SCEC CSEP Workshop: Final Evaluation of the Regional Earthquake Likelihood Models (RELM)
Experiment and the Future of Earthquake Forecasting
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CSEP Results from Time-Dependent Earthquake Forecasts for the *M*9 Tohoku Sequence

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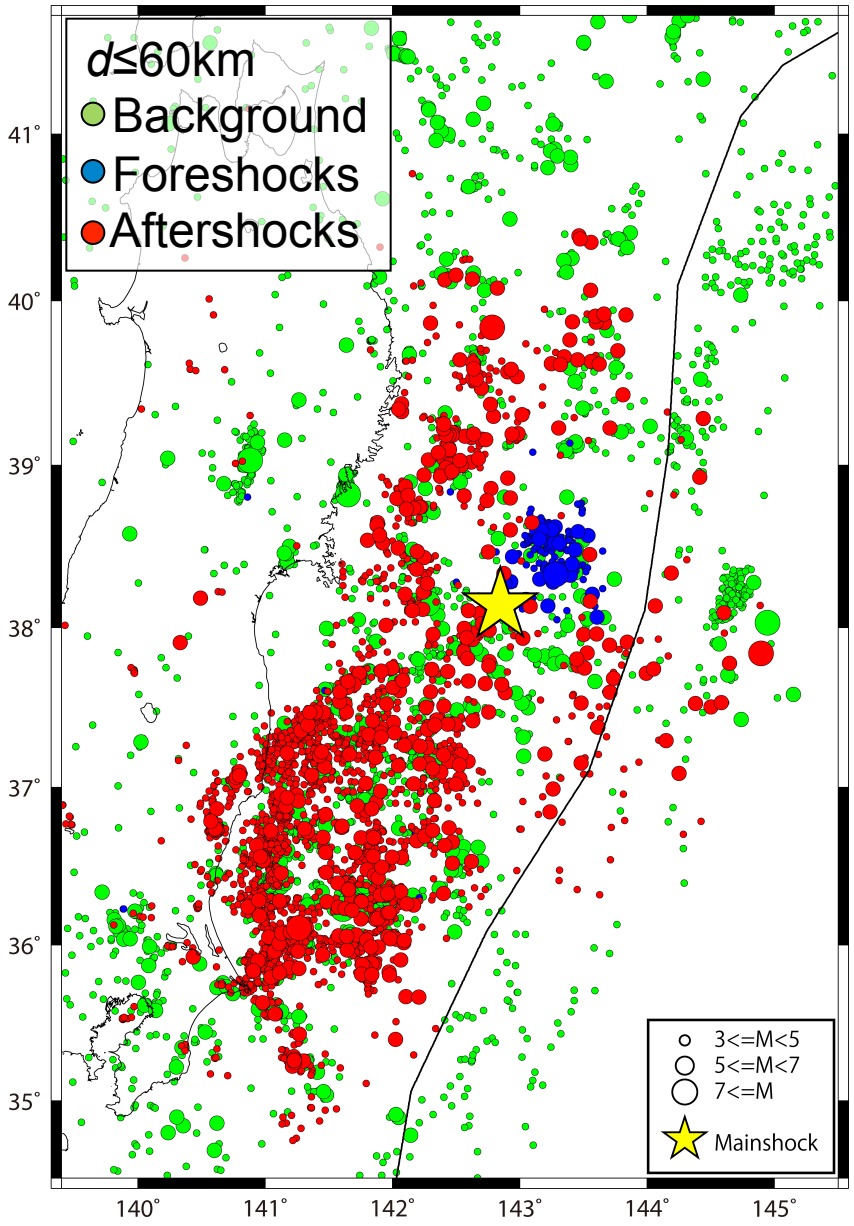
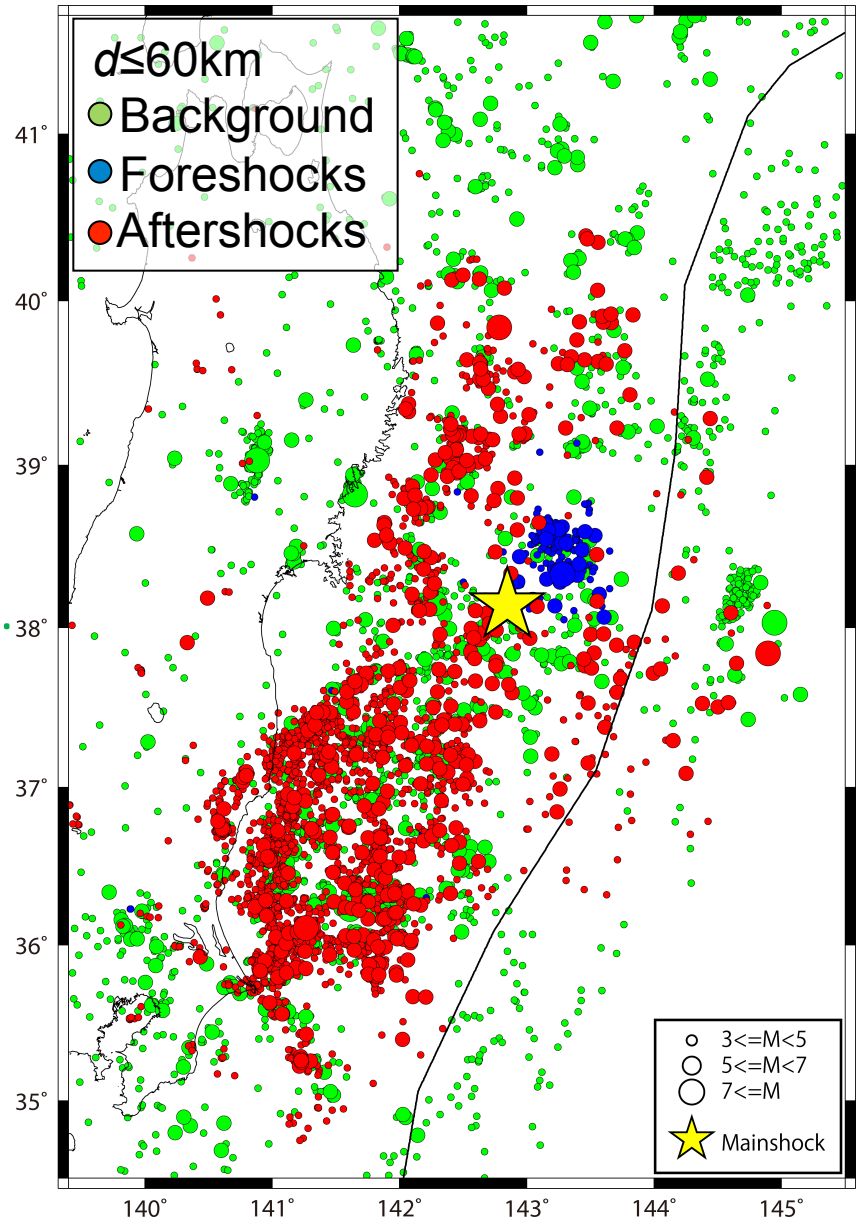
Purpose

- Testing 5 one-day CSEP models against the *M*9 Tohoku sequence
  - ETES (Falcone *et al.* 2010)
    - » Simple ETAS version
    - » Location-independent model parameters
  - ERS (Falcone *et al.* 2010)
    - » ETES + Rate-&-State friction law
  - ETAS (Zhuang 2011)
    - » Forecast through simulation
    - » Location-independent parameters
  - HIST-ETAS5pa (Ogata 2011)
    - » Spatially-varying model parameters
    - » Anisotropic spatial clustering
  - HIST-ETAS7pa (Ogata 2011)
    - » Same as 5pa model
    - » *p* (decay rate) and *q* (spatial kernel) are location-independent



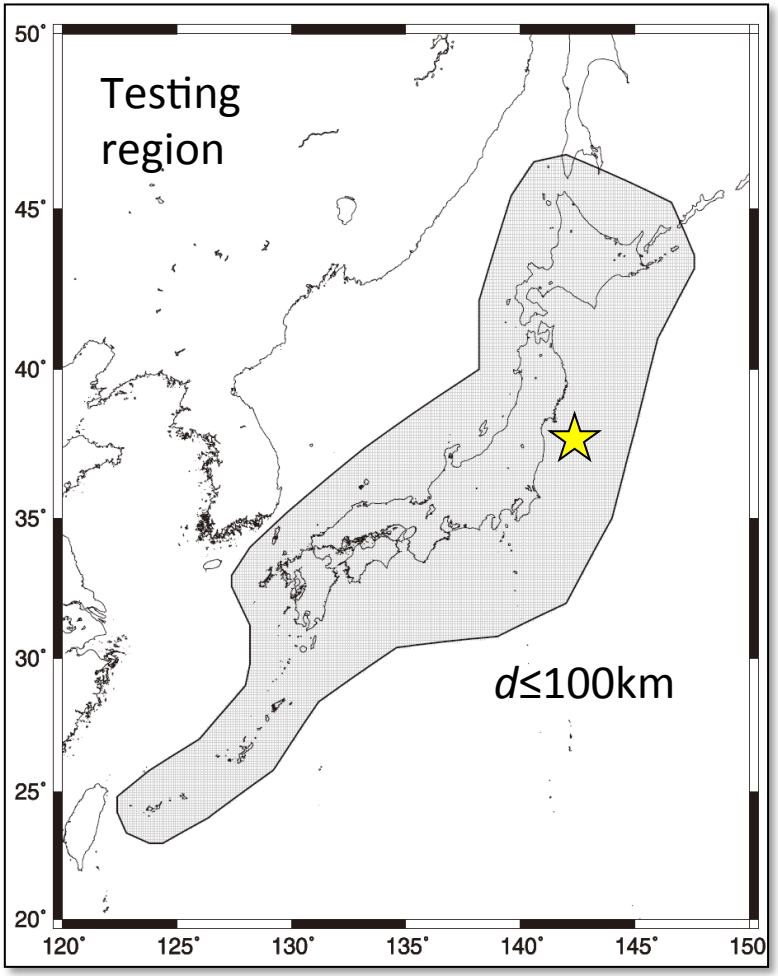
Data used

- Difference from the original CSEP
  - Adding a preliminary JMA (P-JMA) catalog
    - » Incomplete but available immediately
    - » First step toward operability-oriented forecasting
  - Combined JMA/P-JMA catalog
    - » P-JMA catalog (1 Dec. 2011~27 Mar. 2012)
    - » Finalized catalog (~ 30 Nov. 2011)
    - » Use for learning and observation data



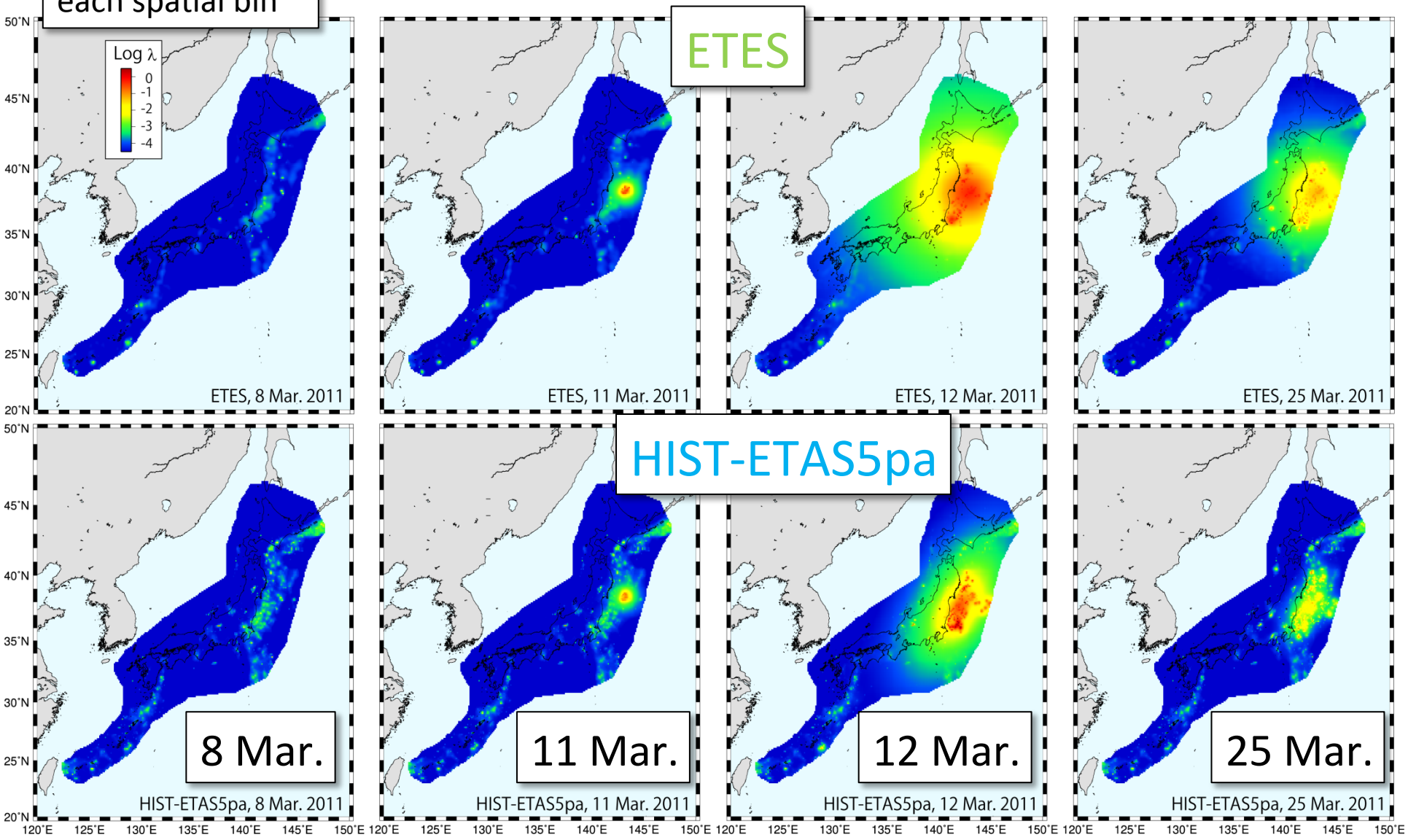
Rules

- See Hirata's talk (*CSEP activity in Japan*)
- Predicts the number of earthquakes in each space-time-magnitude bin
  - Space: 20062 cells of 0.1 x 0.1°
  - Time: 8, 9, 10, …, 27 March, 2011
  - Magnitude: 5.0, 5.1, …, 9.0
- Consistency evaluation
  - N(umber)-test: δ_1 & δ_2 scores
    - » If δ_1 is very small, the forecast rate is too low (an underestimation)
    - » If δ_2 is very small, it is too high (an overestimation)
  - S(pace)-test: ζ score
  - M(agnitude)-test: κ score
  - Significance level: 2.5%



Seismicity forecast maps

λ: # of events for each spatial bin



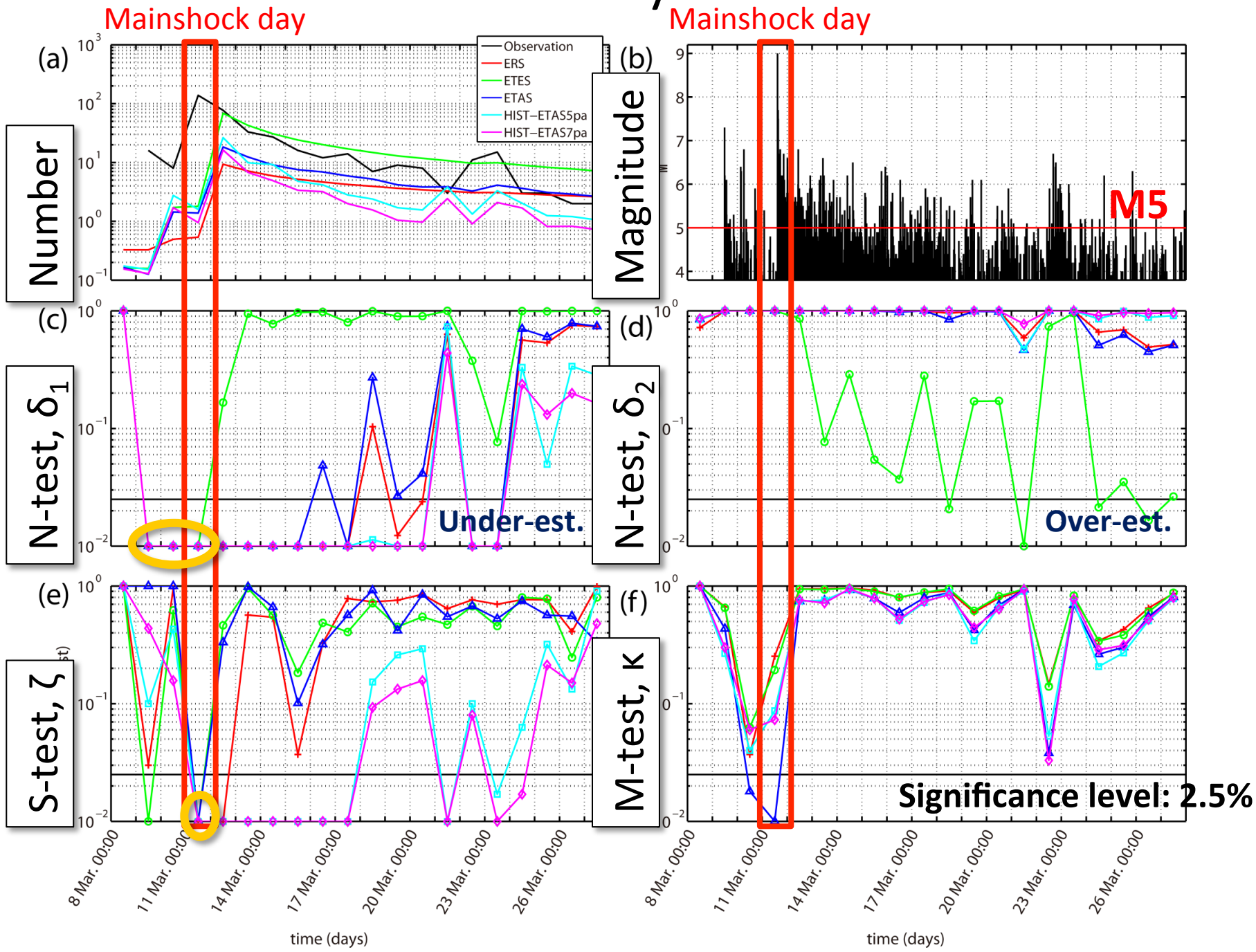
One day before the foreshocks

Day of the mainshock

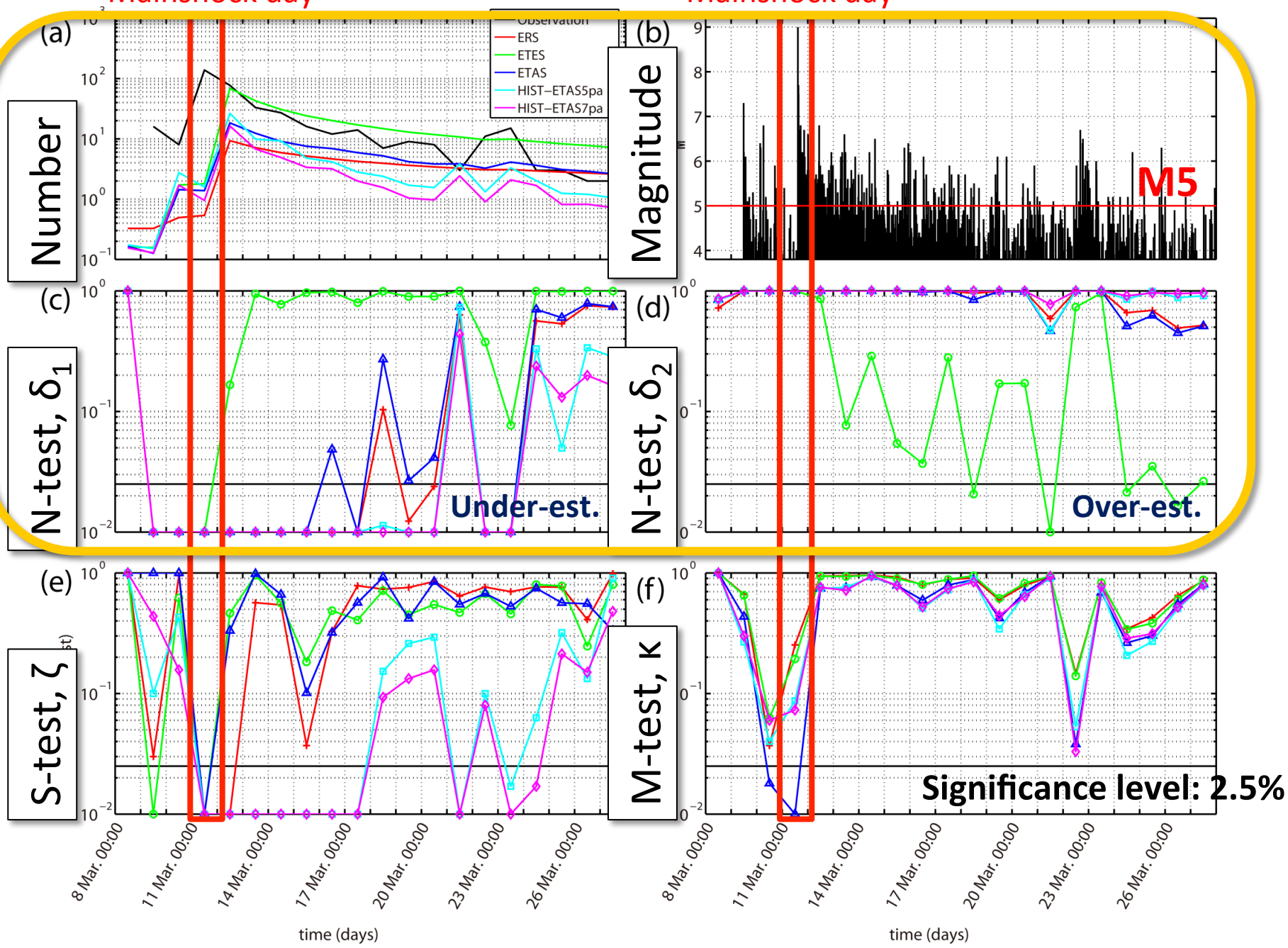
First day after the mainshock

Two weeks later

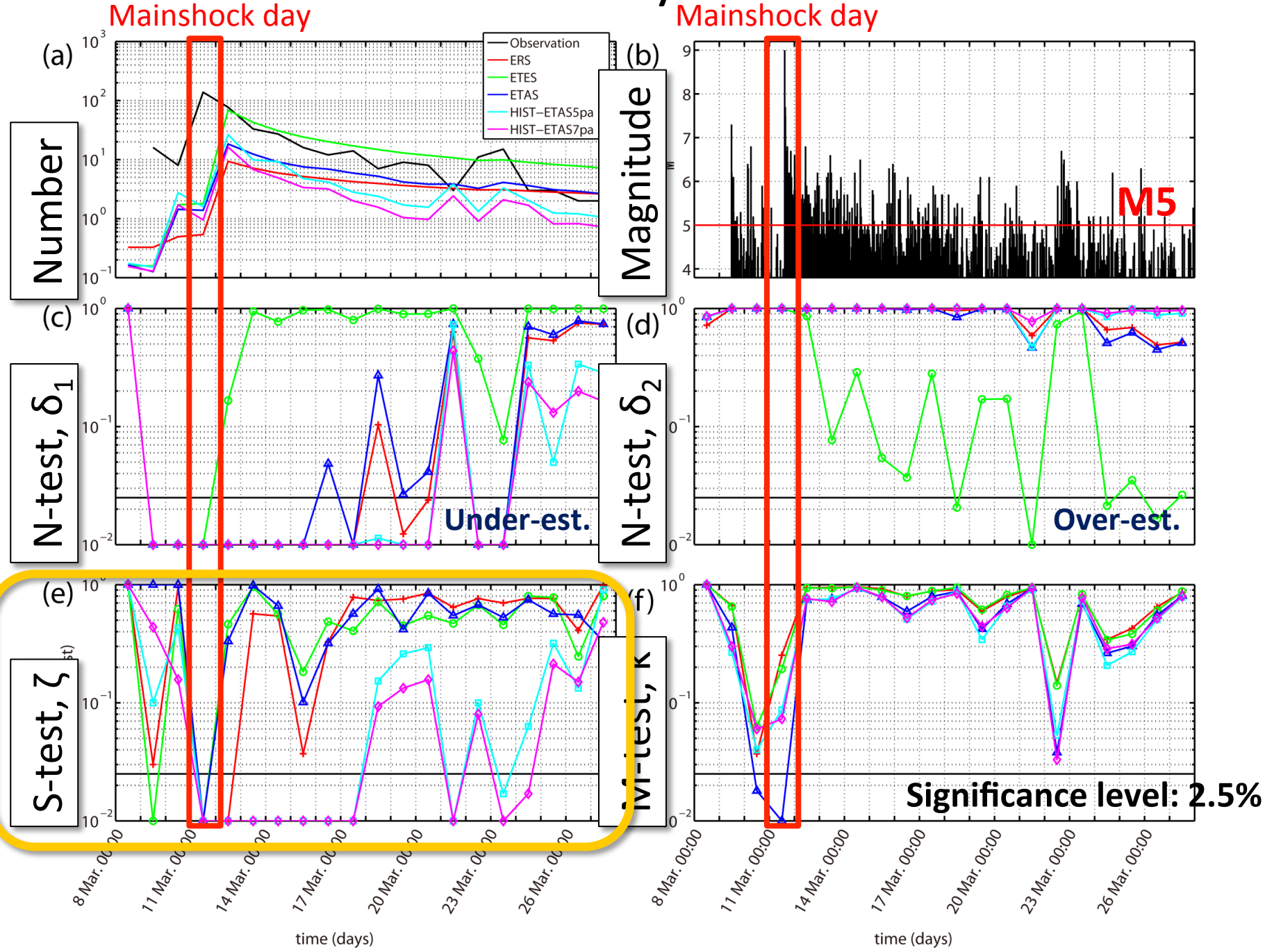
Assessment of one-day forecast models



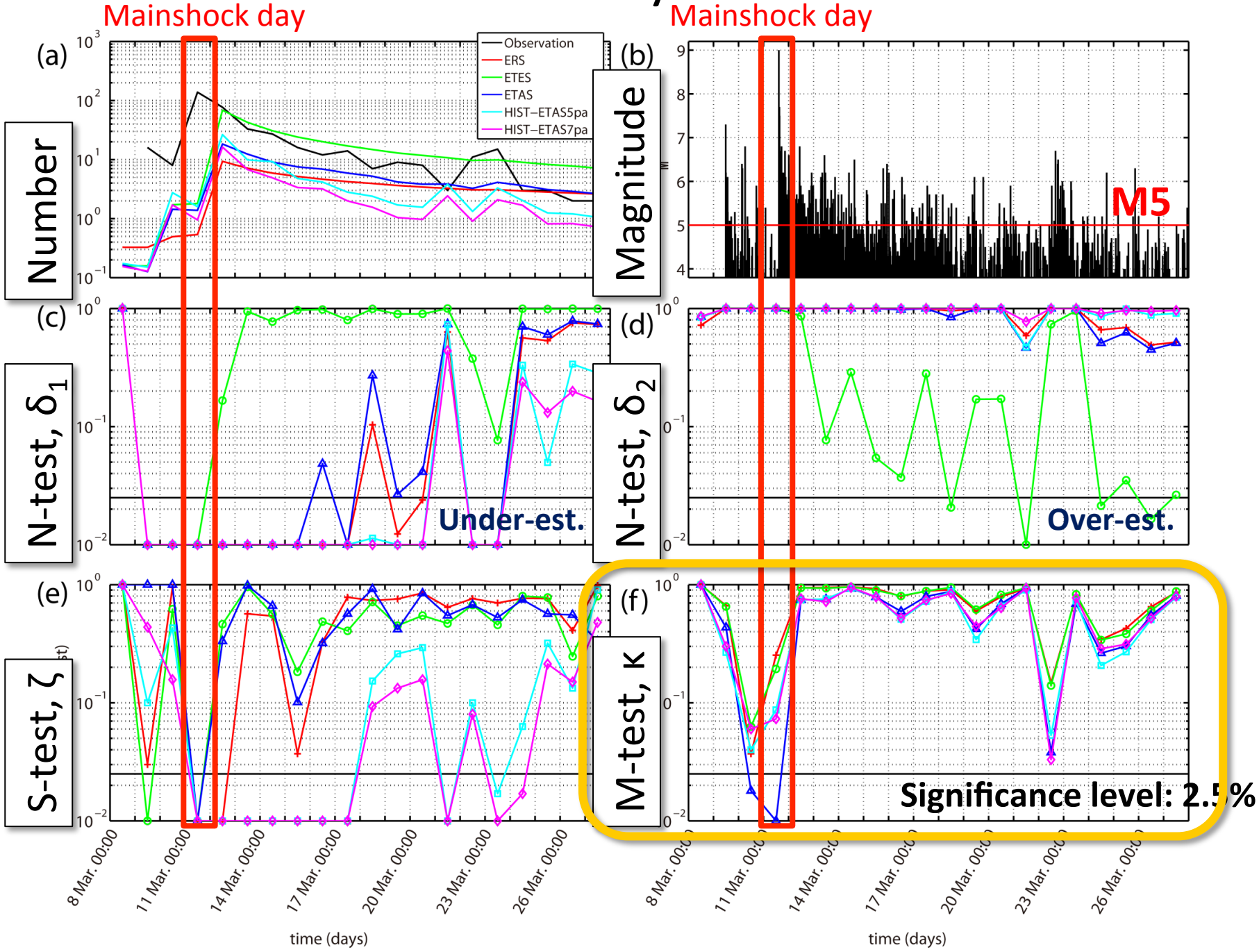
Assessment of one-day forecast models



Assessment of one-day forecast models

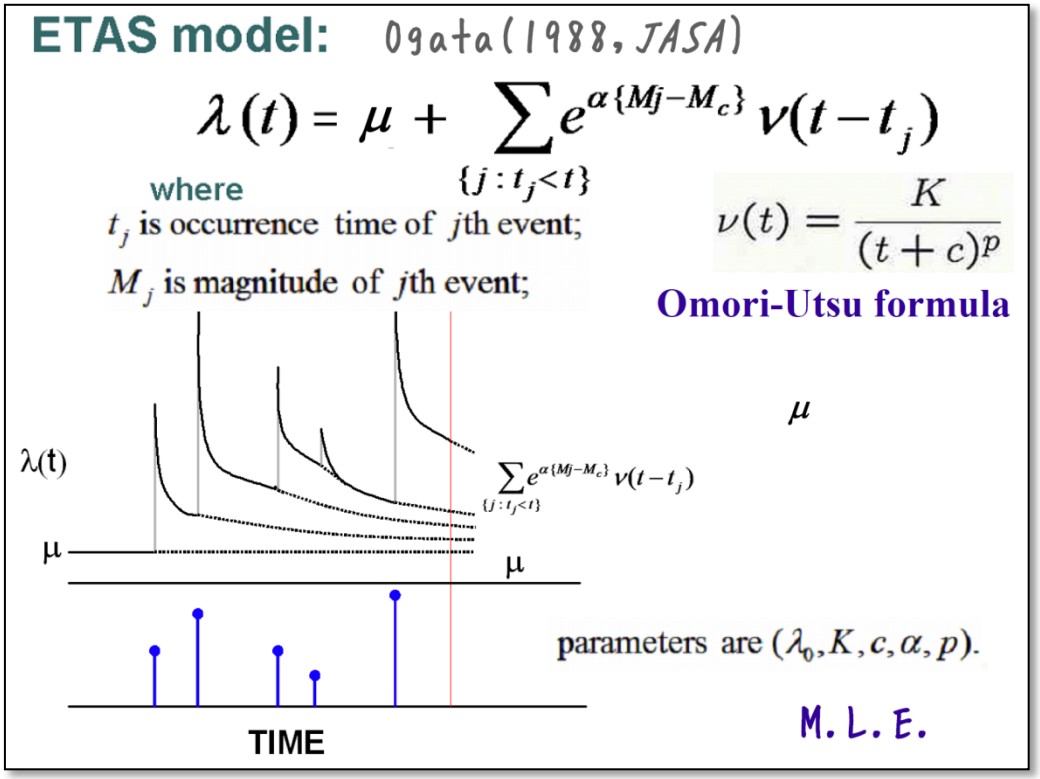


Assessment of one-day forecast models

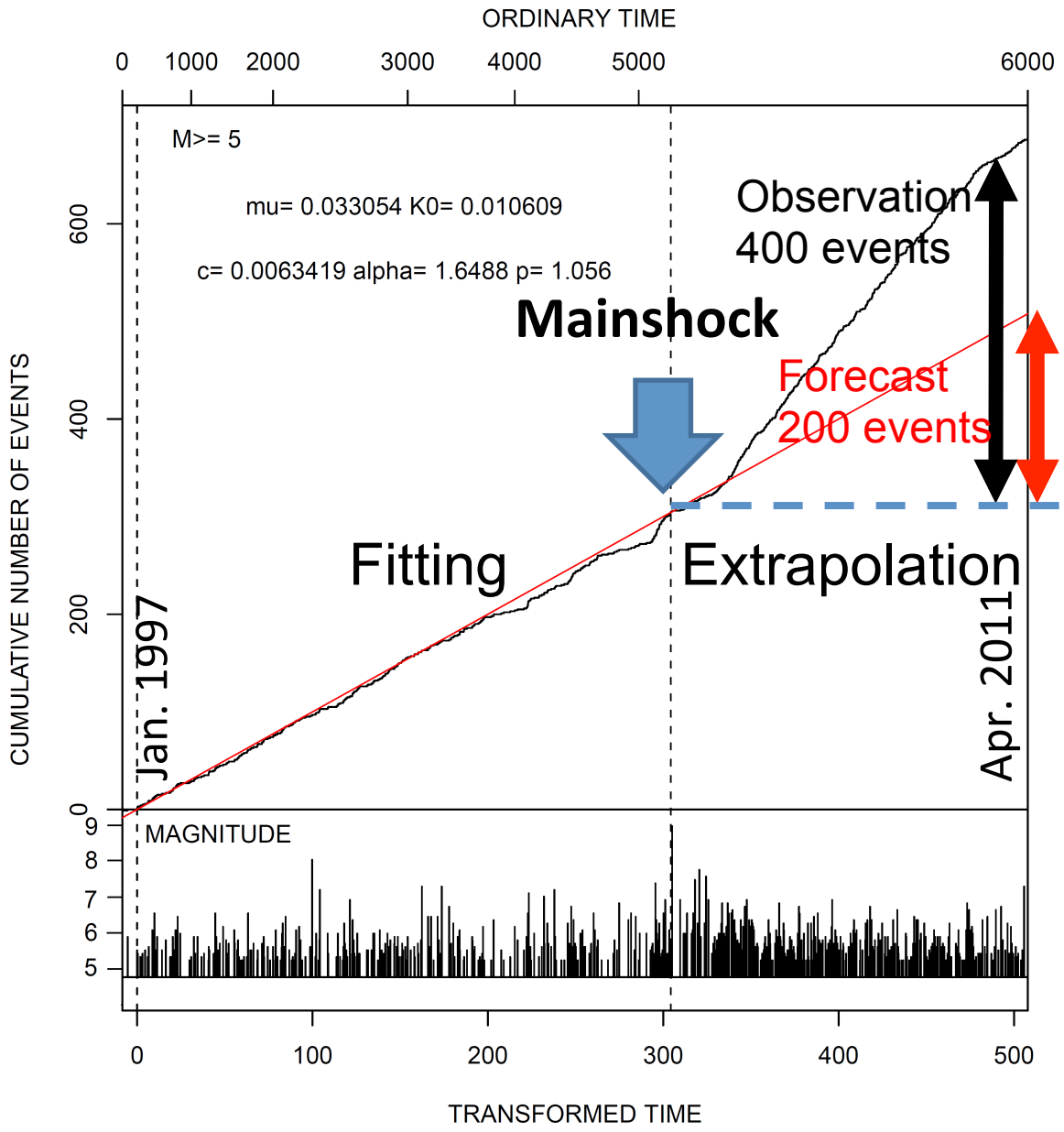


Why time delay?

- Improving forecast accuracy in active seismicity days
  - Updating forecasts more frequently than at one-day intervals
  - Refining a way to simulate immediate secondary aftershocks triggered by aftershocks that supposedly occur in the testing day
    - » Simulation introduced by Zhuang (2011)
    - » But need to be investigated in this approach



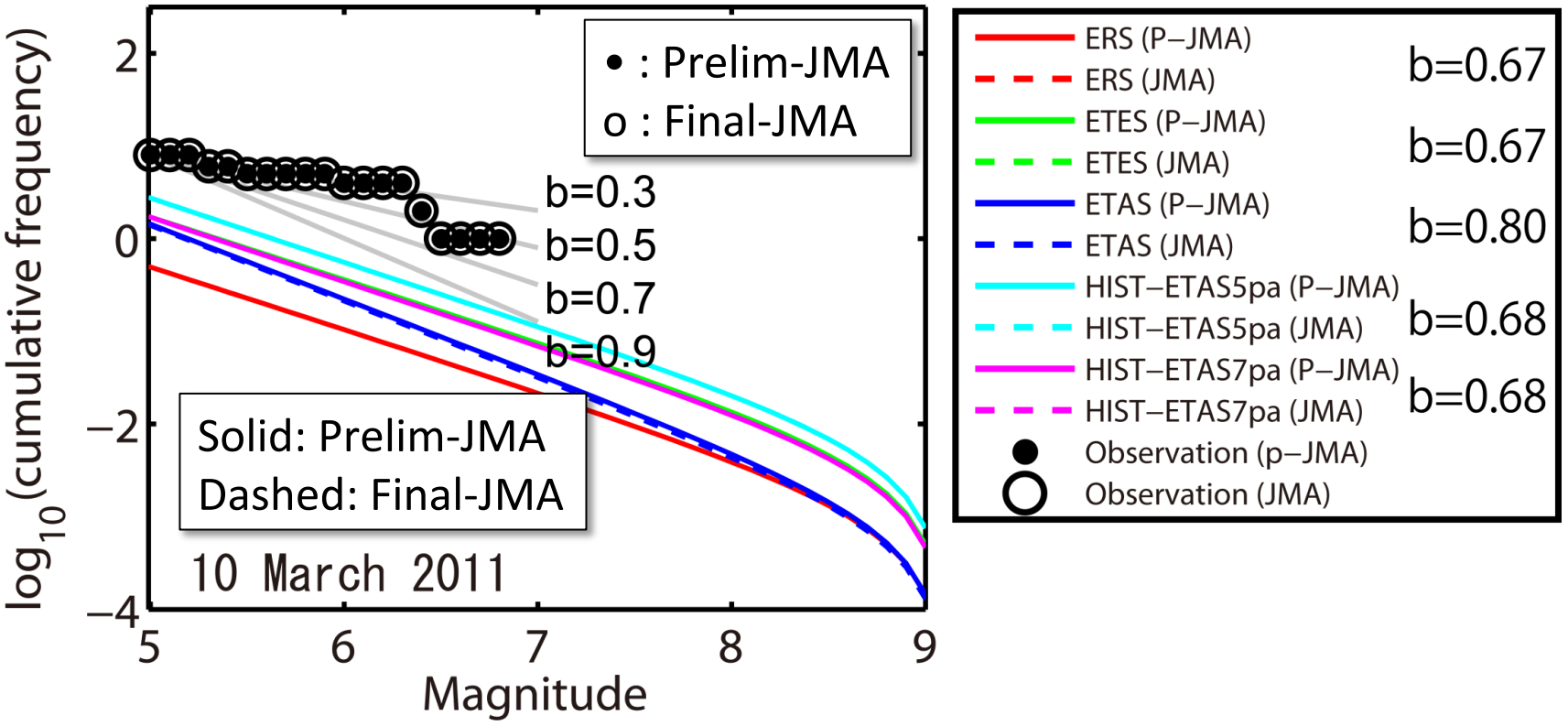
Why underestimate?



- ETAS fitting to seismicity in the aftershock region
  - Extrapolate the trend, taking the mainshock M9.0 into account
  - The mega-quake has remarkably high aftershock fertility
- Framework needed
  - Updating at shorter intervals
  - Flexible revising of model parameters with time

Catalog replacement

- It is unclear how well models perform scientifically
  - Replace the P-JMA catalog with the finalized JMA catalog (as of 12 Dec. 2011)
- No significant change in both forecast and observation
- No responsibility for the models' general tendency to underpredict the number of earthquakes



Summary

- This study differs from the CSEP tradition
  - Use P-JMA catalog, incomplete but immediately available
  - Toward operability-oriented forecasting
- Encouragingly, at least one model passed the test in most combinations of the target day and the testing method
  - Incomplete data used & No prior info on the mega-quake
  - But, important forecasts right after the quake are difficult
- Conclusion unchanged by replacing with finalized catalog
  - The models perform stably over the replacement
  - Further research to assure the reliability of forecasts right after main quakes
- Seismicity is expected to remain high in all parts of Japan
  - Urgently promote research on time-dependent earthquake predictability to prepare for subsequent earthquakes

Parameter		ETES[a]	ERS[a]	ETAS[b]	HIST-ETAS5pa[c]	HIST-ETAS7pa[c]
Model	p (decay parameter)	1.0004	N/A	1.149	Spatially varying 0.7-1.6	1.16
	b (frequency-magnitude distribution)[d]	0.73 (0.67)	1.00 (0.67)	(0.80)	Spatially varying 0.4-1.5 (0.6-0.9)	Spatially varying 0.4-1.5 (0.6-0.9)
	q (exponent of the spatial kernel)	1.84	1.50	1.71	Spatially varying 1.6-2.0	1.69
	$\Delta\tau_0$ (stress change) [Mpa]	N/A	0.003	N/A	N/A	N/A
	$A\sigma$ (multiplicative parameter) [Mpa]	N/A	0.0003	N/A	N/A	N/A
Input data[e,f]	Magnitude range	≥ 3.3	≥ 3.3	≥ 4.0	≥ 4.0	≥ 4.0
	Starting time	1 January 1978	1 January 1978	1 January 1965	1 October 1997[g]	1 October 1997[g]

[a]Parameter values are obtained from a parameter file in the model software.

[b]See Zhuang (2011) for details. No value in b is seen in Zhuang (2011).

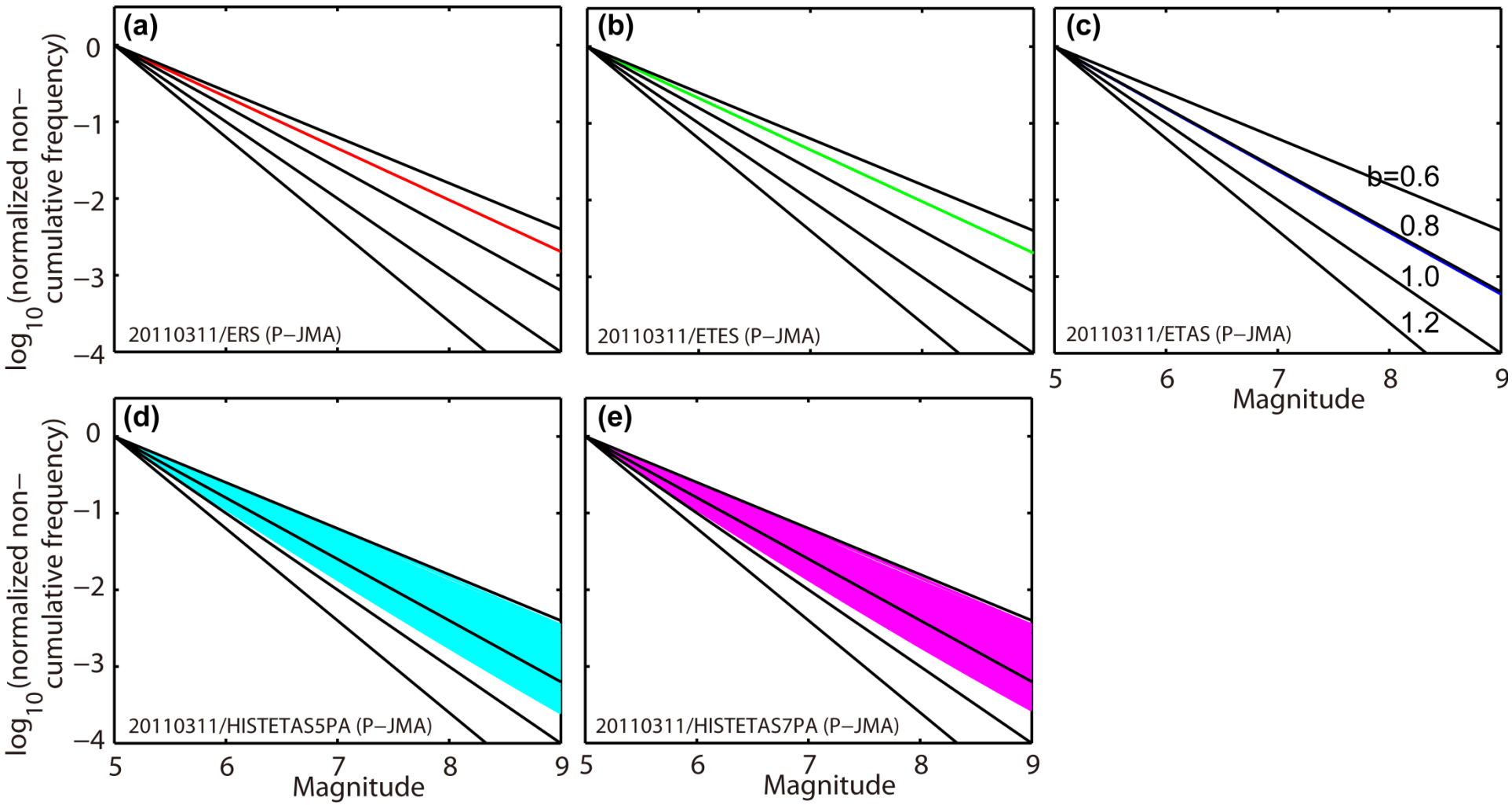
[c]See Ogata (2011) for details.

[d]Values in parentheses are for 11 March 2011 (Fig. S1). These resultant values are not necessarily equal to the initial inputs that are not parenthesized.

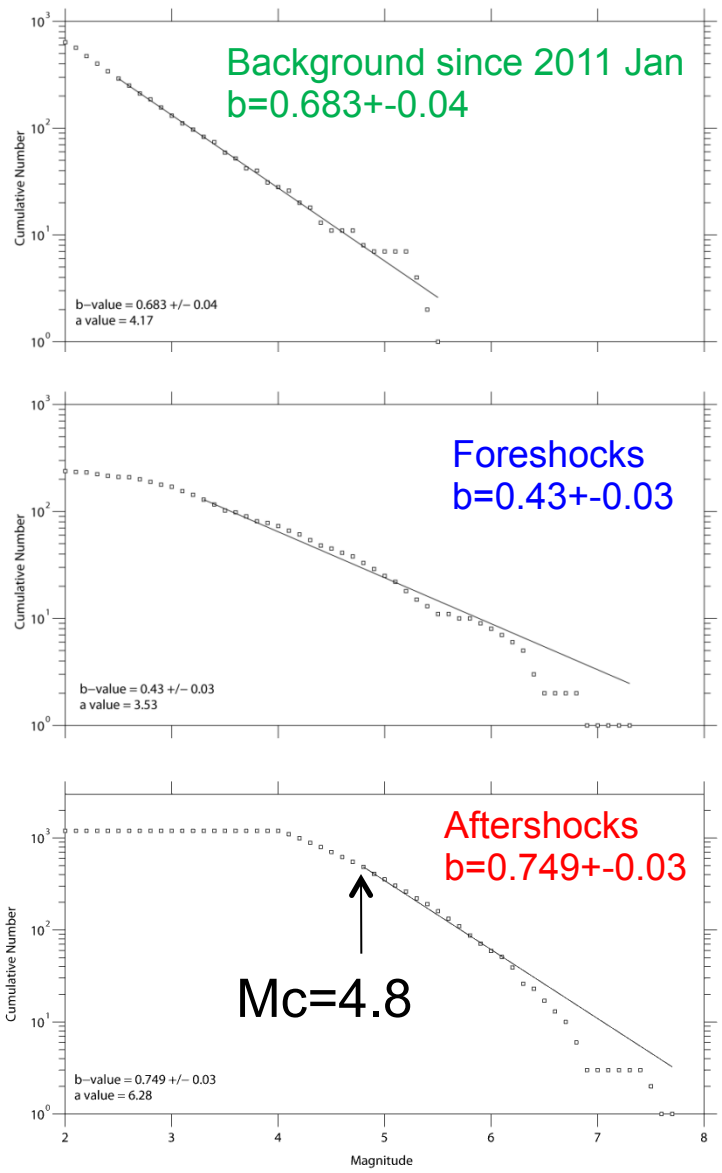
[e]The five models consider all earthquakes down to 100-km depth.

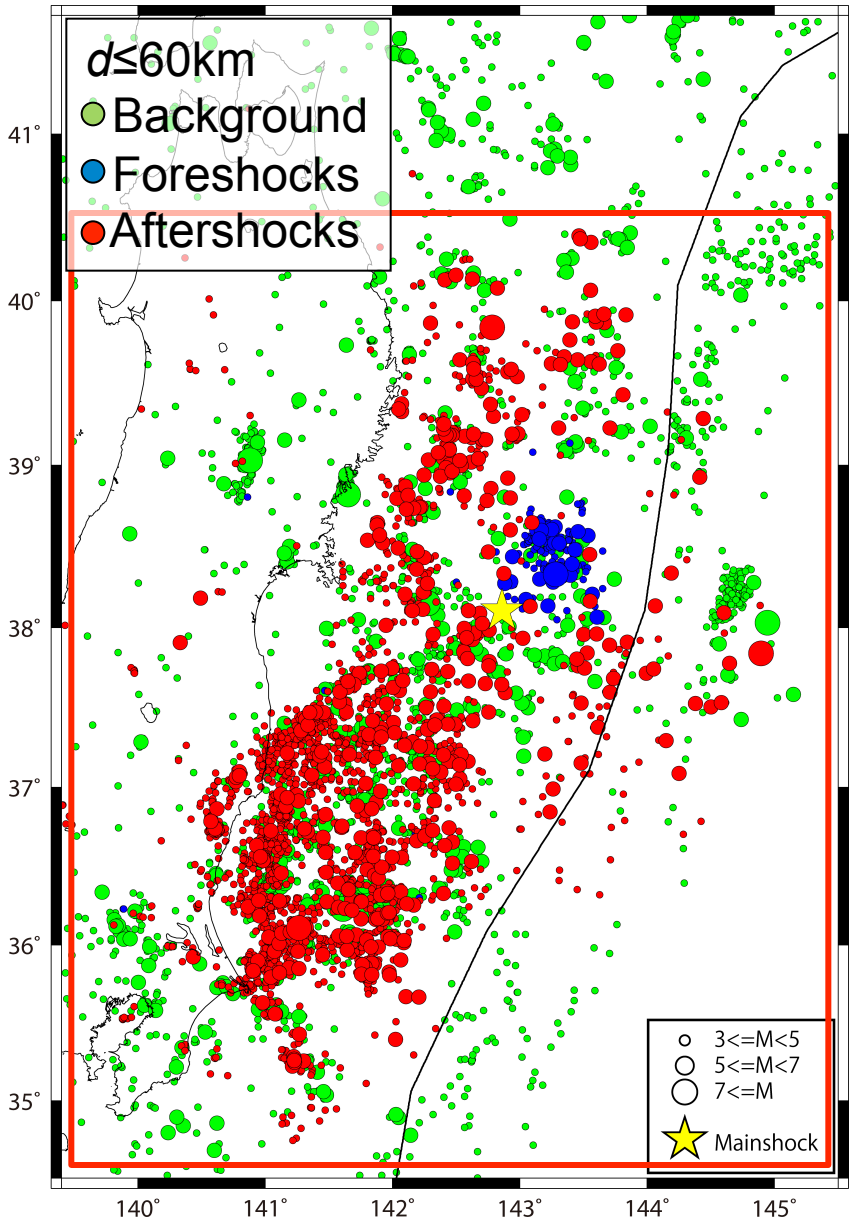
[f]The five models do not preprocess to remove earthquake clusters from the learning data (no catalog declustering).

[g]Dataset since 1885 up to September 1997 is also used as the history of the HIST-ETAS models.


(a)
(b)
(c)
(d)
(e)
log10(normalized non−cumulative frequency)
0
−1
−2
−3
−4
20110311/ERS (P−JMA)
20110311/ETES (P−JMA)
20110311/ETAS (P−JMA)
20110311/HISTETAS5PA (P−JMA)
20110311/HISTETAS7PA (P−JMA)
b=0.6
0.8
1.0
1.2
5
6
7
8
9
Magnitude

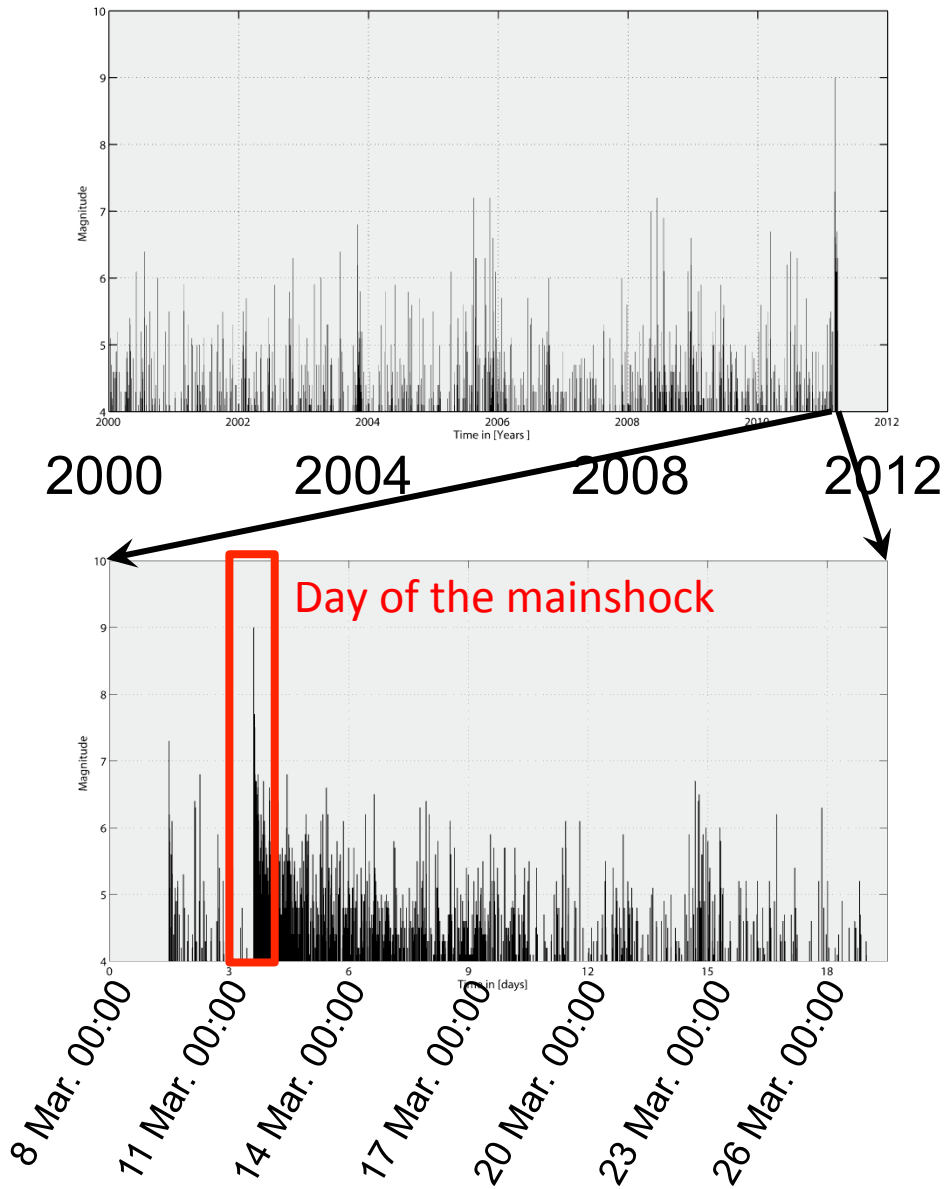
Seismicity before and after the quake

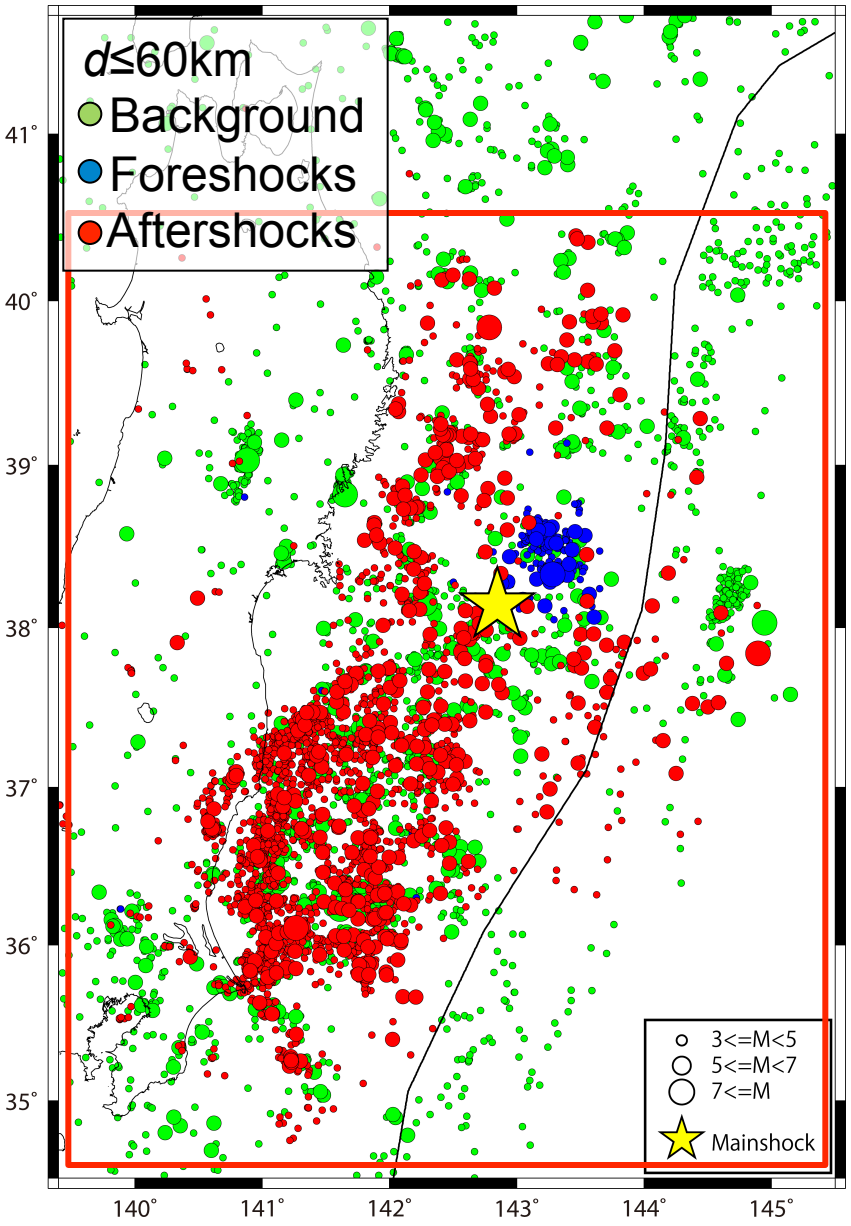


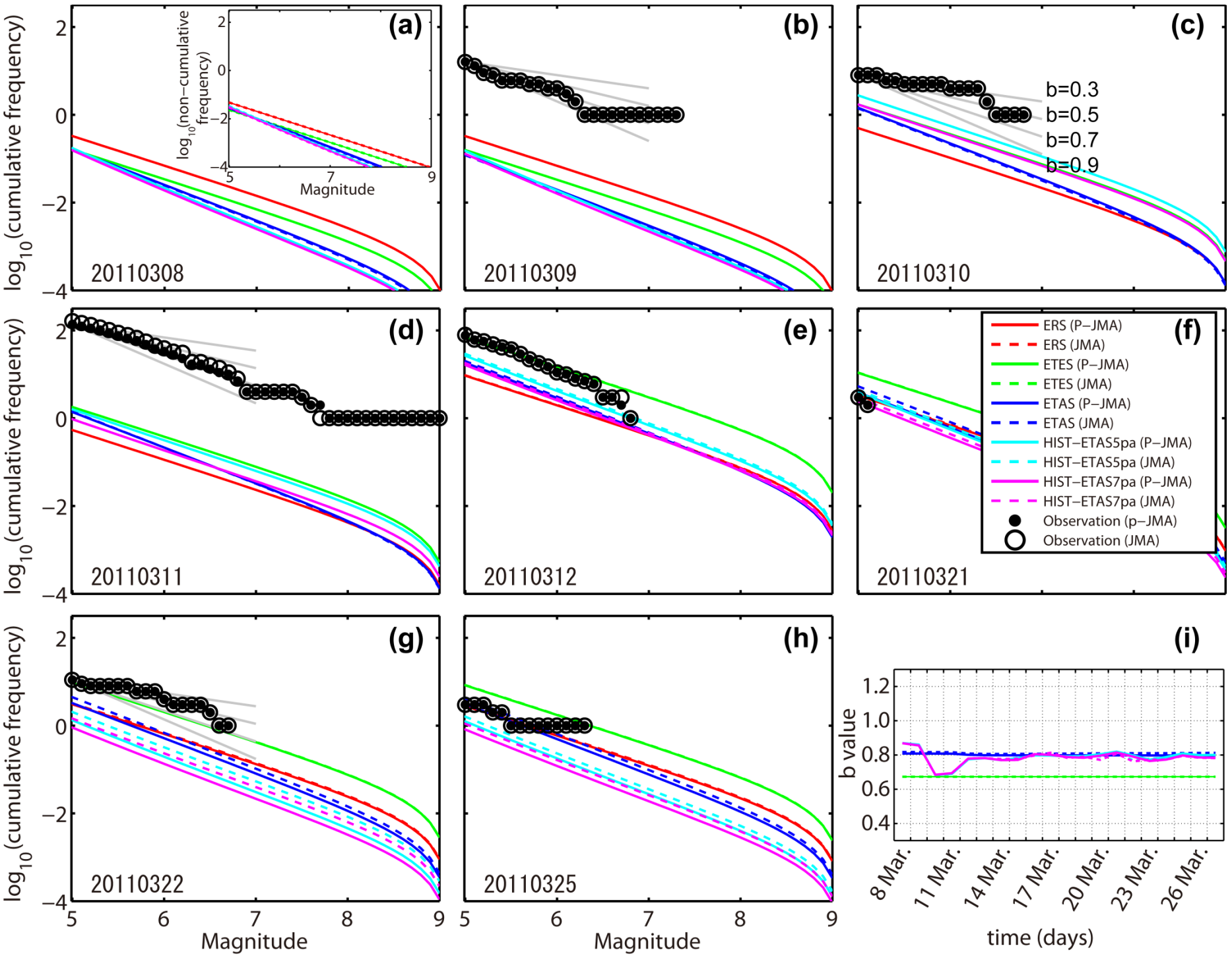


Nanjo et al. (2011)

Seismicity before and after the quake






(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
20110308
20110309
20110310
20110311
20110312
20110321
20110322
20110325
log10(cumulative frequency)
log10(non−cumulative frequency)
Magnitude
b=0.3
b=0.5
b=0.7
b=0.9
ERS (P−JMA)
ERS (JMA)
ETES (P−JMA)
ETES (JMA)
ETAS (P−JMA)
ETAS (JMA)
HIST−ETAS5pa (P−JMA)
HIST−ETAS5pa (JMA)
HIST−ETAS7pa (P−JMA)
HIST−ETAS7pa (JMA)
Observation (p−JMA)
Observation (JMA)
b value
8 Mar.
11 Mar.
14 Mar.
17 Mar.
20 Mar.
23 Mar.
26 Mar.
time (days)