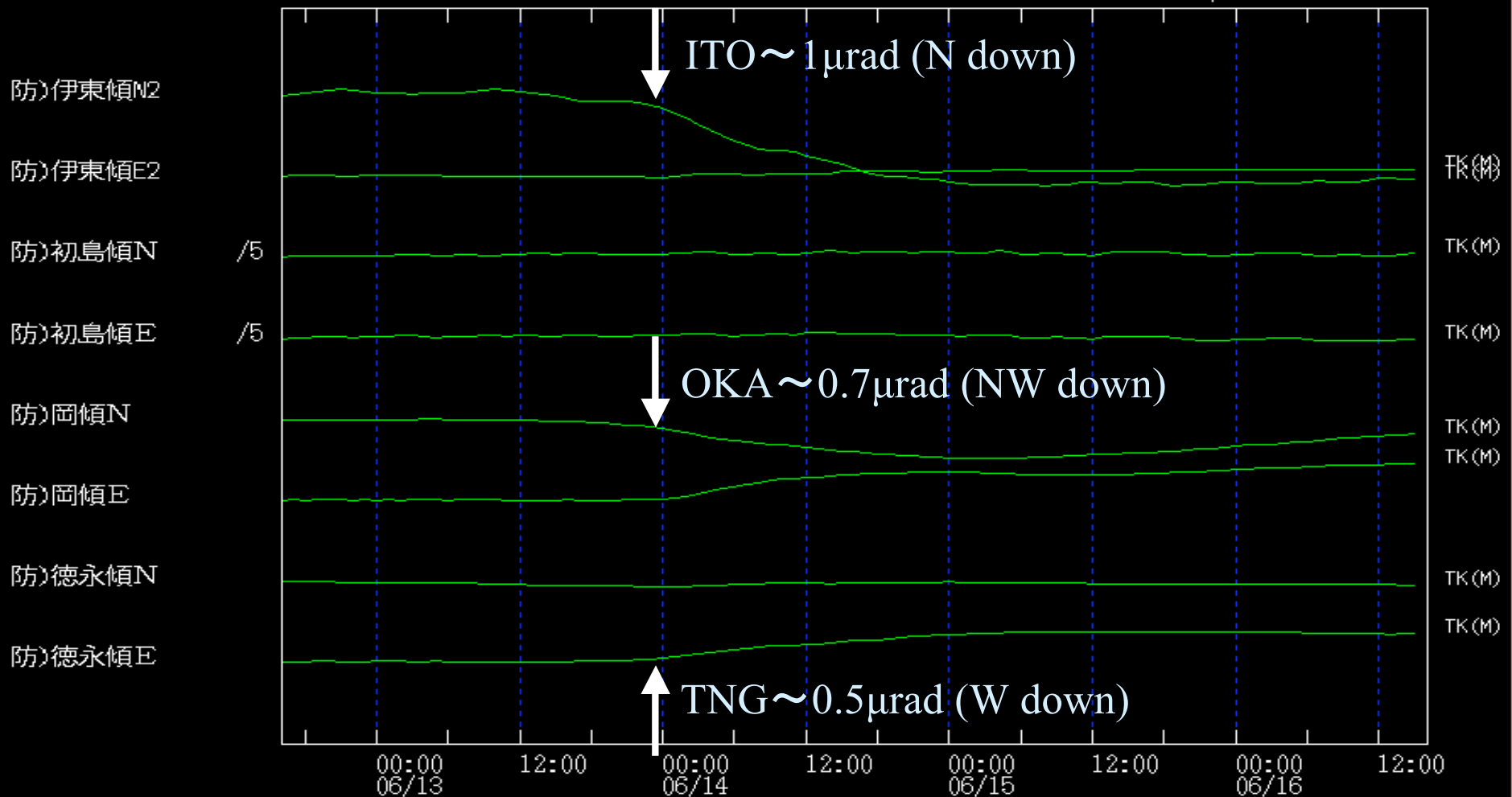
ファイル(F) パラメータ(P) 描画(D) 期間(T) 次ページ(N) 前ページ(V) グループ(G)

ページ: 4 / 5

## 防災科研傾斜(時間値オフライン補正)伊豆東部

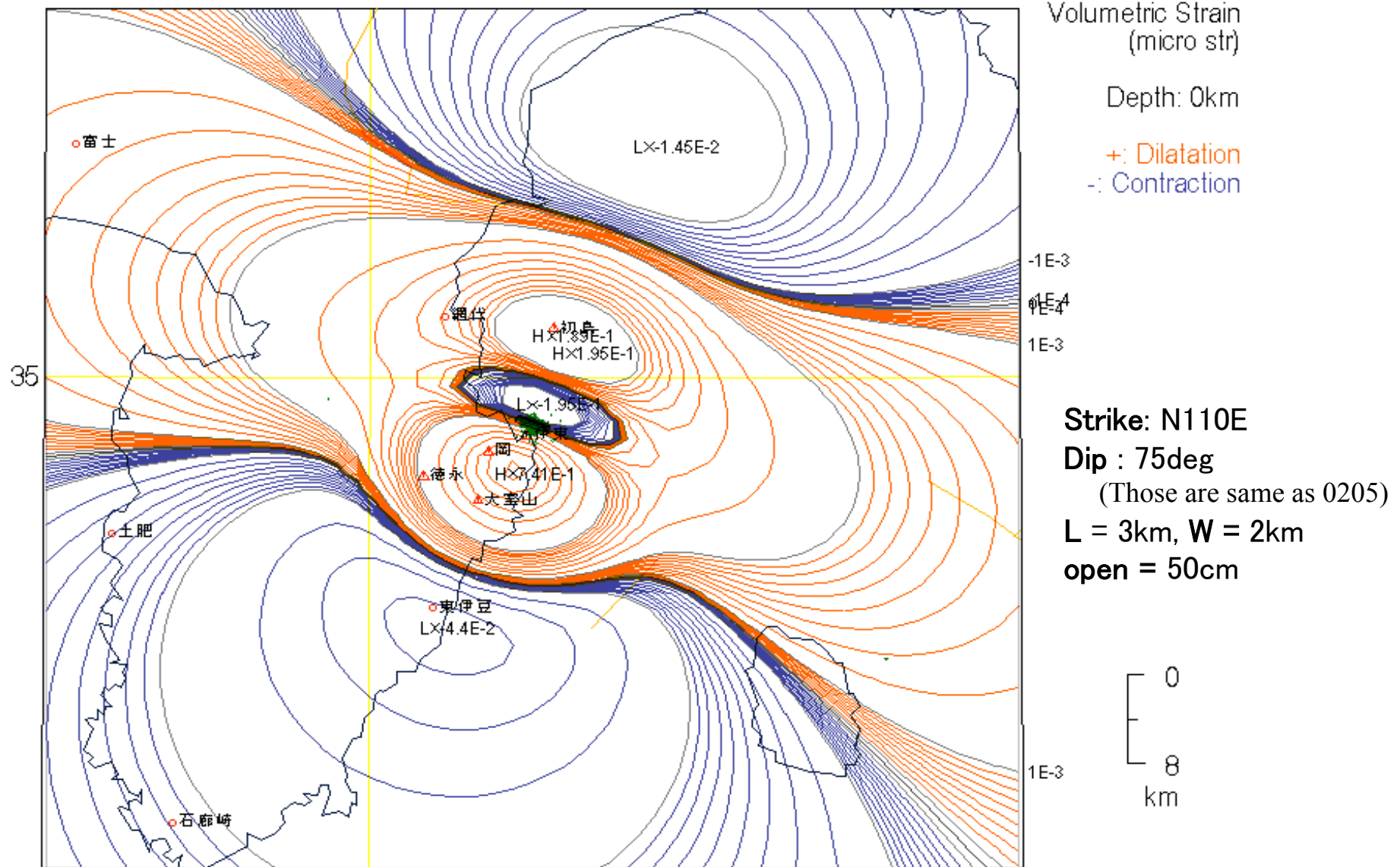
2003/06/12 16:00 -- 2003/06/16 16:00

EXP.NEup 1.0E-06 radian



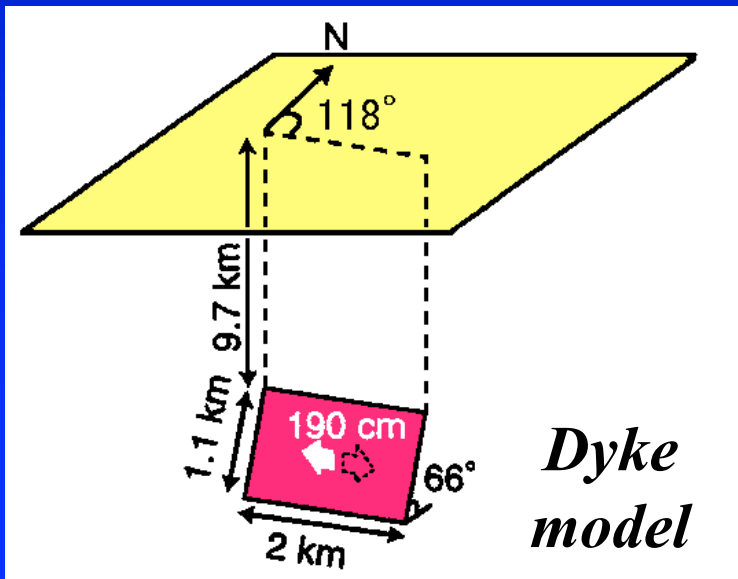
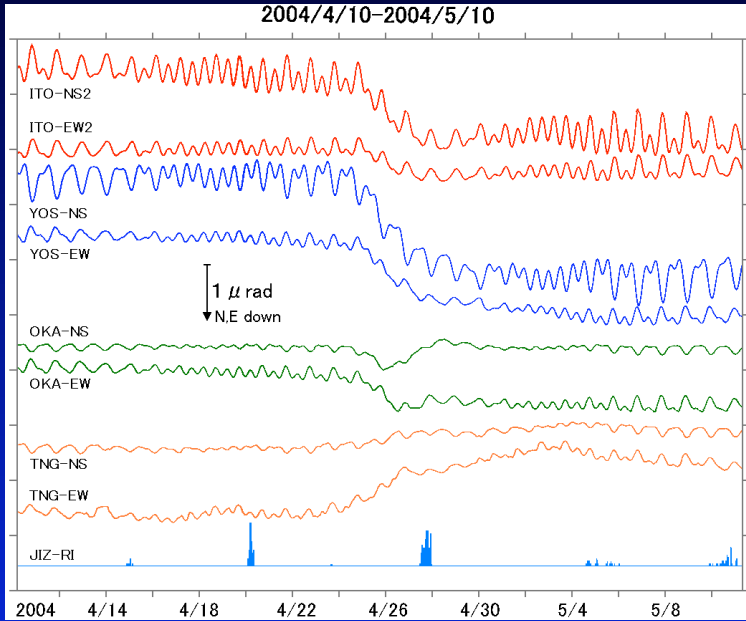
2003/06/16 15:55

# Dyke intrusion model for the swarm 0306

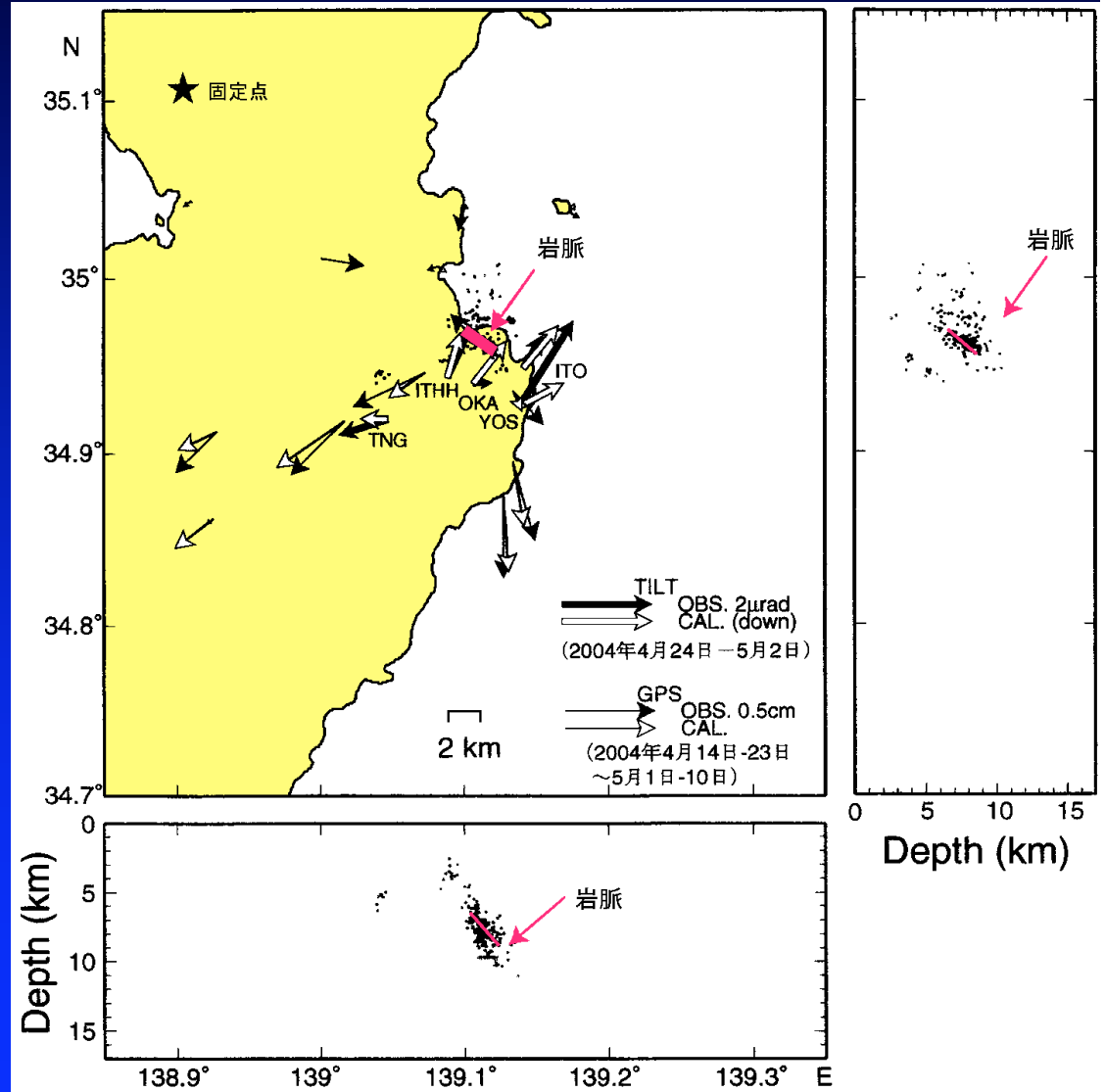


# Swarm on April 2004

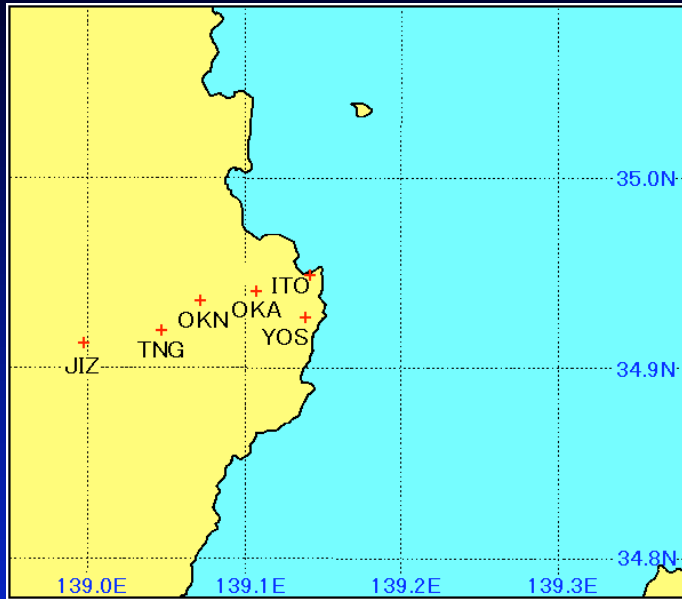
## Tilt changes



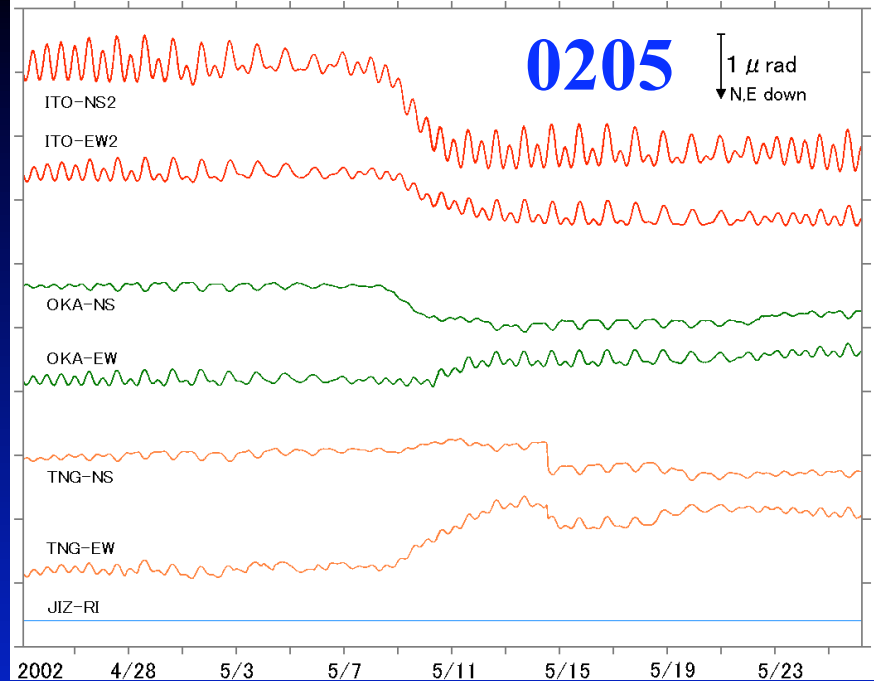
## Tilt vectors and GPS displacements



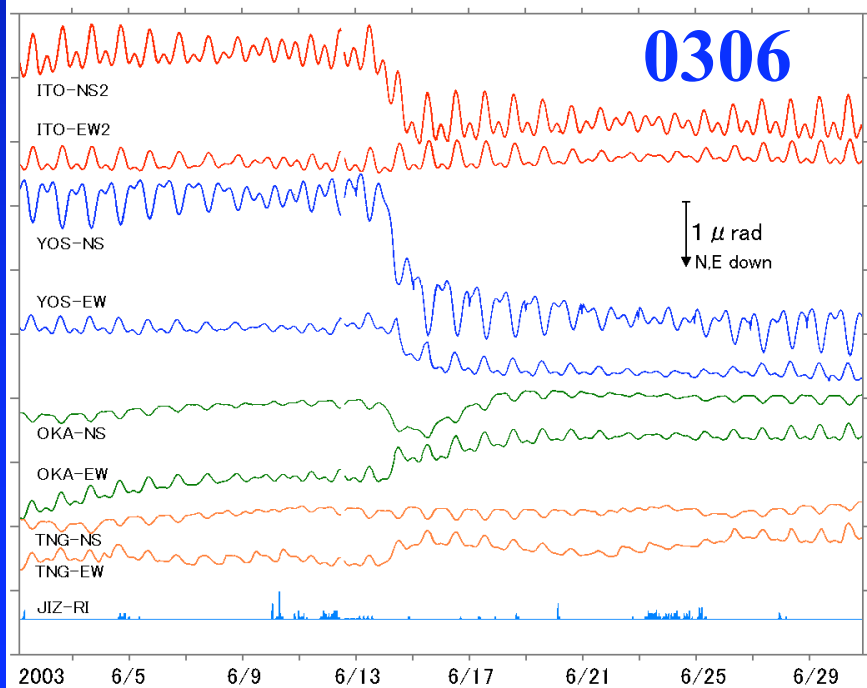
# Tlit changes for recent swarms



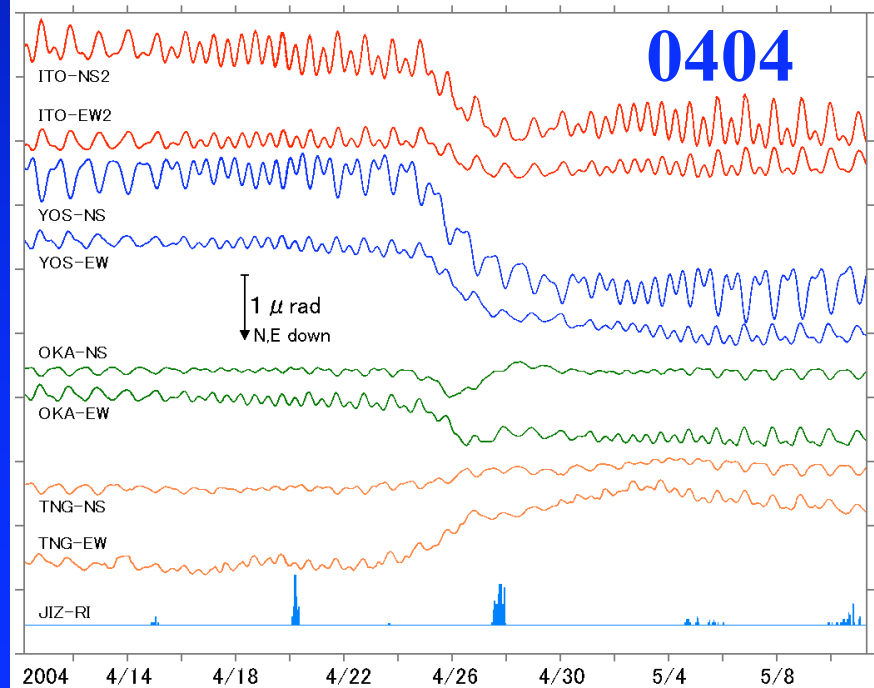
2002/4/25–2002/5/25



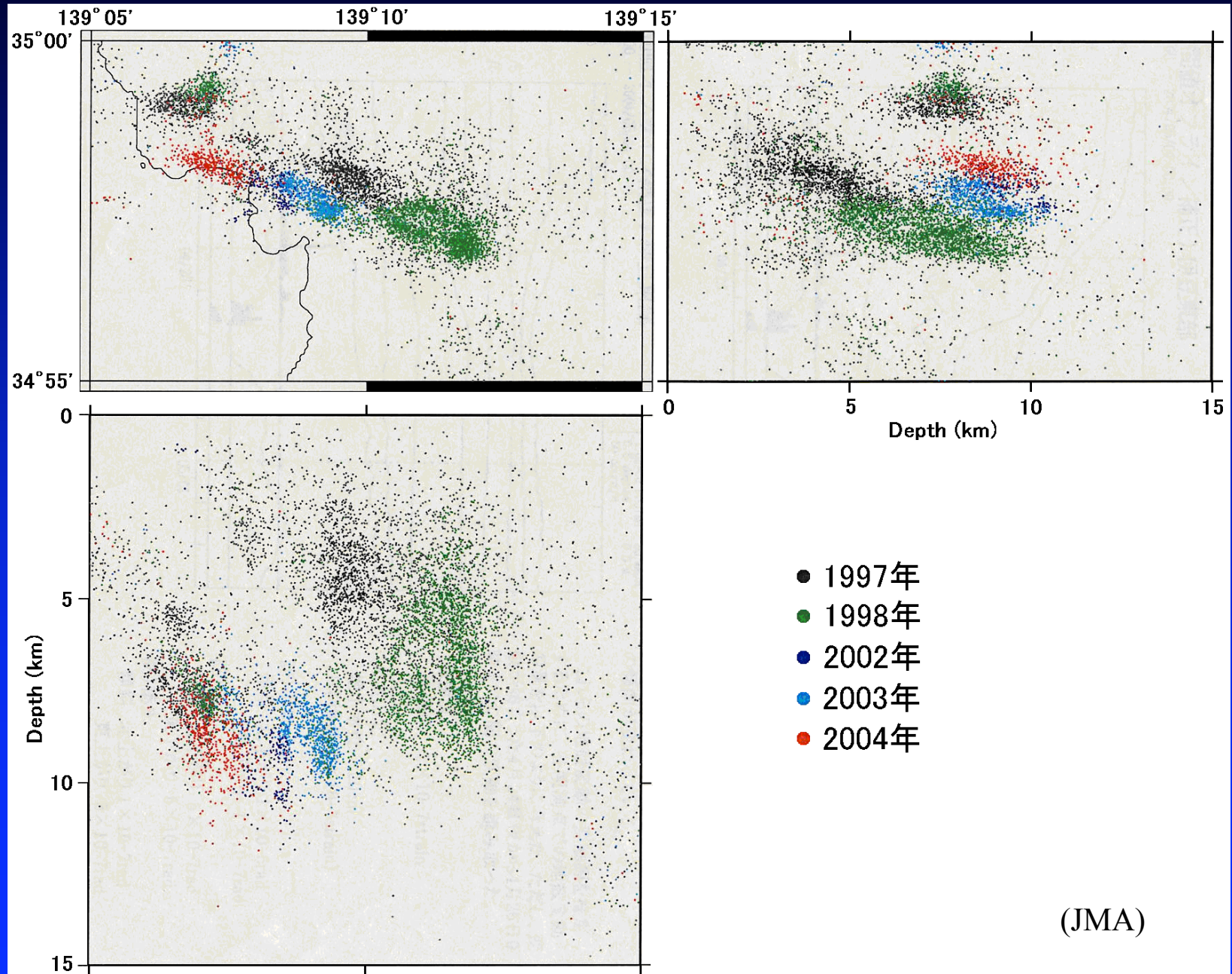
2003/6/1–2003/6/30



2004/4/10–2004/5/10



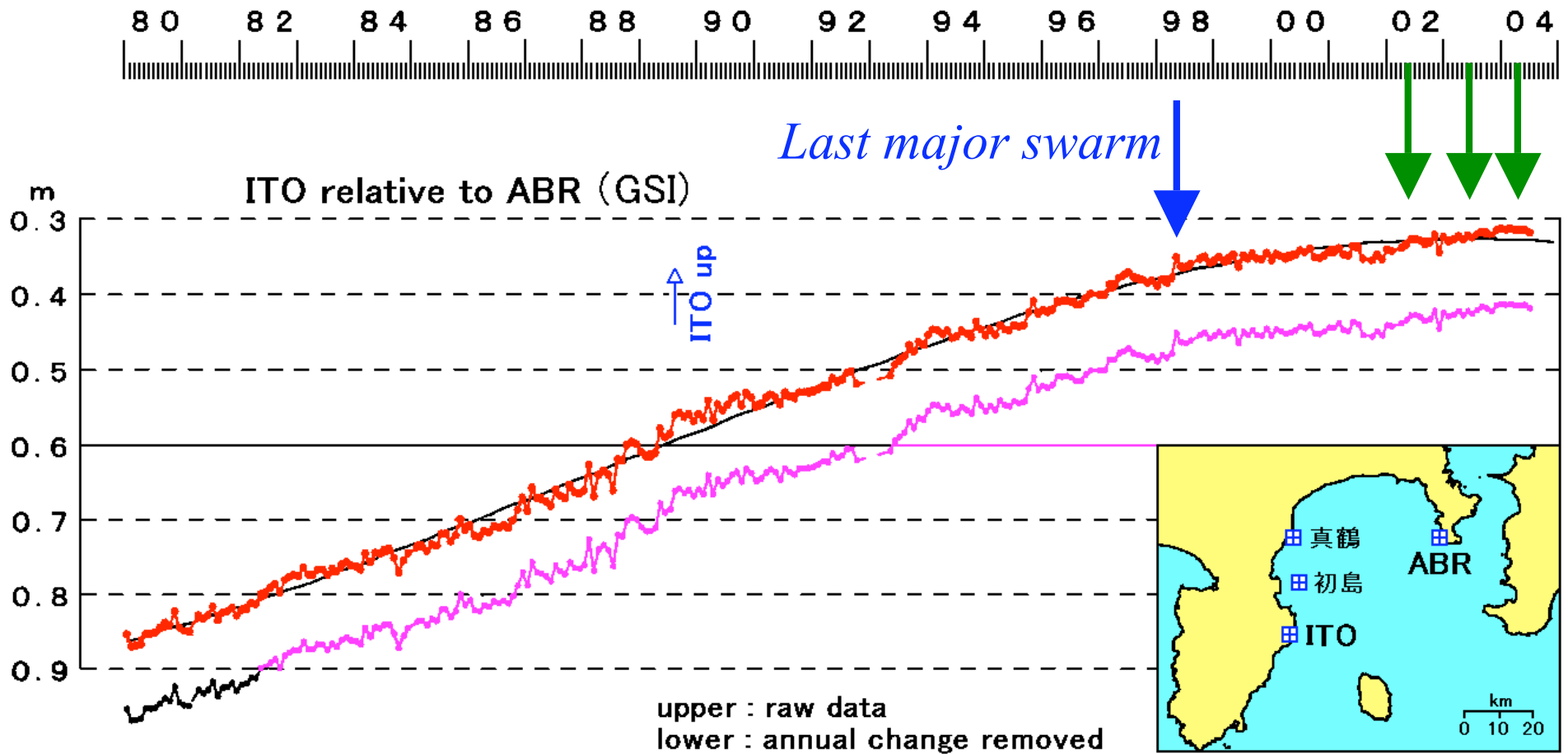
# Hypocenters of recent swarms (relocated by DD method)



(JMA)

# Did crustal deformation stop ? (tidal observation)

*Recent swarms*





# Questions

- (1) Until when the swarm activity will continue ?
- (2) Will major swarm follow in near future ?
- (3) Will volcanic event like in July 1989 recur ?

## Technical challenge

How quickly can we issue an alarm preceding to the start of major swarm activity ?