Background swarm earthquake rates modulated by volumetric strain changes

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Abstract: Off the east coast of Izu Peninsula is a submarine volcanic region, where earthquake swarms have been observed many times caused by magma intrusions. Temporal duration of the swarm activity is known to be correlated with the largest volumetric strain change in 24 hr at Higashi-Izu station at about 20 km distance apart. After correcting for the aftershock rate, we have found that the strain changes accurately predict the background rates that are directly related to the driving stress from magma intrusions. The causal relationship between the background rate changes and the temporal changes of volumetric strain depends on the distances of the station from the locations of magma intrusions.

1. Observations

- **The Eastern offshore of Izu peninsula, Japan, has been subject to recurrent earthquake swarm events** (Fig.1) which coincide with magma intrusion events measured by volumetric strain changes (Fig.2). Each swarm lasts around 2 weeks.
- **The background rates $\mu(t)$** is highly time dependent (Fig.3) by the **non-stationary ETAS model** (1).

$$\lambda(t) = \mu(t) + \sum_{i;t_i<t} \frac{K_0(t)\exp\{-\alpha(M_i - M_c)\}}{(t-t_i+c)^p} \quad (1)$$

- **The cross-correlation of the volumetric strain with the background rates $\mu(t)$** is higher than that with hourly #events (Table 1).

Max cross-correlation in hours lag	Strain vs #events	Strain vs $\mu(t)$	Strain vs *# declustered events*
1988	0.50 (0)	0.56 (–15)	0.50 (–10)
1989	0.51 (–1)	0.53 (–14)	0.51 (–6)
1993	0.51 (0)	0.70 (–15)	0.62 (–3)
1995	0.44 (0)	0.53 (–13)	0.46 (–11)
1997	0.50 (–5)	0.54 (–13)	0.51 (–5)
1998	0.47 (0)	0.55 (–13)	0.50 (–8)
2006	0.38 (0)	0.57 (–13)	0.49 (–12)
2009	0.52 (–7)	0.58 (–14)	0.55 (–10)

Table.1. Cross-correlation of volumetric strain with $\mu(t)$ and with #events.

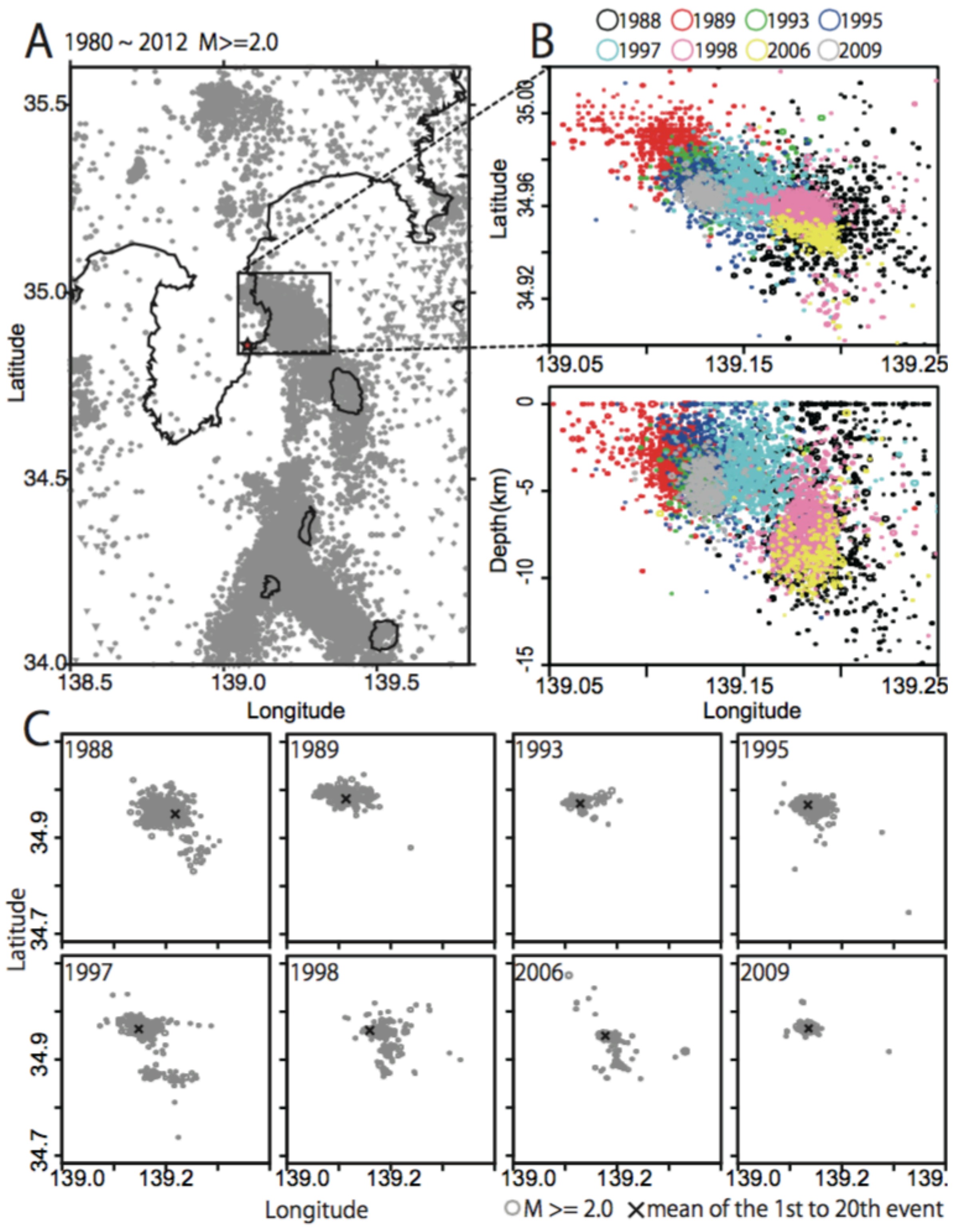

Fig. 1. Seismicity in Izu region (A, B) and 8 major swarm distributions (C).

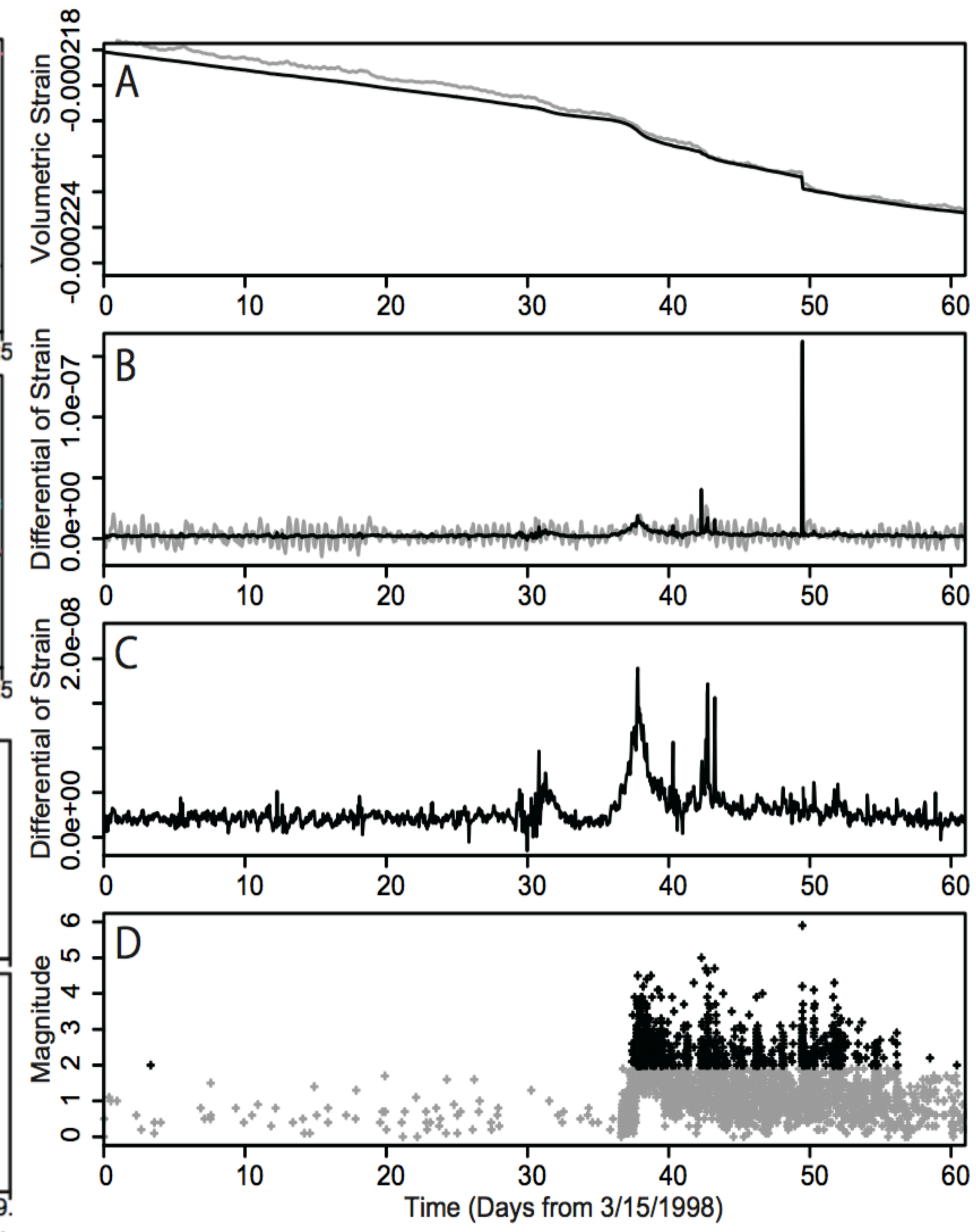

Fig. 2. Volumetric strain measured at the nearest station (star mark in Fig.1 A). Black is the raw measurement, gray is modified by removing effects of tide, rainfall, etc.

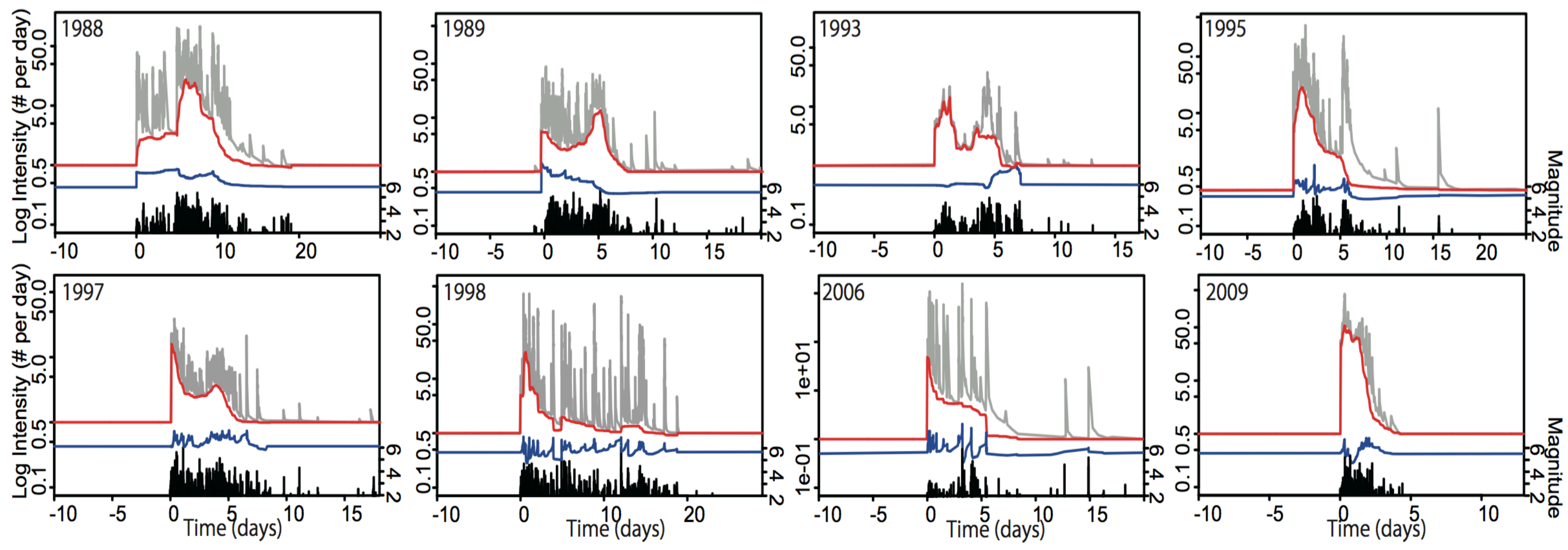

Fig.3. Estimated time-dependent background rate (***μ*(*t*), red**) and aftershock productivity (***K*₀(*t*), blue**) in (1).

These observations indicate that it is possible to predict earthquake swarm events from volumetric strain.

2. Causal relationship of background rate against volumetric strain

a. Apply **a linear regression model** (2), where z_{t-i} is the hourly difference of volumetric strain at time *t-i*, and β_i represents its coefficient (Fig.4).

$$\mu(t) = \beta_0 z_t + \beta_1 z_{t-1} + \beta_2 z_{t-2} + \cdots + \beta_M z_{t-M} + \varepsilon_M \quad (2)$$

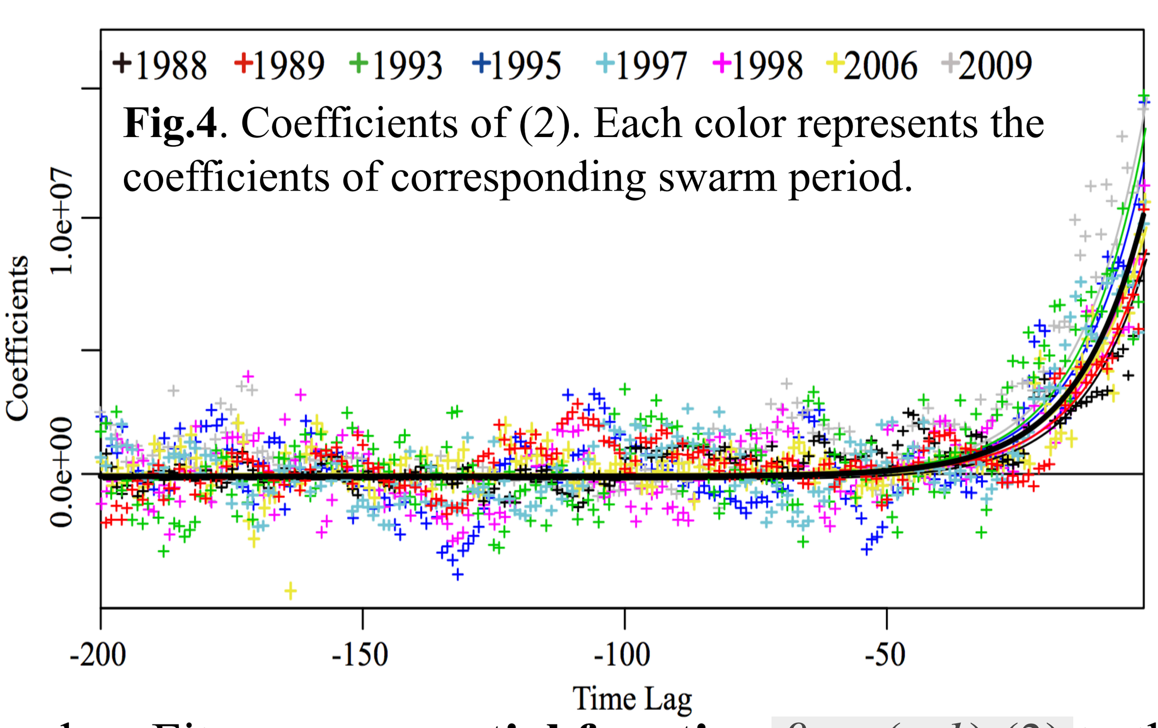

Fig.4. Coefficients of (2). Each color represents the coefficients of corresponding swarm period.

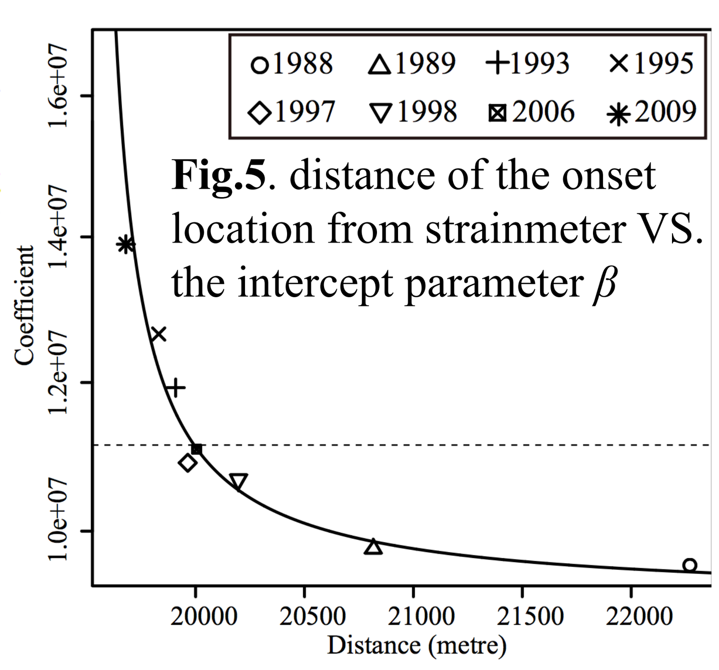

Fig.5. distance of the onset location from strainmeter VS. the intercept parameter β

b. Fit **an exponential function** $\beta\exp(-\sigma k)$ (3) to the coefficients

	Total	1988	1989	1993	1995	1997	1998	2006	2009
$\beta(\times 10^7)$	1.16	0.95	0.99	1.19	1.28	1.10	1.06	1.11	1.39
σ	0.078	0.074	0.080	0.074	0.081	0.074	0.080	0.078	0.078

Table.2. parameter estimate of (3).

The intercept parameter β has a significant relation with the onset location of the swarm events (Fig.5).

c. Take **the swarm onset location** into account (4), where β_d is given by ***βd=v1+v2v3+d.***

$$\hat{\mu}(t) \approx \beta_d \sum_{k=0}^{K} e^{-\sigma k} z_{t-k} \quad (4)$$

d. Use **(4) as a predictor** of the background seismicity and **put it into the ETAS model** for prediction (Fig.6).

$$\lambda_\theta(t \mid H_t) = \mu + \sum_{\{i:S<t_i<t\}} K_0 e^{\alpha(M_i - M_z)} \Big/ (t-t_i+c)^p \quad \text{ETAS model}$$

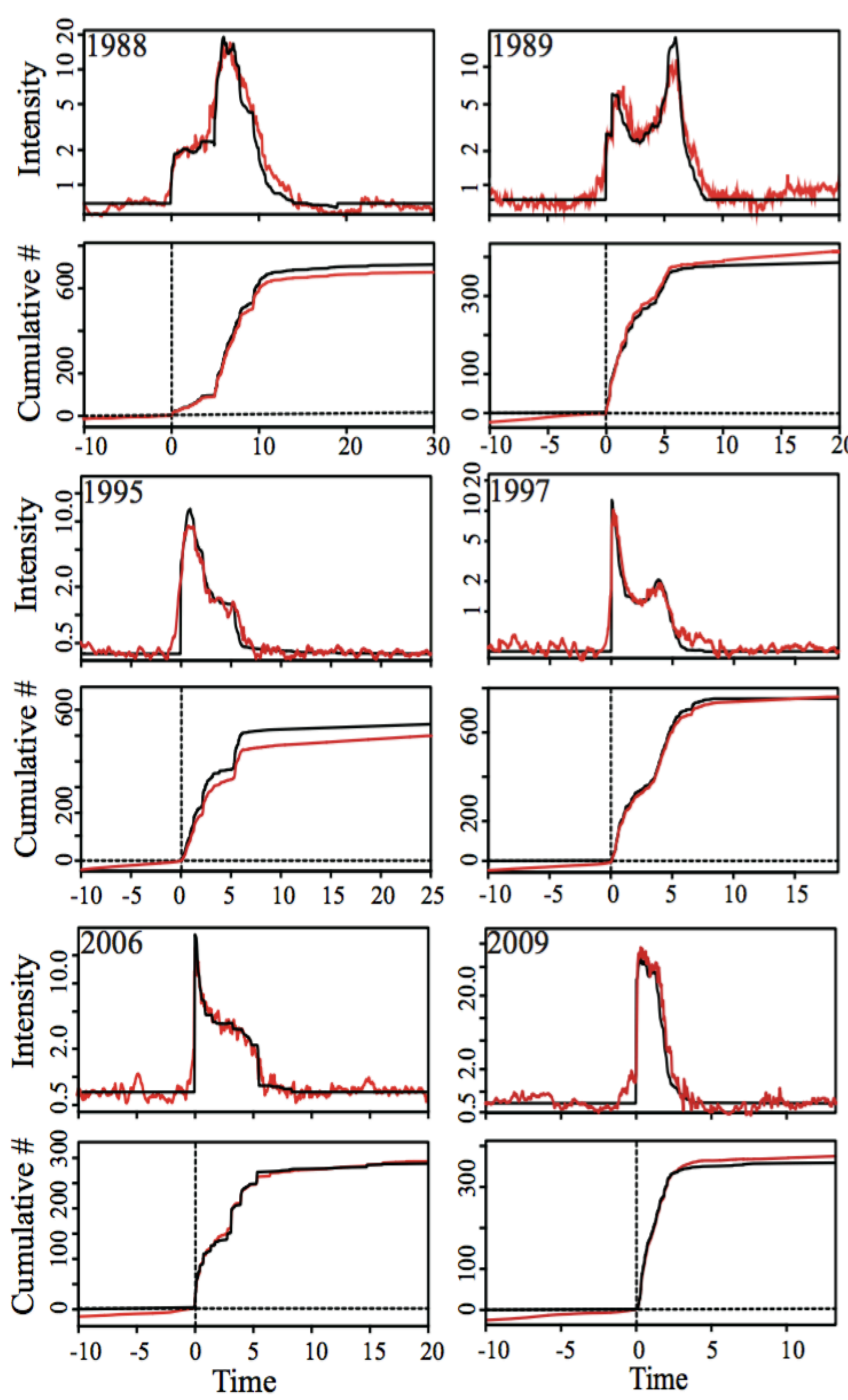

Fig.6. Swarm predictions by (4) from the volumetric strains.

(**A-top**) black curve shows the background rate changes $\mu(t)$ of the non-stationary ETAS model (1), red curve shows background rate by the predictor (4).
(**A-mid**) the observed and predicted cumulative curve of the swarm