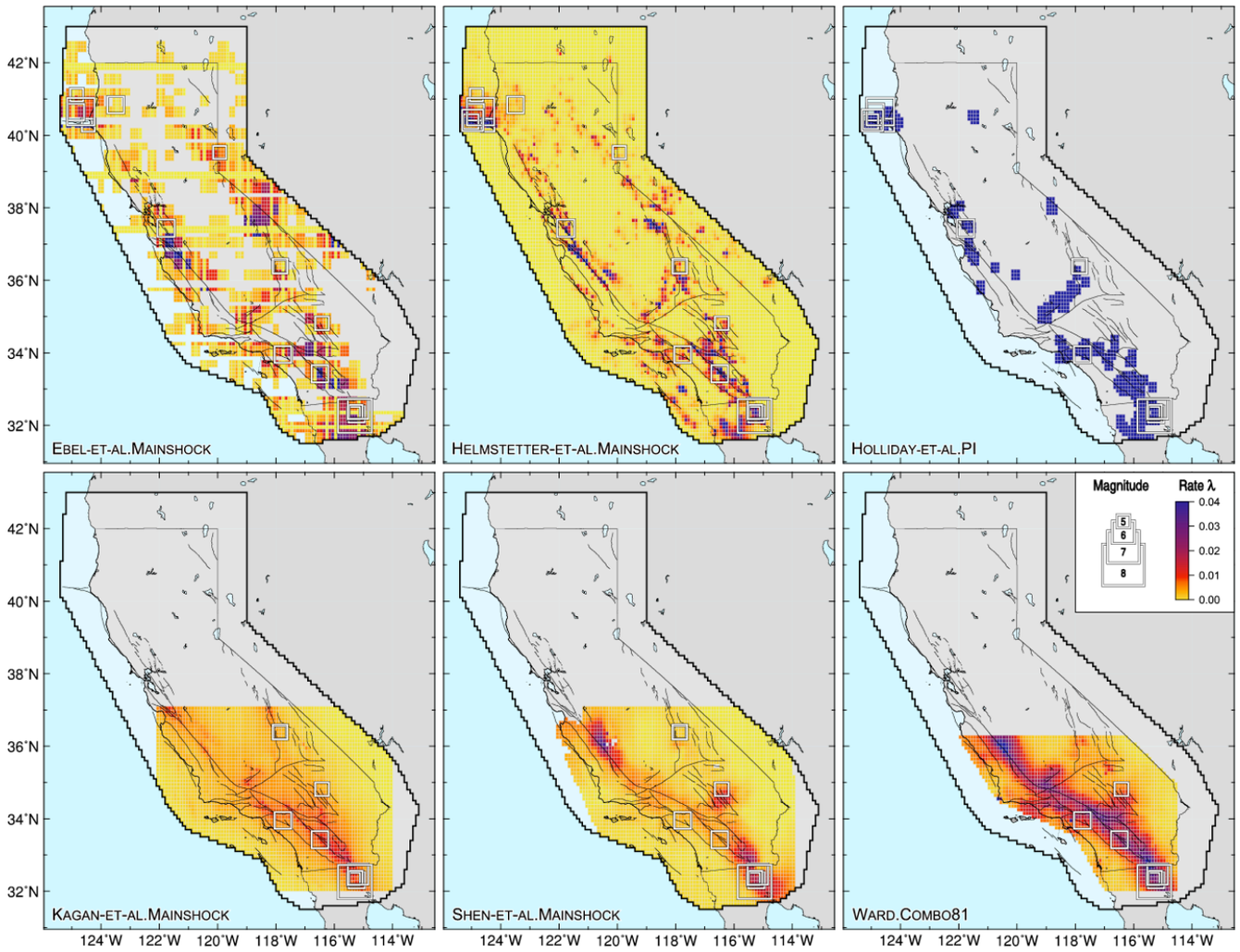
Earthquake Occurrence Hypotheses and the RELM Experiment

Negative-binomial rate fluctuations, conditional likelihood test results & retrospective testing



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Princeton University

CSEP workshop, Rancho Mirage, June 6, 2012

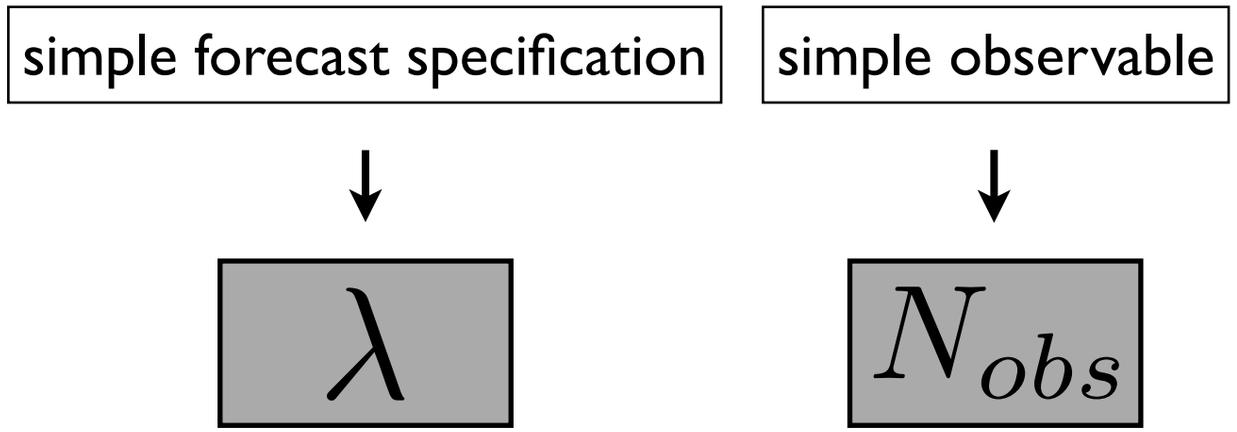
Outline & Conclusions

Seismicity fluctuations are not Poissonian.
N-test results using a negative-binomial distribution.

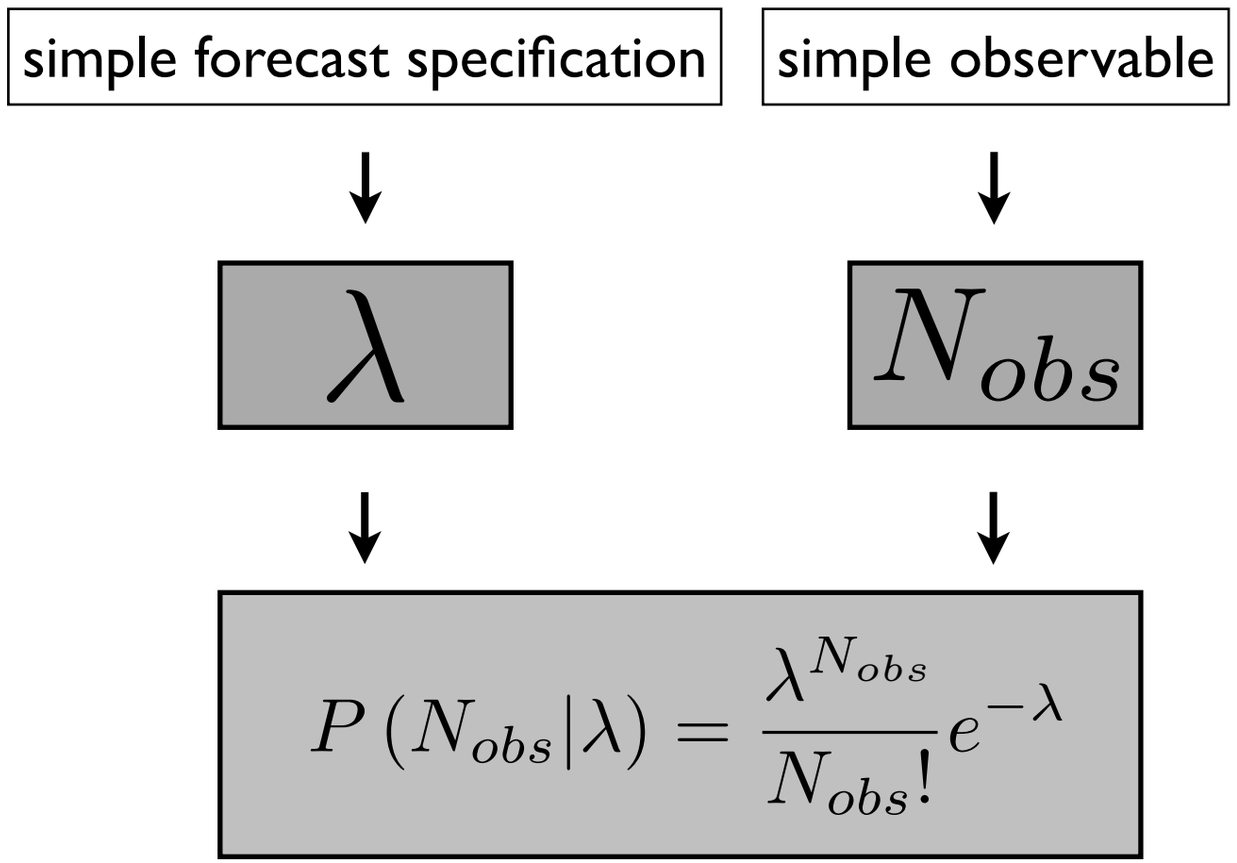
Revealing model strengths/weaknesses takes multiple tests.
Results from several conditional likelihood tests.

RELM results are “mostly” stable with respect to past data.
Results from retrospective testing.

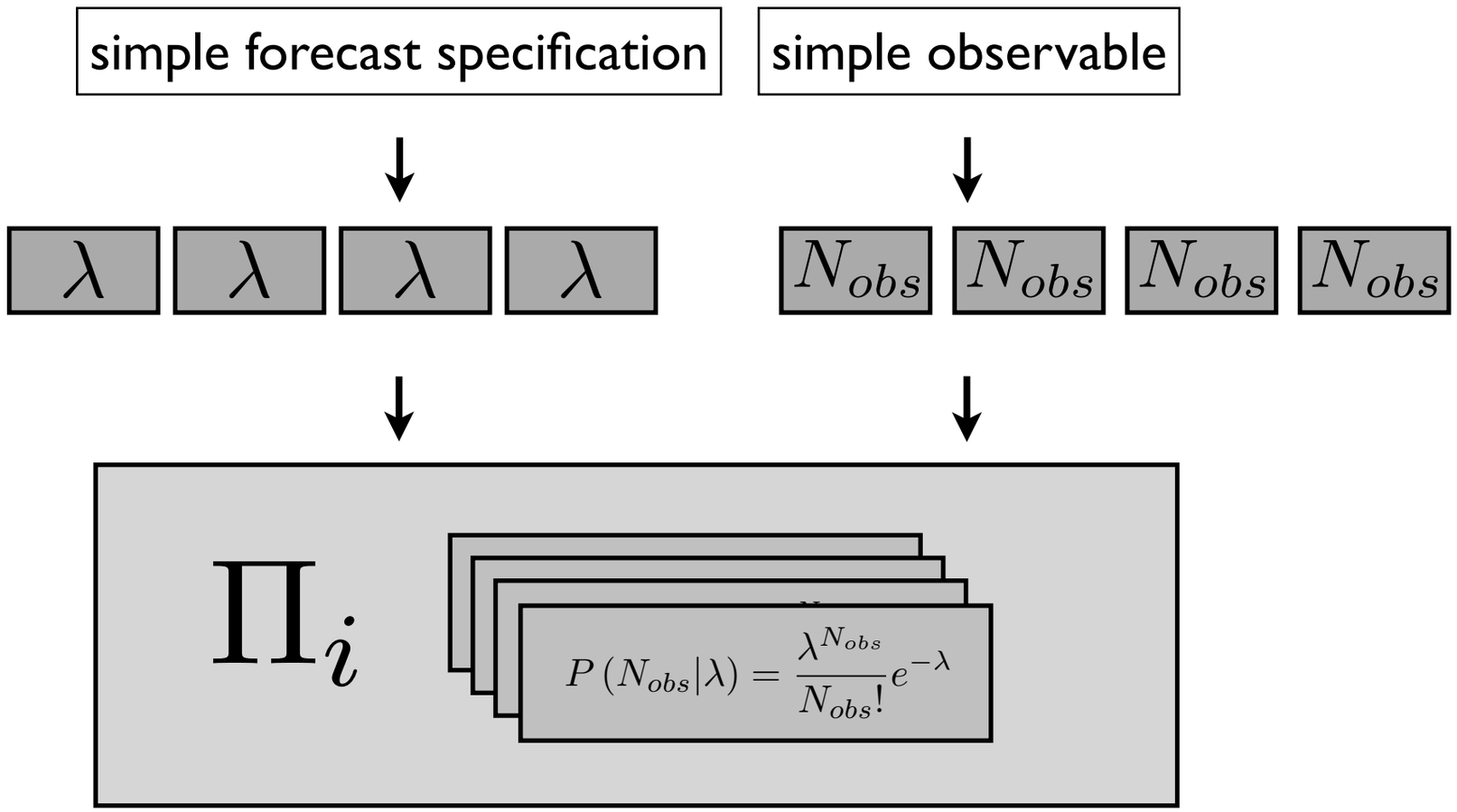
The Poisson forecast
specification is simple and intuitive.



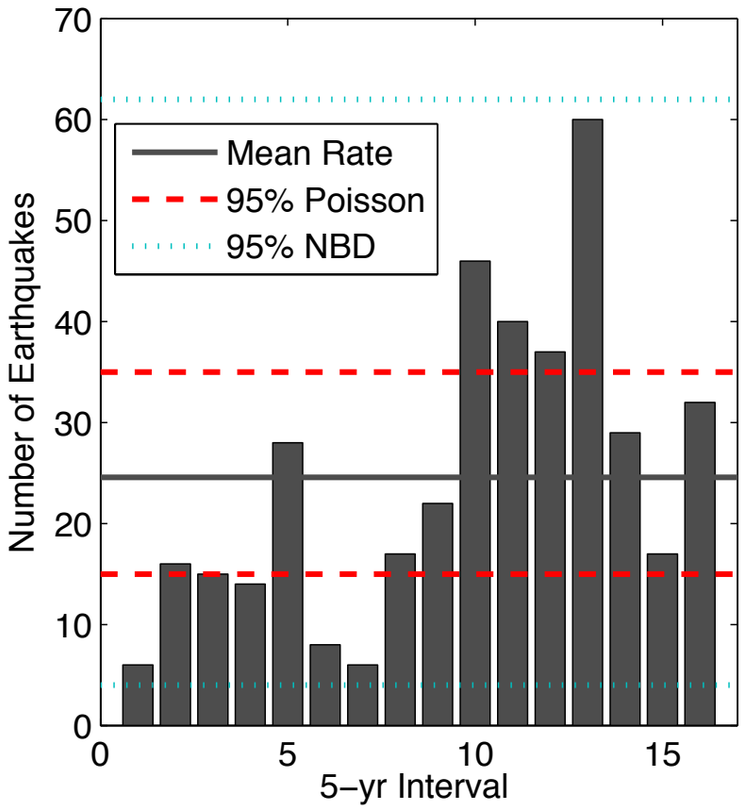
The comparison is simple and probabilistic.

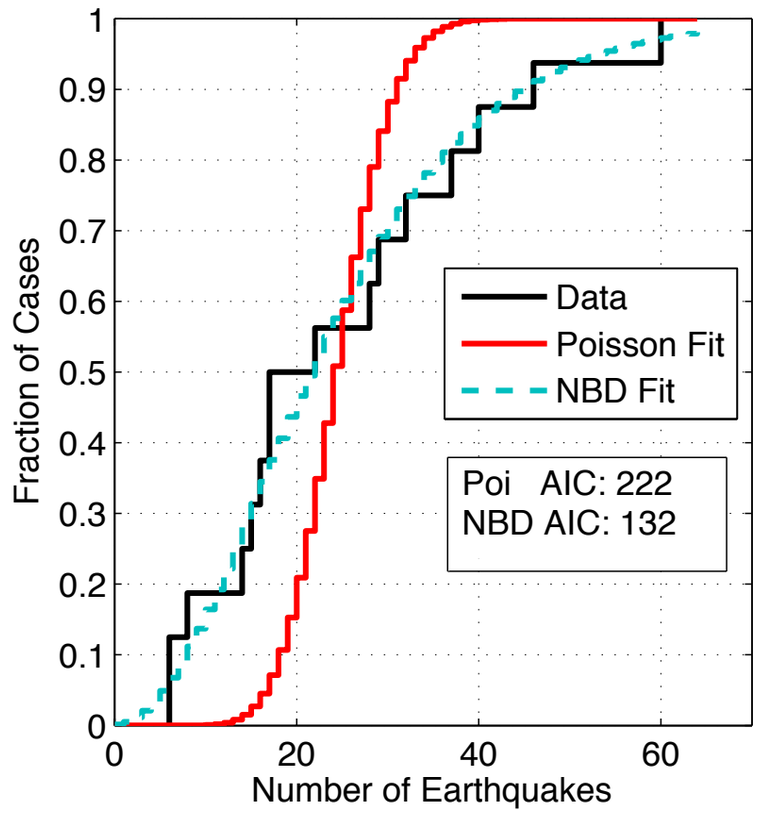


The Poisson grid allows for easy joint evaluations.



But 5yr rate fluctuations are not Poissonian.





Poisson

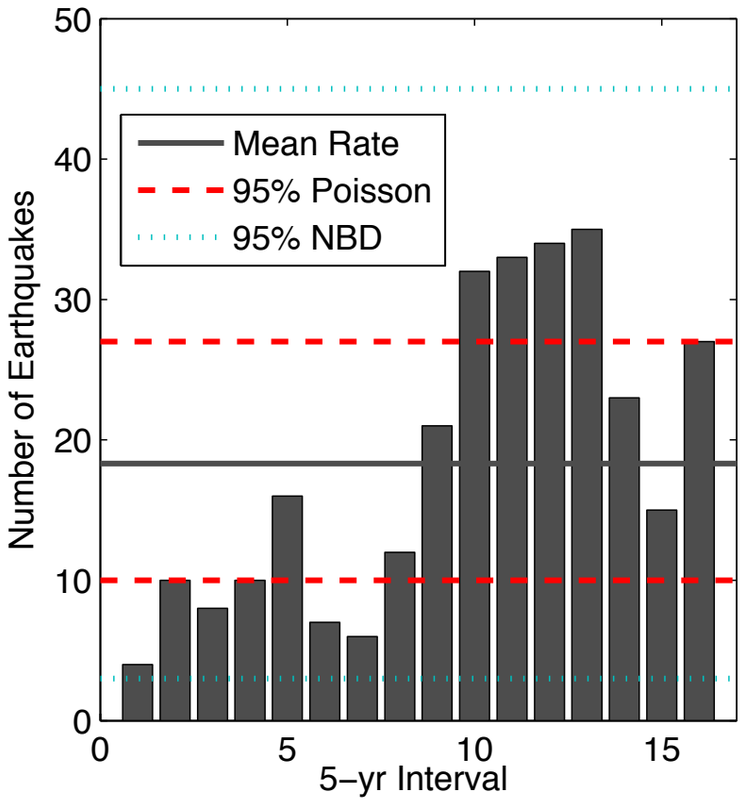
$$P\left(N_{obs}|\lambda\right) = \frac{\lambda^{N_{obs}}}{N_{obs}!}e^{-\lambda}$$

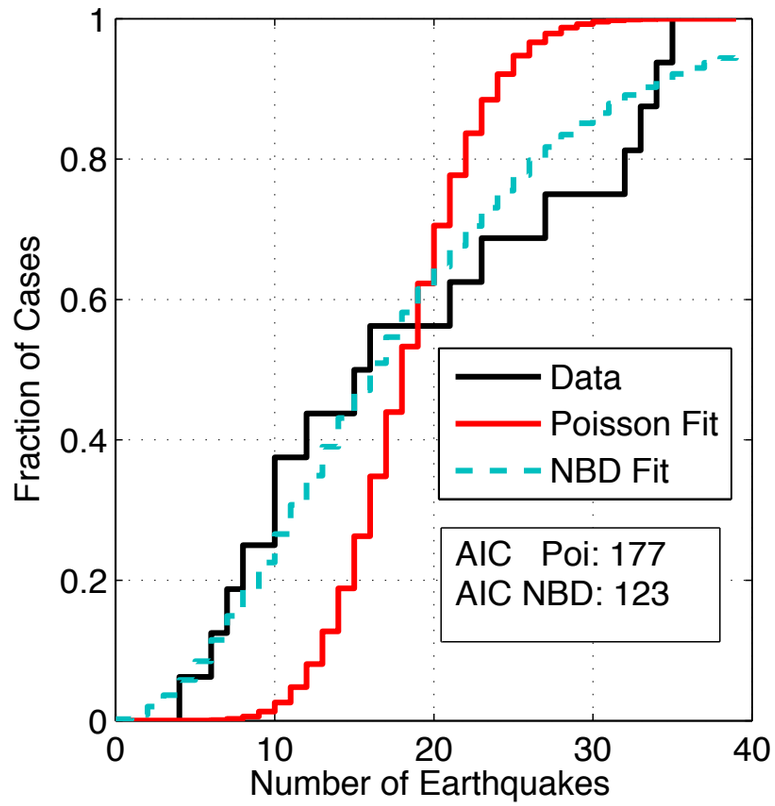
Negative binomial (NBD)

$$P(N_{obs}|\tau,\nu) = \frac{\Gamma(\tau + N_{obs})}{\Gamma(\tau)N_{obs}!}\nu^{\tau}(1-\nu)^{N_{obs}}$$

Not even when declustered.

[Reasenberg (1985) declustering with 'standard' parameters.]





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Negative-binomial forecasts

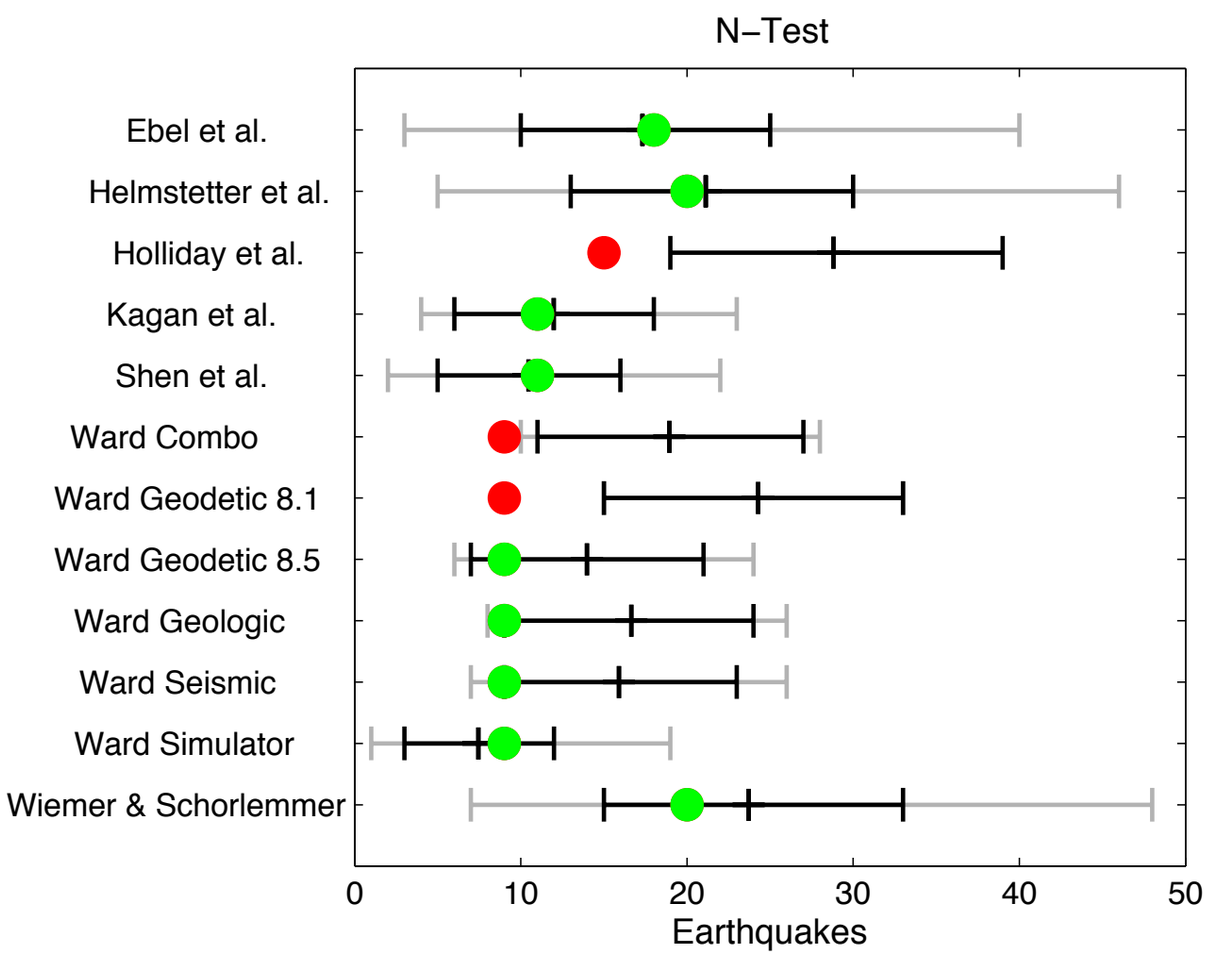
Instead of Poisson, use a better 5-yr rate distribution for the N-test.

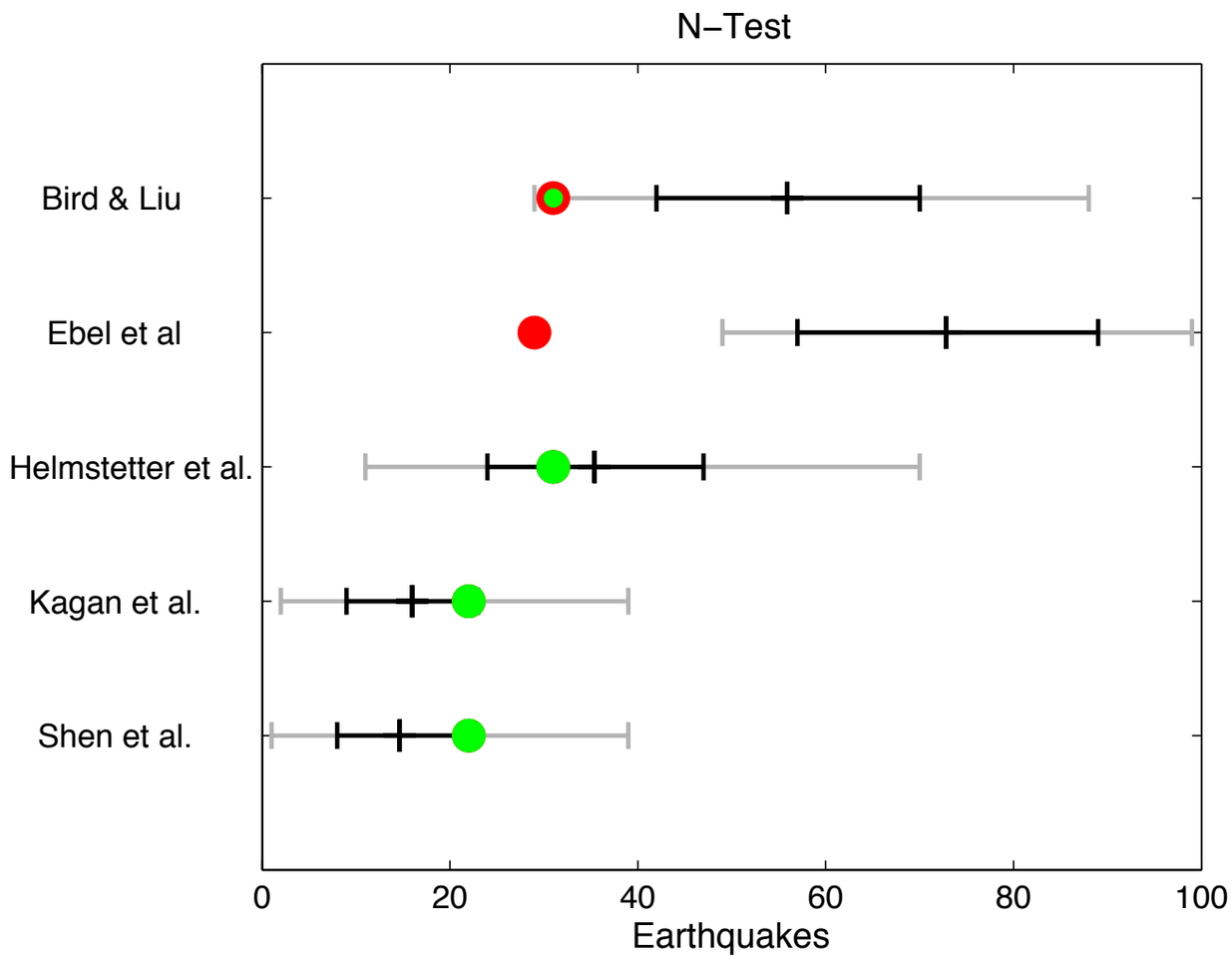
Negative-binomial distributions
means from forecasts' total expected number of earthquakes.
variances from observed 5-yr rate variability in unmasked regions

$$P(N_{obs}|\tau,\nu) = \frac{\Gamma(\tau + N_{obs})}{\Gamma(\tau)N_{obs}!}\nu^{\tau}(1-\nu)^{N_{obs}}$$

$$P\left(N_{obs}|\lambda\right) = \frac{\lambda^{N_{obs}}}{N_{obs}!}e^{-\lambda}$$

Negative-binomial N-tests.





The negative-binomial distribution (NBD) broadens uncertainties in most cases.
If the observed rate variance is smaller than the expected rate, NBD not defined.

No attempt to estimate rate variability in each cell - just the whole region.

We should ask modelers to provide rate distributions.

Outline & Conclusions

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RELM results are "mostly" stable with respect to past data.
Results from retrospective testing.

Additional conditional likelihood tests.

Conditional Likelihood Score (cL-Test):
Given the observed number of earthquakes,
is the observed joint likelihood score of
locations & magnitudes
consistent with the expected score?

compared with the S-test by Zechar et al., 2010:
Given the observed number of earthquakes,
is the observed marginal likelihood score of
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Given the observed number of earthquakes,
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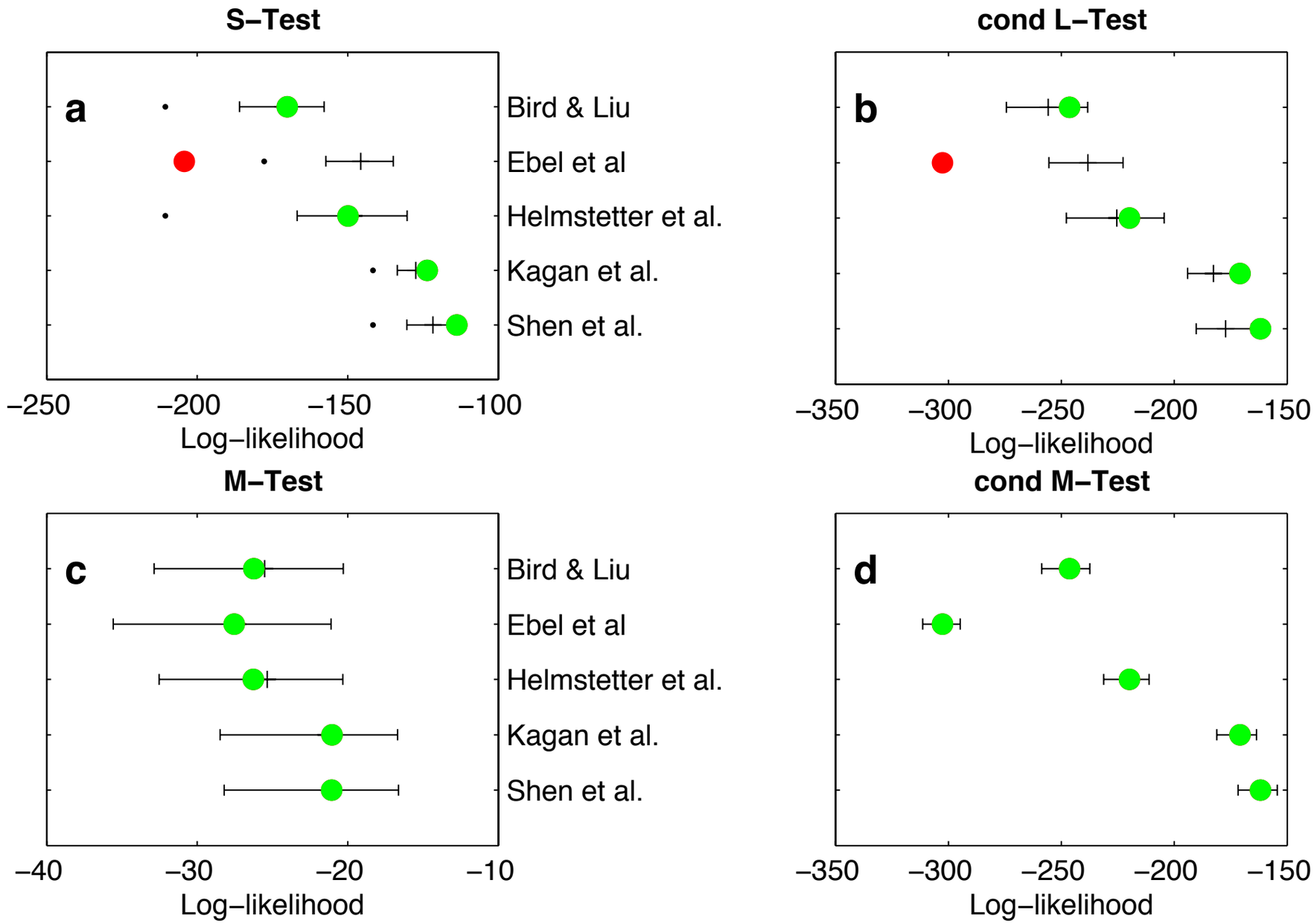
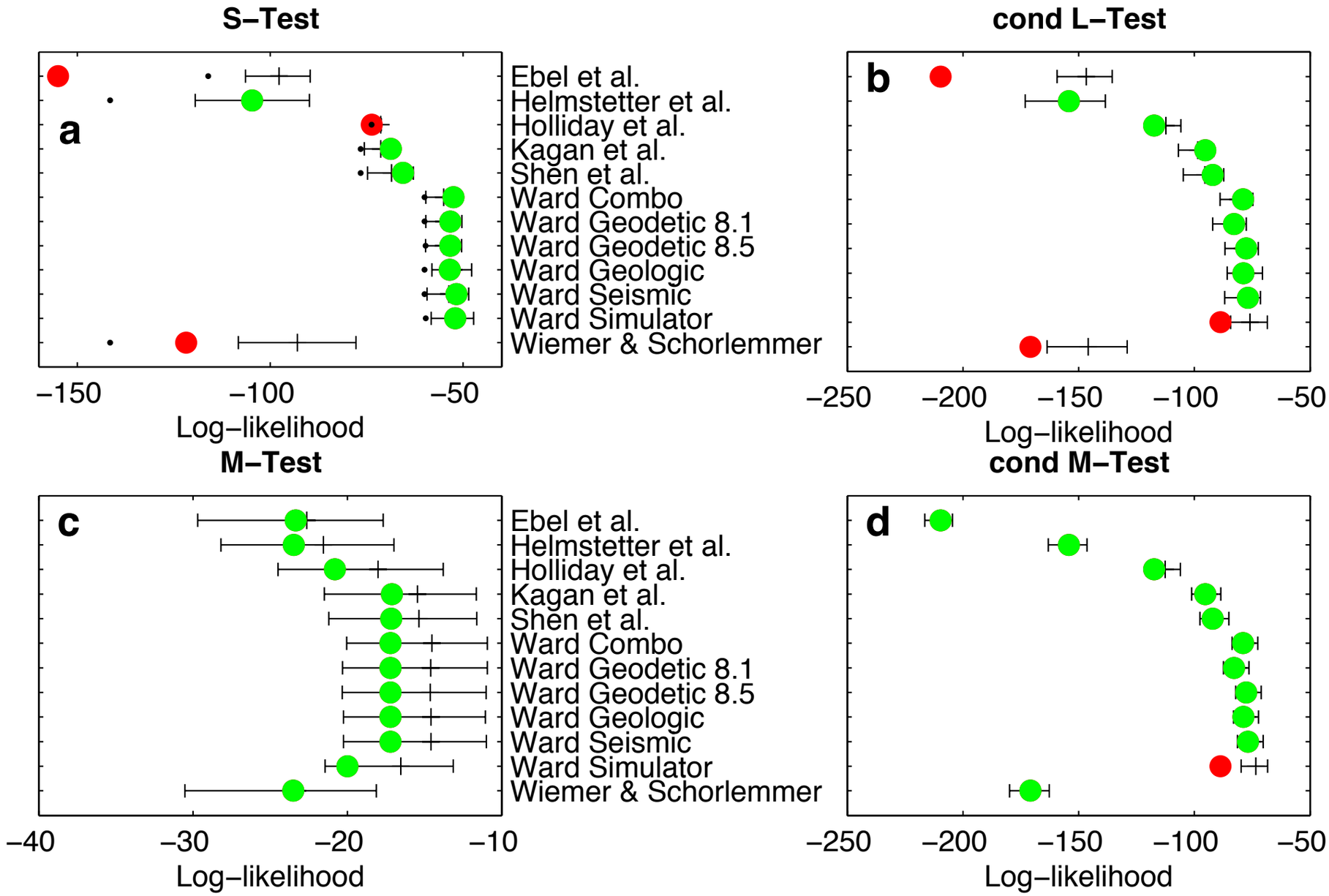
Conditional Magnitude Score (cM-Test):
Given the observed number and the observed locations of earthquakes,
is the observed joint likelihood score of
locations and magnitudes
consistent with the expected score?

compared with the M-test by Zechar et al., 2010:
Given the observed number and the observed locations of earthquakes,
is the observed marginal likelihood score of
magnitudes
consistent with the expected score?

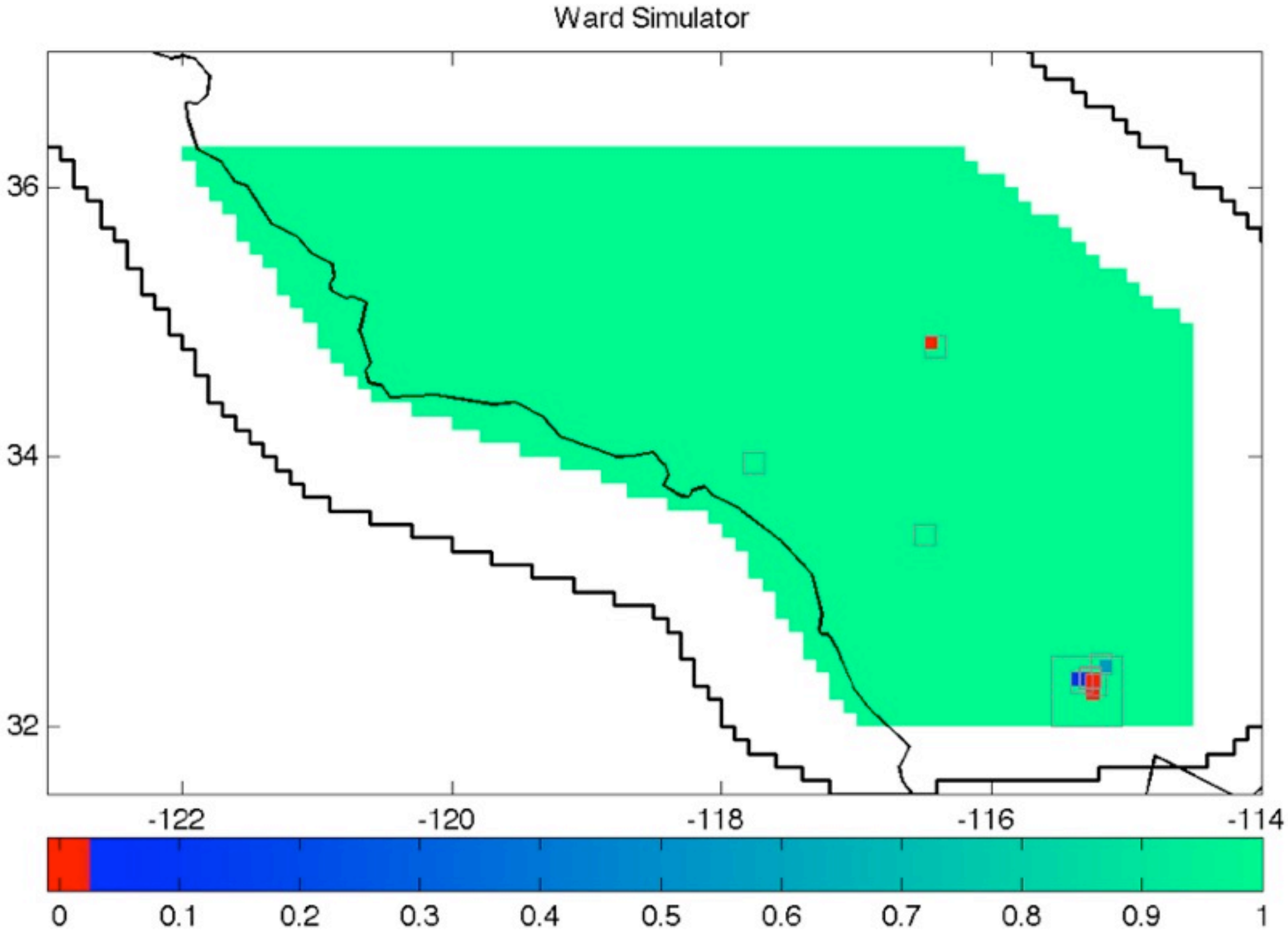
No additional weaknesses in ms+as class.



Conditional likelihood tests reveal model weaknesses.

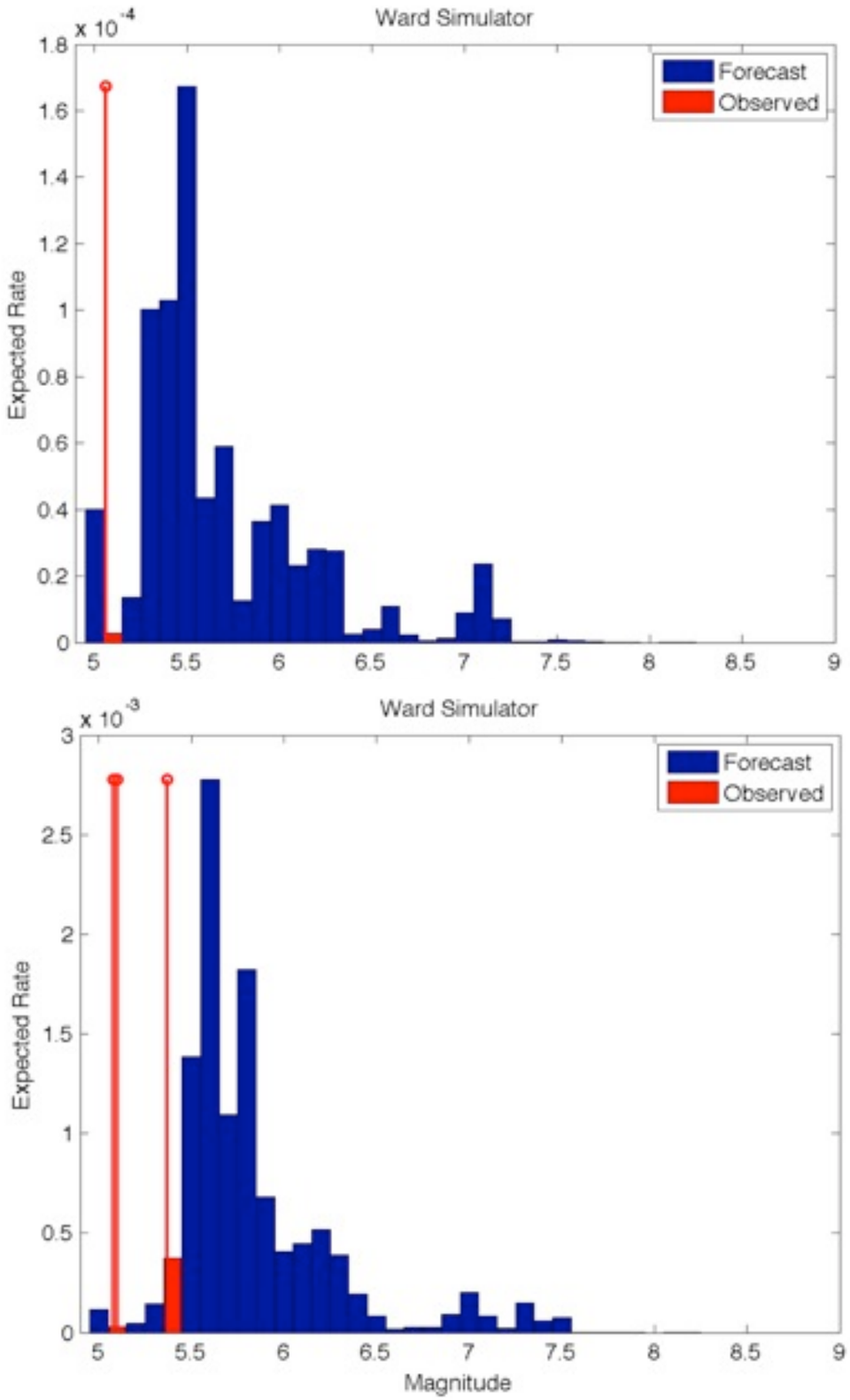


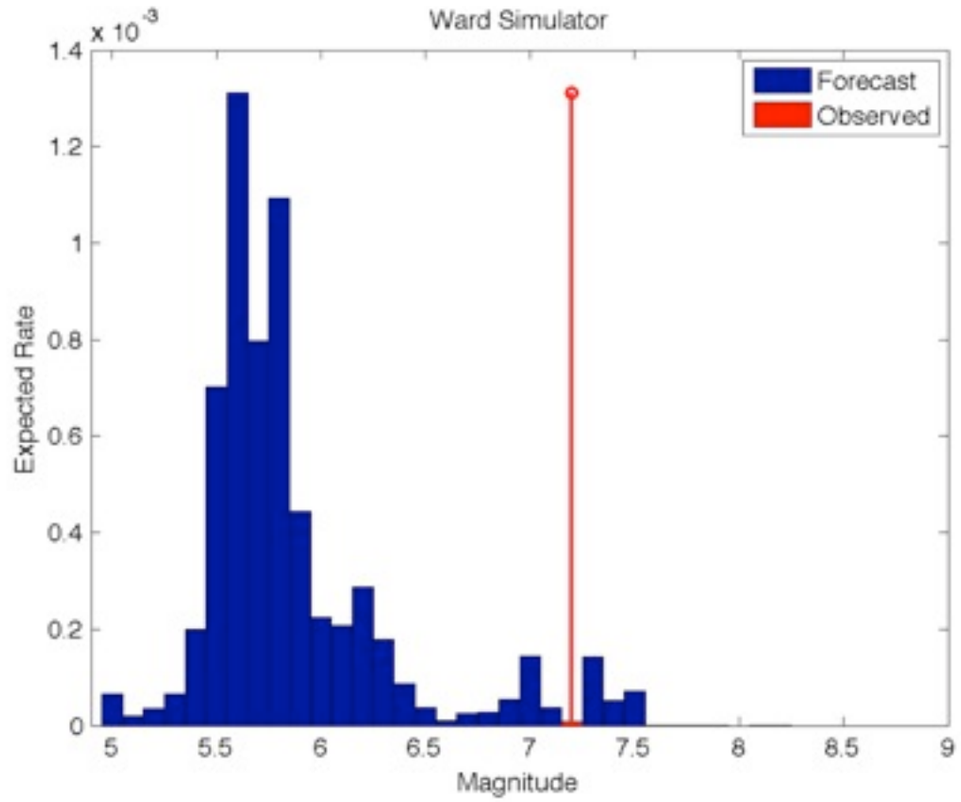
Where do problematic magnitudes occur?



Conditional M-test quantile (per spatial bin)

Where do problematic magnitudes occur?





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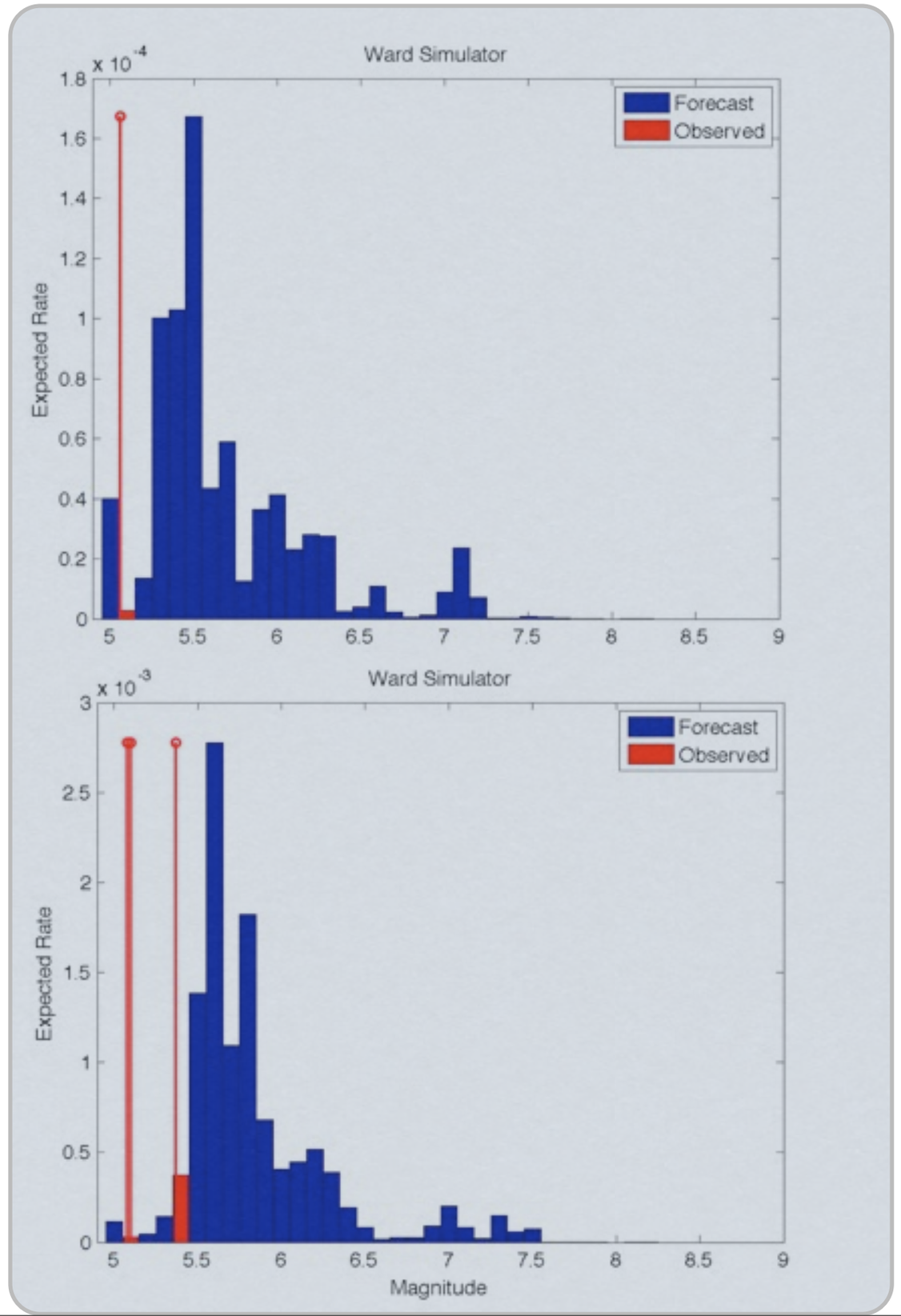

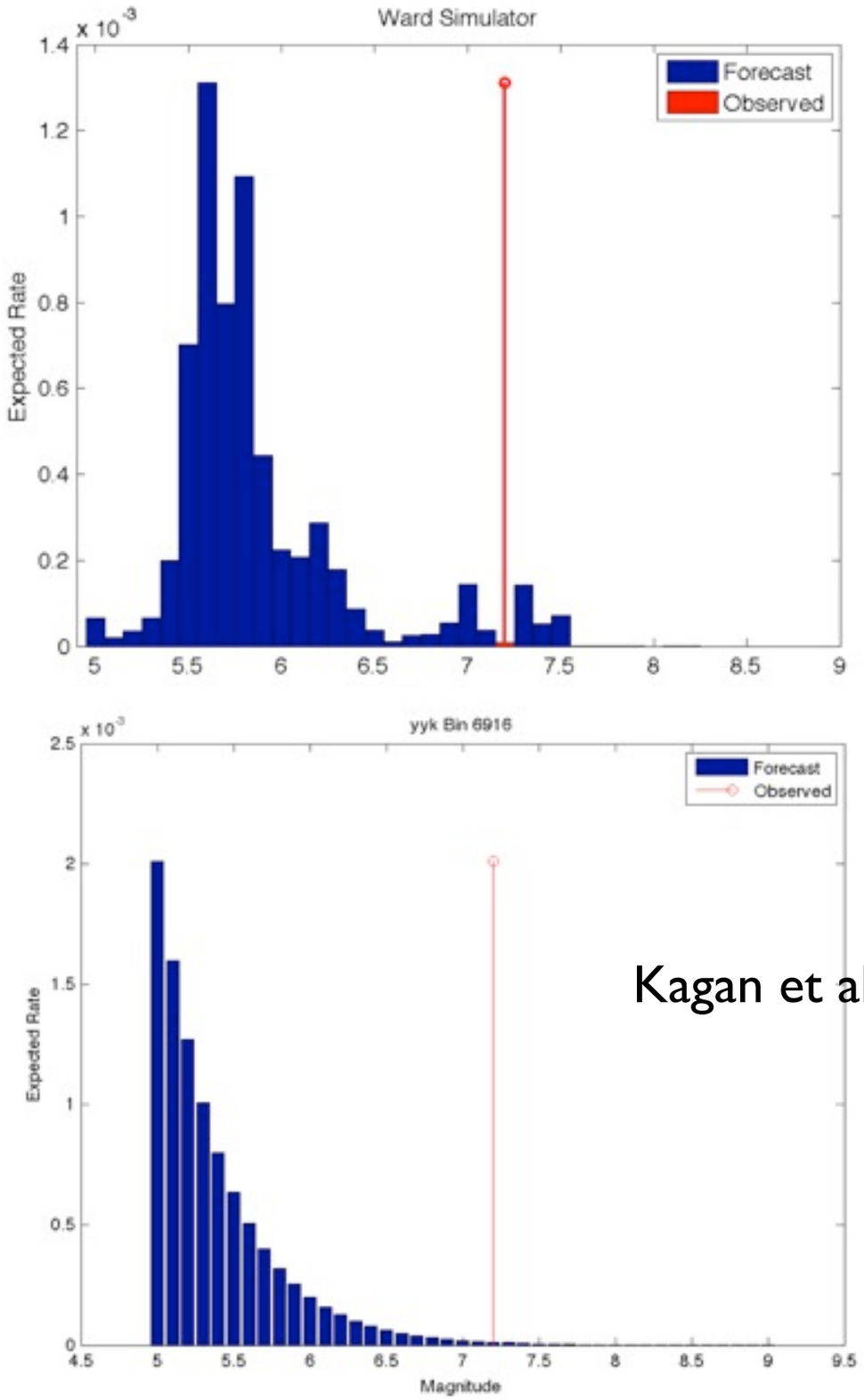

Kagan et al.

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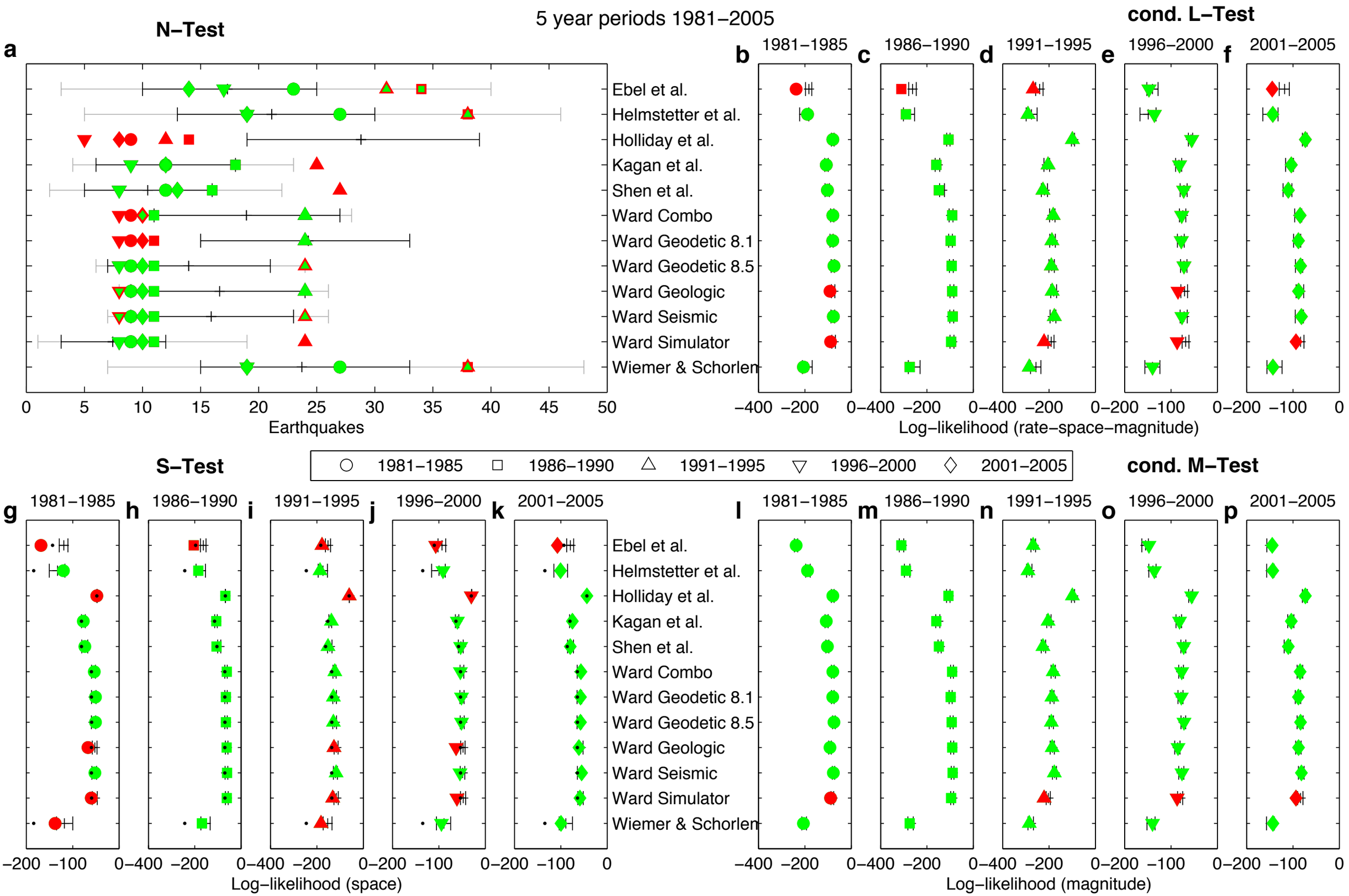
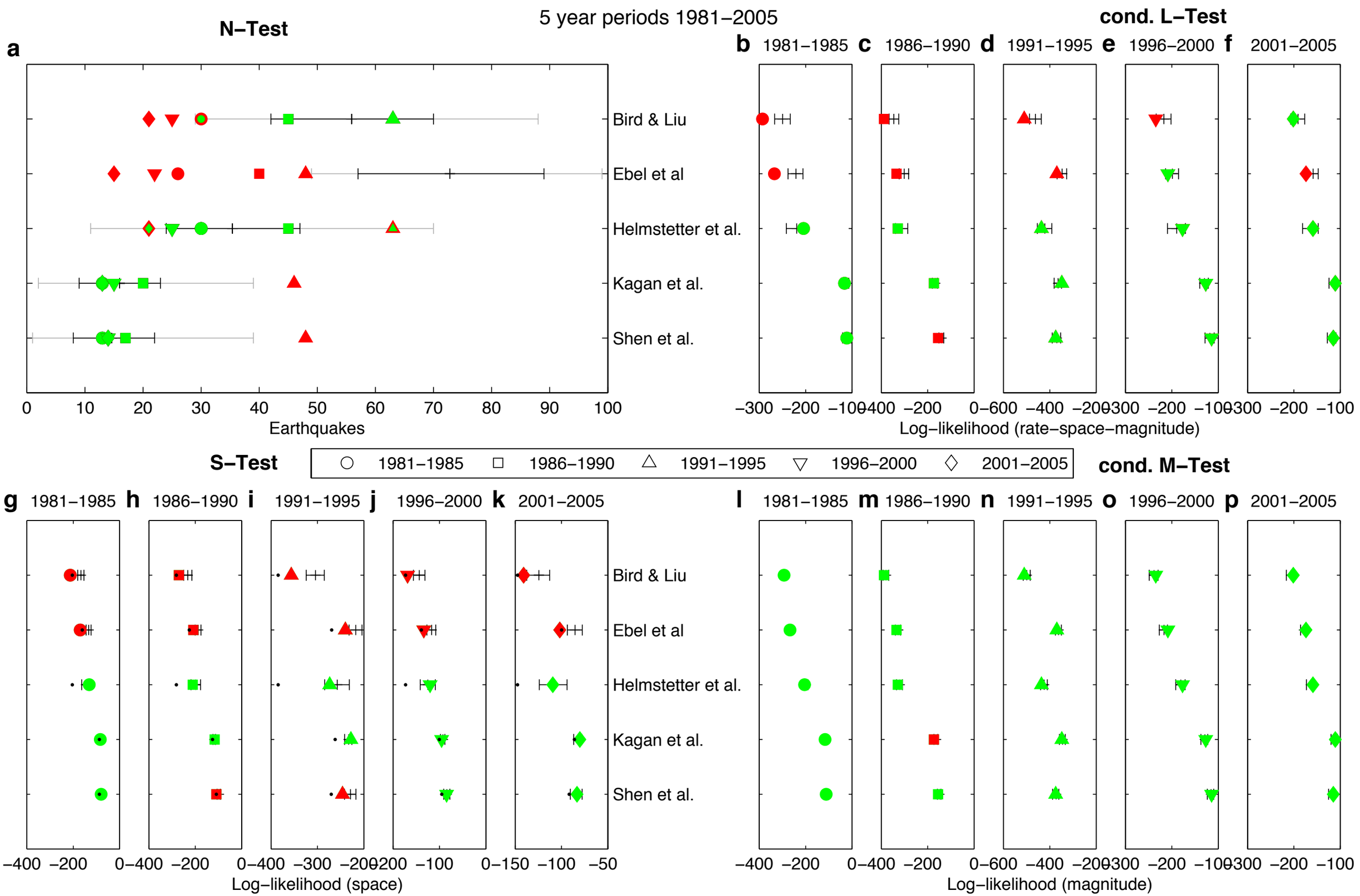
Retrospective Testing: Mainshocks



Summary of failed tests of mainshock forecasts

	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010
Ebel et al.	cL, S	cL, S	cL, S	S	cL, S	cL, S
Helmstetter et al.						
Holliday et al.	N, S	N	N, S	N, S	N	N, S
Kagan et al.			N			
Shen et al.			N			
Ward combo				N	N	N
Ward geodetic 8.1	N	N		N	N	N
Ward geodetic 8.5						
Ward geologic	cL, S		S	cL, S		
Ward seismic						
Ward simulator	cL, S, cM		N, cL, S, cM	cL, S, cM	cL, cM	cL, cM
Wiemer & Schorlemmer	S		S			cL, S

Retrospective Testing: ms+as



Summary of failed tests of ms+as forecasts

	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010
Bird & Liu	cL, S	cL, S	cL, S	N, cL, S	N, S	
Ebel et al.	N, cL, S	N, cL, S	N, cL, S	N, S	N, cL, S	N, cL, S
Helmstetter et al.						
Kagan et al.		cM	N			
Shen et al.		cL, S	N, S			

Summary Results

Mainshocks:

Ebel et al. is inconsistent with spatial distribution.
Helmstetter et al. passes all tests.
Holliday et al. overpredicts and fails 4 of 6 S-tests.
Kagan et al. underpredicts once, and passes all other tests.
Shen et al. underpredicts once, and passes all other tests.
Ward combo overpredicts because Ward geodetic 8.1 overpredicts.
Ward geodetic 8.1 overpredicts, but passes all cL, S, M, cM tests.
Ward geodetic 8.5 passes all tests.
Ward geologic fails 3 of 6 S-tests.
Ward simulator fails 3 of 6 S-tests, and 5 of 6 cM-tests.
Ward seismic passes all tests.
Wiemer & Schorlemmer fails 3 of 6 S-test.

Mainshocks+aftershocks:

Bird & Liu overpredicts twice and fails 5 of 6 S-tests (not the RELM period).
Ebel et al. overpredicts and fails all S-tests.
Helmstetter et al. passes all tests.
Kagan et al. underpredicts once and fails cM test once.
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Summary Results: Geodetic Models

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Summary Results: Simulators

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Summary Results: Fault-Based Models

Mainshocks:

Ebel et al. is inconsistent with spatial distribution.
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Ward simulator fails 3 of 6 S-tests, and 5 of 6 cM-tests.
Ward seismic passes all tests.
Wiemer & Schorlemmer fails 3 of 6 S-test.

Mainshocks+aftershocks:

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Ebel et al. overpredicts and fails all S-tests.
Helmstetter et al. passes all tests.
Kagan et al. underpredicts once and fails cM test once.
Shen et al. underpredicts once and fails S-test twice.

Summary Results: Seismicity-Based Models

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Ward simulator fails 3 of 6 S-tests, and 5 of 6 cM-tests.
Ward seismic passes all tests.
Wiemer & Schorlemmer fails 3 of 6 S-test.

Mainshocks+aftershocks:

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Conclusions

Seismicity fluctuations are not Poissonian.

- N-test results using a negative-binomial distribution.
- But how to deal with bin-specific rate variability?

RELM results are "mostly" stable with respect to past data.

- Fault-based models often inconsistent with spatial distribution.
- Geodesy-based models often consistent (except Ward 8.1)
- Ward Simulator mostly fails S & cM test.
- Seismicity-based models mixed:
  - Ebel et al. fails most S-tests (trivial, since uncorrected).
  - Helmstetter et al. passes all tests.
  - Kagan et al. passes most tests (one N and one cM test??).
  - Wiemer & Schorlemmer fails most S-tests (same in Italy).