Earthquake Magnitude Prediction Using a Machine Learning Model

Neri Berman[1,2], Oleg Zlydenko[2], Oren Gilon[2], and Yohai Bar-Sinai[1]

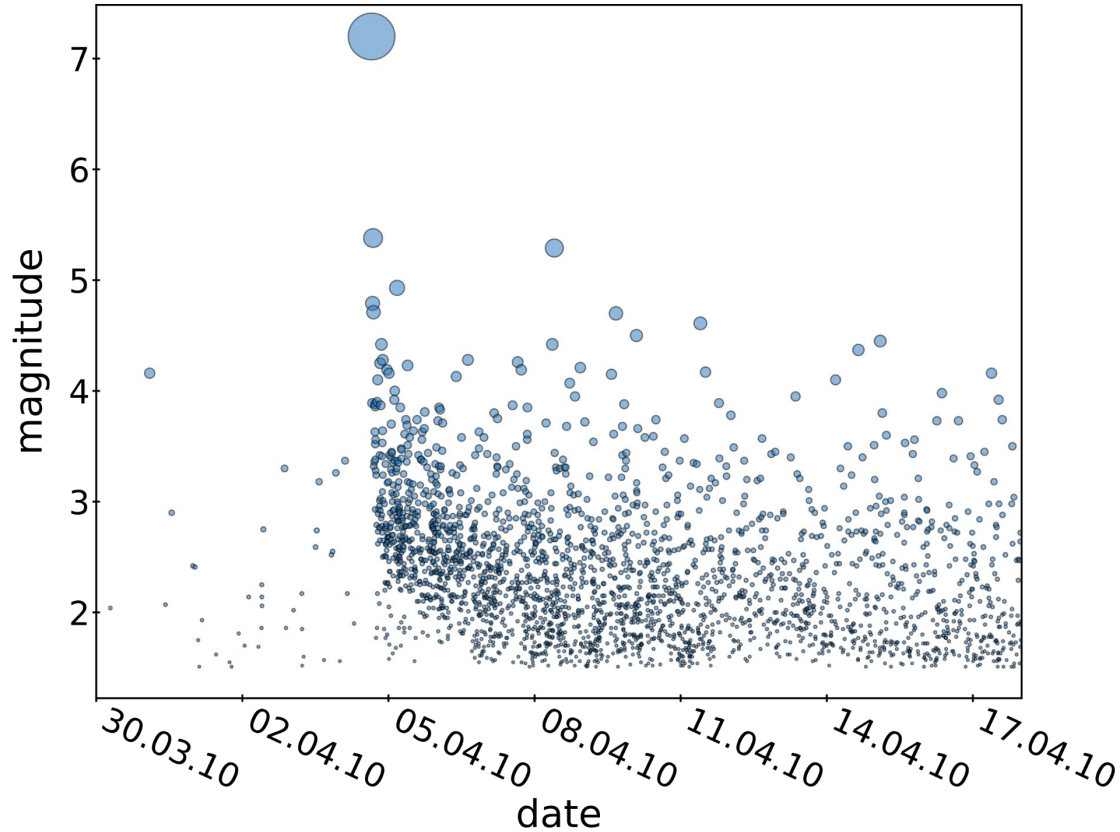[1] Tel Aviv University, Physics, Tel Aviv, Israel
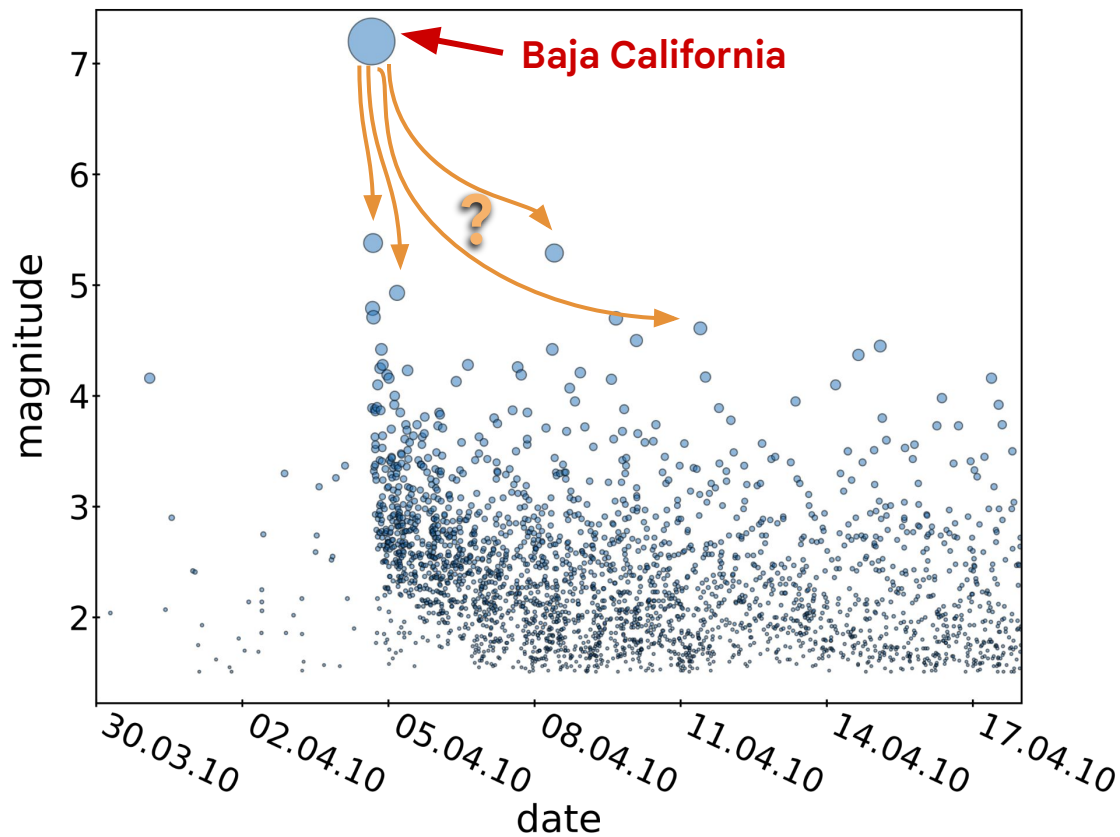[2] Google Research, Tel Aviv, Israel

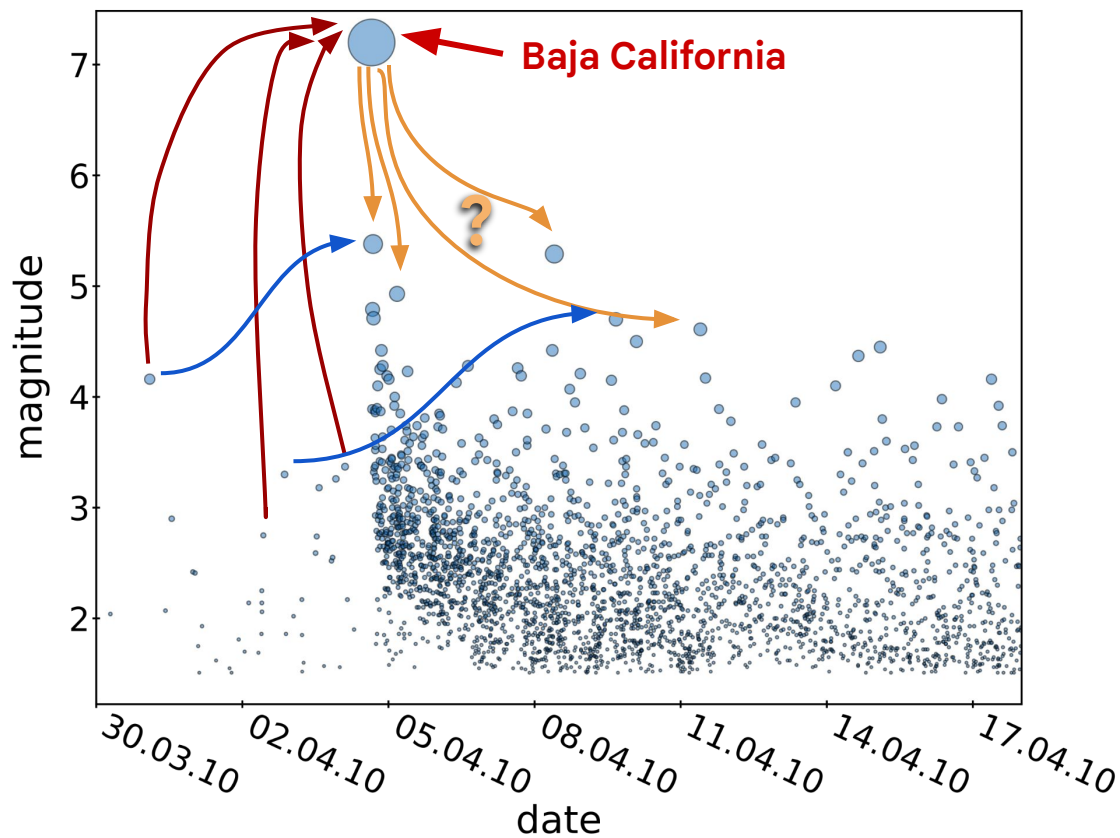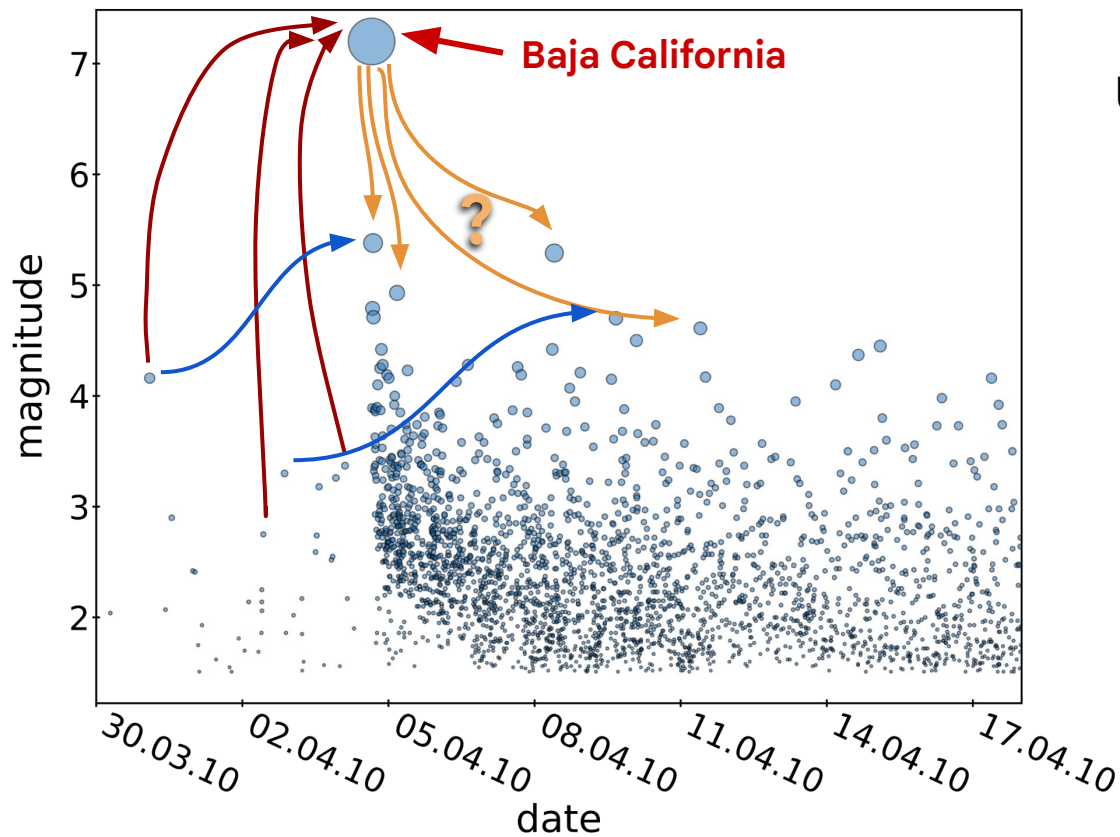# Are earthquake magnitudes history dependent?

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Baja California

Under debate…

- Petrillo and Zhuang , 2022
- A. Stallone and W. Marzocchi, 2019
- J. Davidsen et al, 2012
- J. Davidsen and A. Green, 2011
- E. Lippiello et al, 2008
- M. J. Werner and D. Sornette, 2008
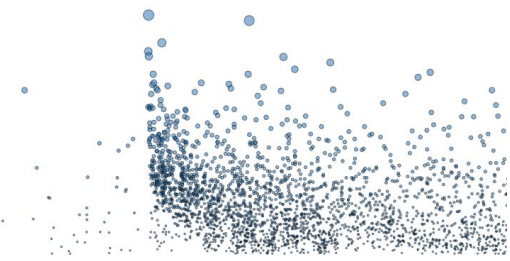- P. Bak and C. Tang, 1989
- ……..
- …..
- …

Are earthquake magnitudes history dependent?

In practice, It's common to consider magnitudes as independent

As in ETAS

$$\lambda(t, x, y) = \mu(x, y) + \sum_{i:t_i < t} \kappa(m_i) \quad g(t - t_i) \quad f(x - x_i, y - y_i; m_i)$$

Seismicity rate   Background rate   Magnitude predictor   Temporal dependance   Spatial dependance

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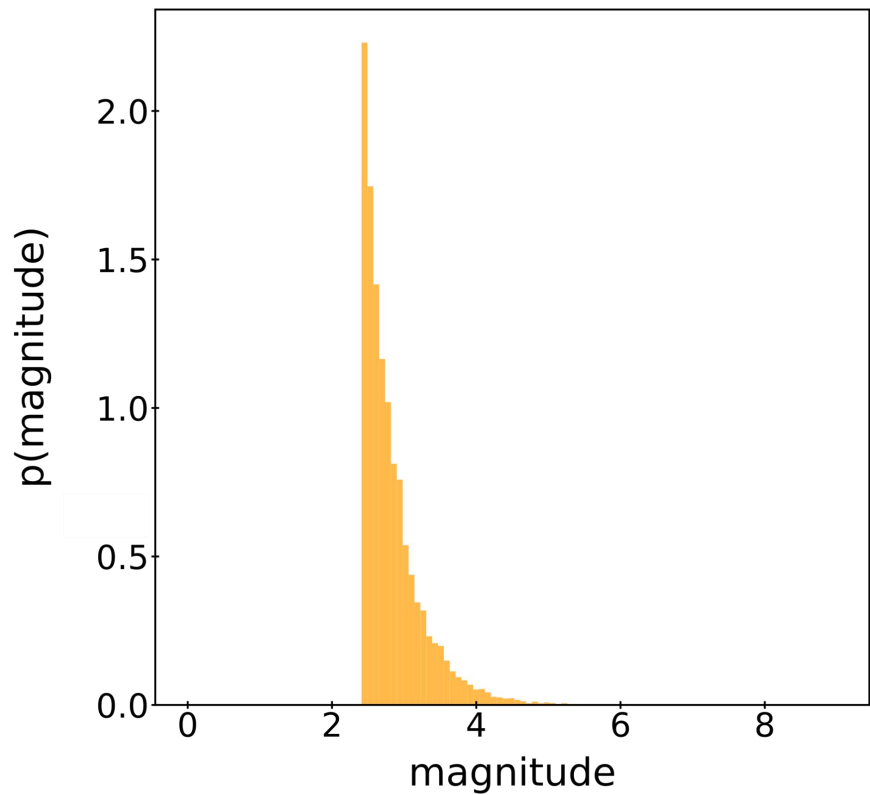Seismicity rate   Background rate   Magnitude predictor   Temporal dependence   Spatial dependence

Independent of time, space and history
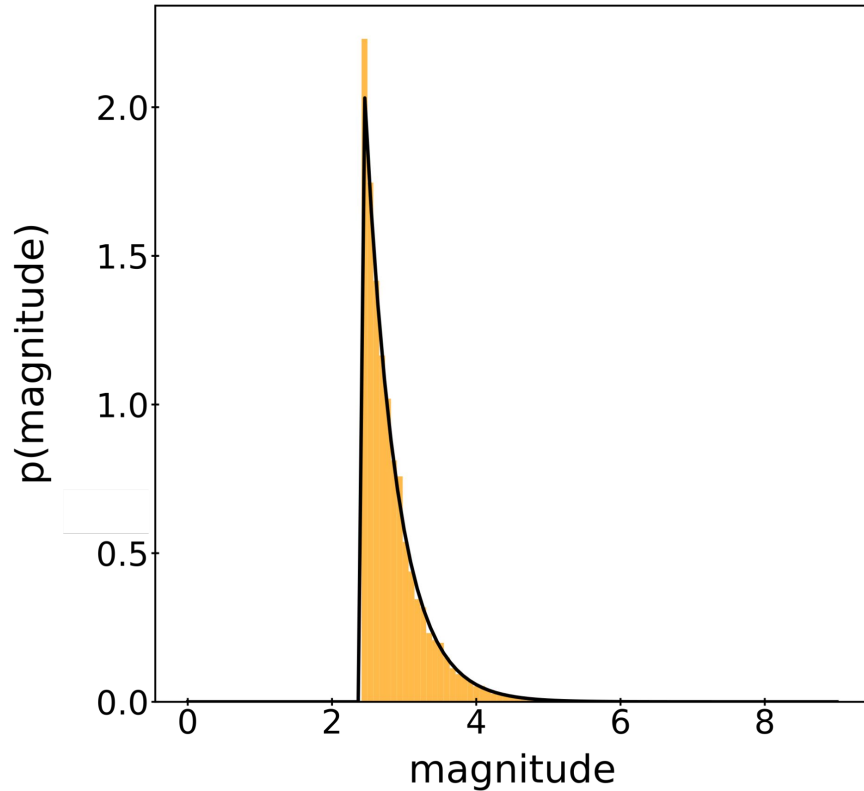
Magnitudes are statistically independent
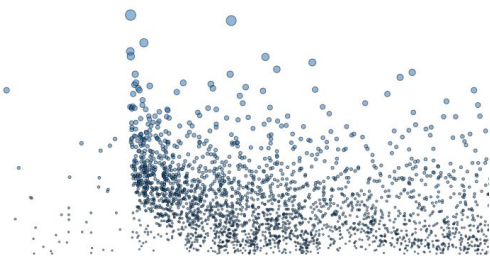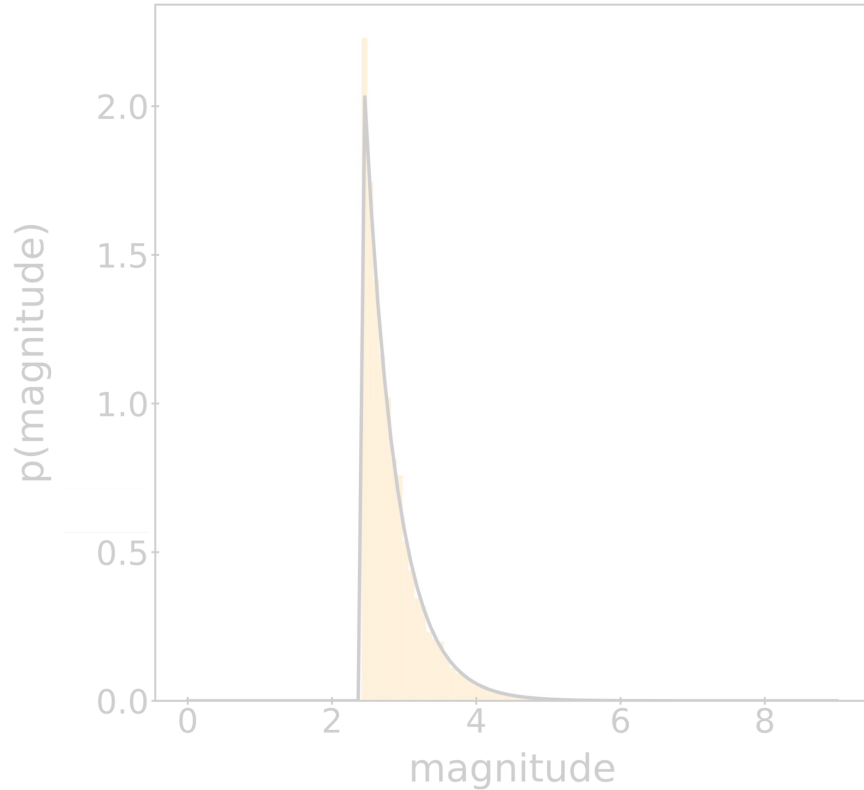
$\kappa(m_i)$ - Gutenberg-Richter as a magnitude predictor

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The Gutenberg Richter distribution

$$\kappa(m) = \beta e^{-\beta(m_c - m)}$$

$\kappa(m_i)$ - Gutenberg-Richter as a magnitude predictor

Better prediction of magnitudes based on history?

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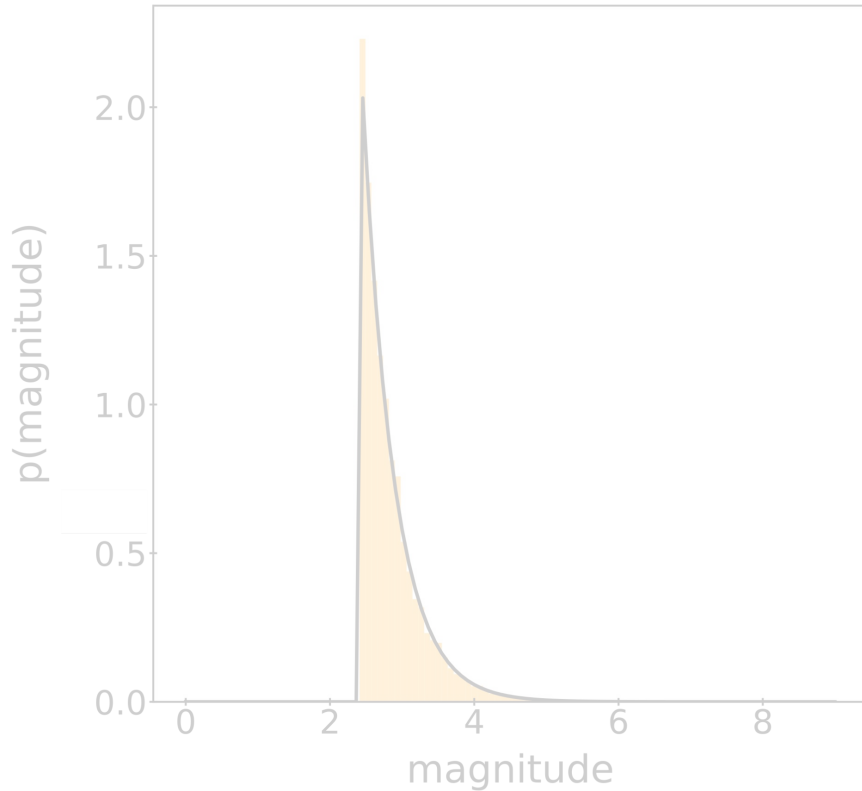
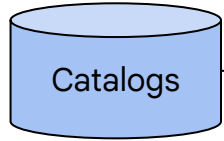Better prediction of magnitudes based on history?

$$\kappa(m) = \beta e^{-\beta(m_c - m)}$$

Replacing with a ML model

$$\tilde{\kappa}_{\vec{x},t}(m| \text{ history prior to } t)$$

Model architecture

Data source   Data encoding   Data decoding   Prediction

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Catalogs

$$F_1^{(i)} = \frac{1}{(\vec{r} - \vec{r}_i)^2}$$

$$F_2^{(i)} = \exp M_i$$

$$F_3^{(i)} = \frac{1}{(t - T_i)}$$

$$F_4^{(i)} = \cdots$$

LSTM

Latent state

Fully connected NN

Time-space query

Expected magnitude pdf
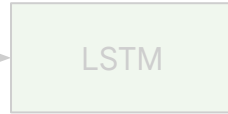
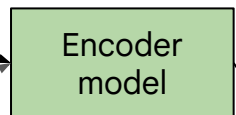| time	x	y	depth	M$_W$
t_1	x_1	y_1	d_1	m_1
⋮	⋮	⋮	⋮	⋮
t_N	x_N	y_N	d_N	m_N

Spatial & Temporal functions
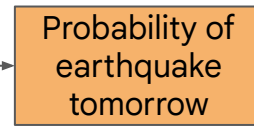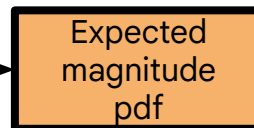
(x, y, t)

Neural Network

p(m)
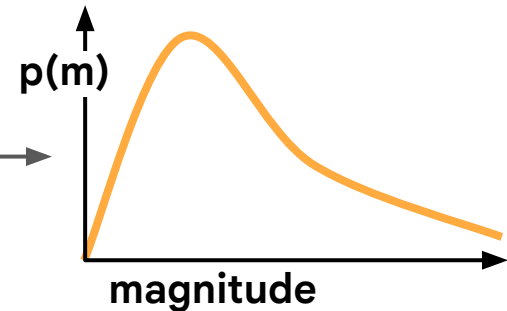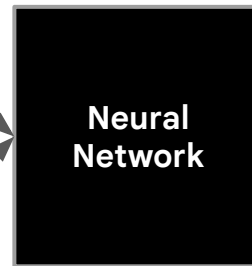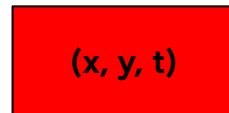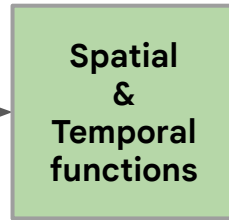
magnitude

The wider effort

Data sources → Data encoding → Latent state → Data decoding → Prediction

Data sources: Catalogs, Seismic waves, GPS, ...

Data encoding: LSTM, Encoder model, Encoder model, Encoder model, Encoder model, ...

Latent state

Data decoding: Fully connected NN, Fully connected NN, Decoder model, Decoder model, ...

Prediction: Expected magnitude pdf, Probability of earthquake tomorrow, ETAS-like probability output, Biggest earthquake in 10 years, ...
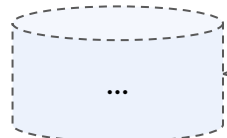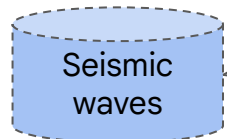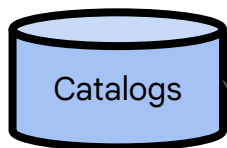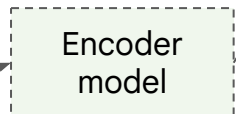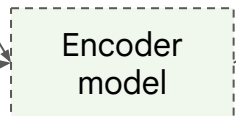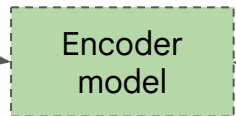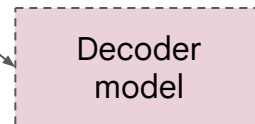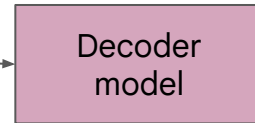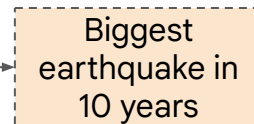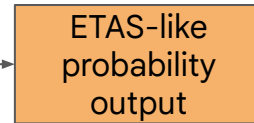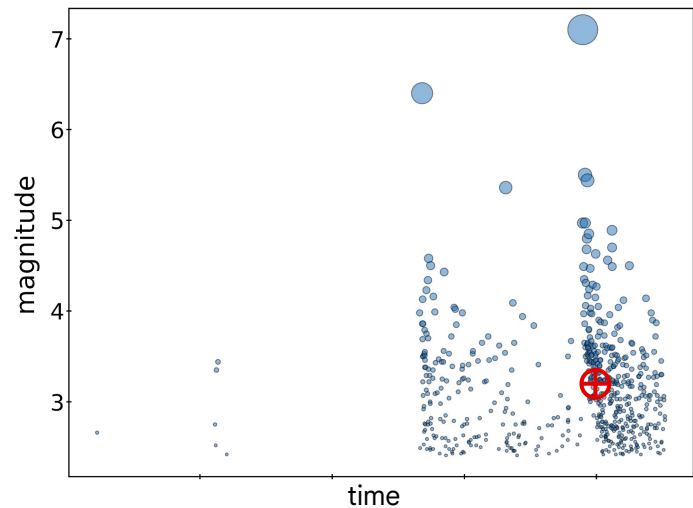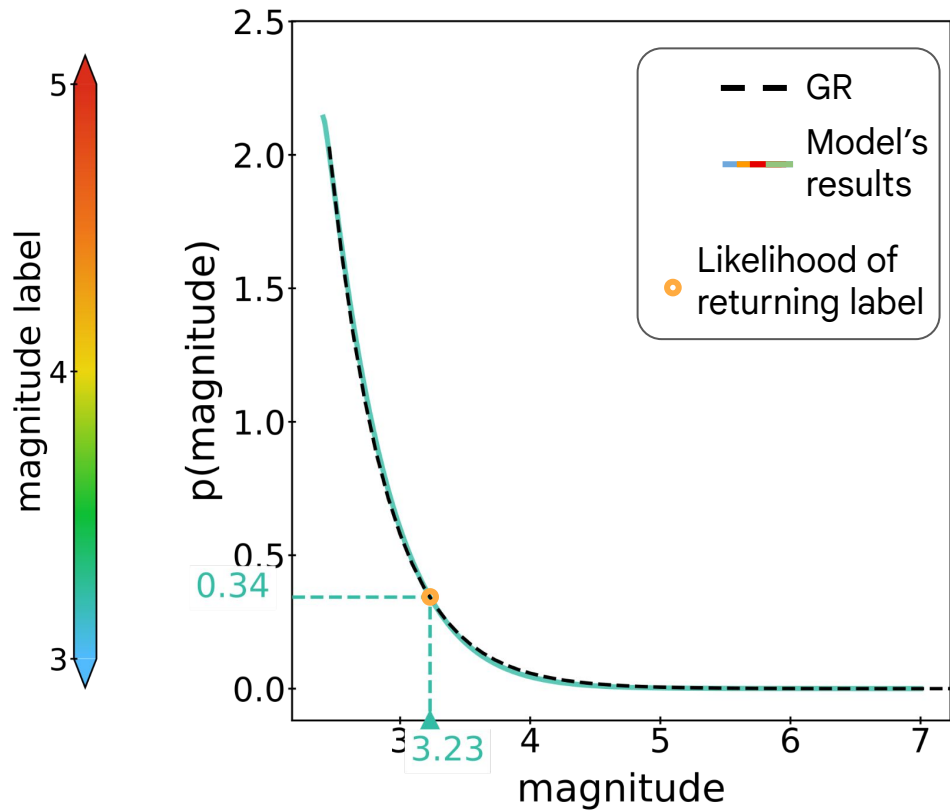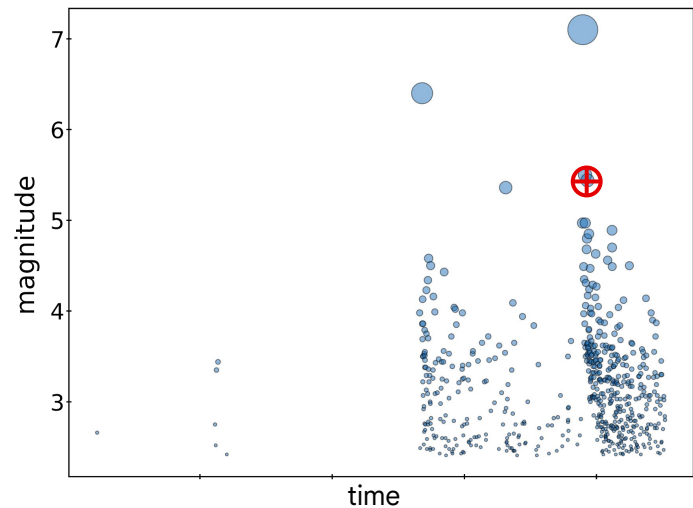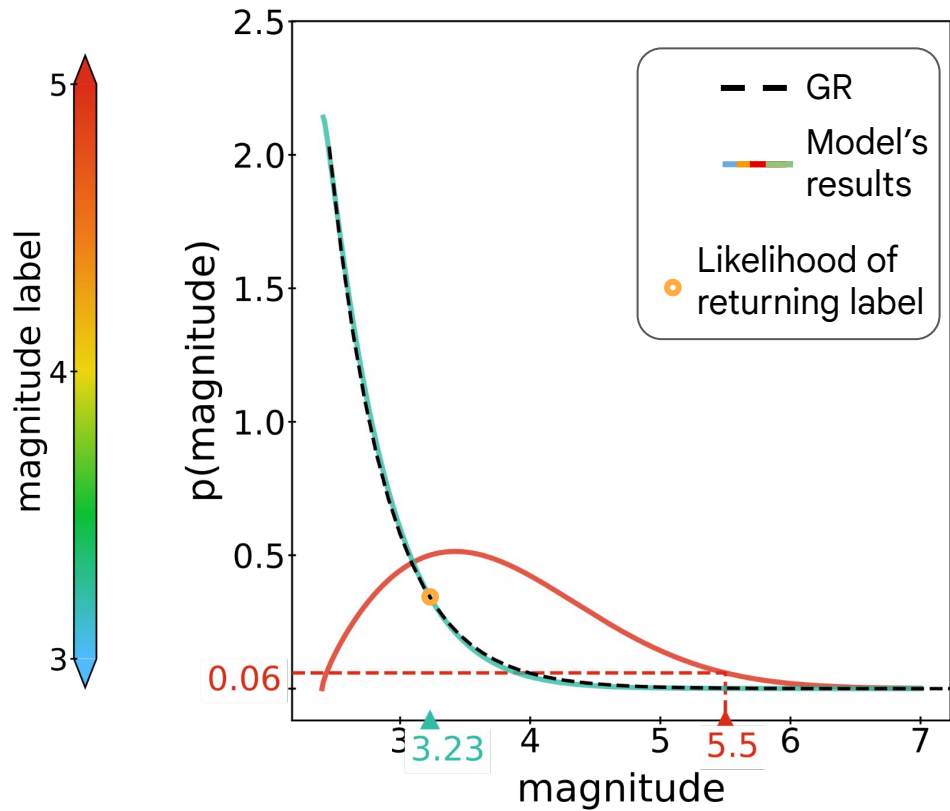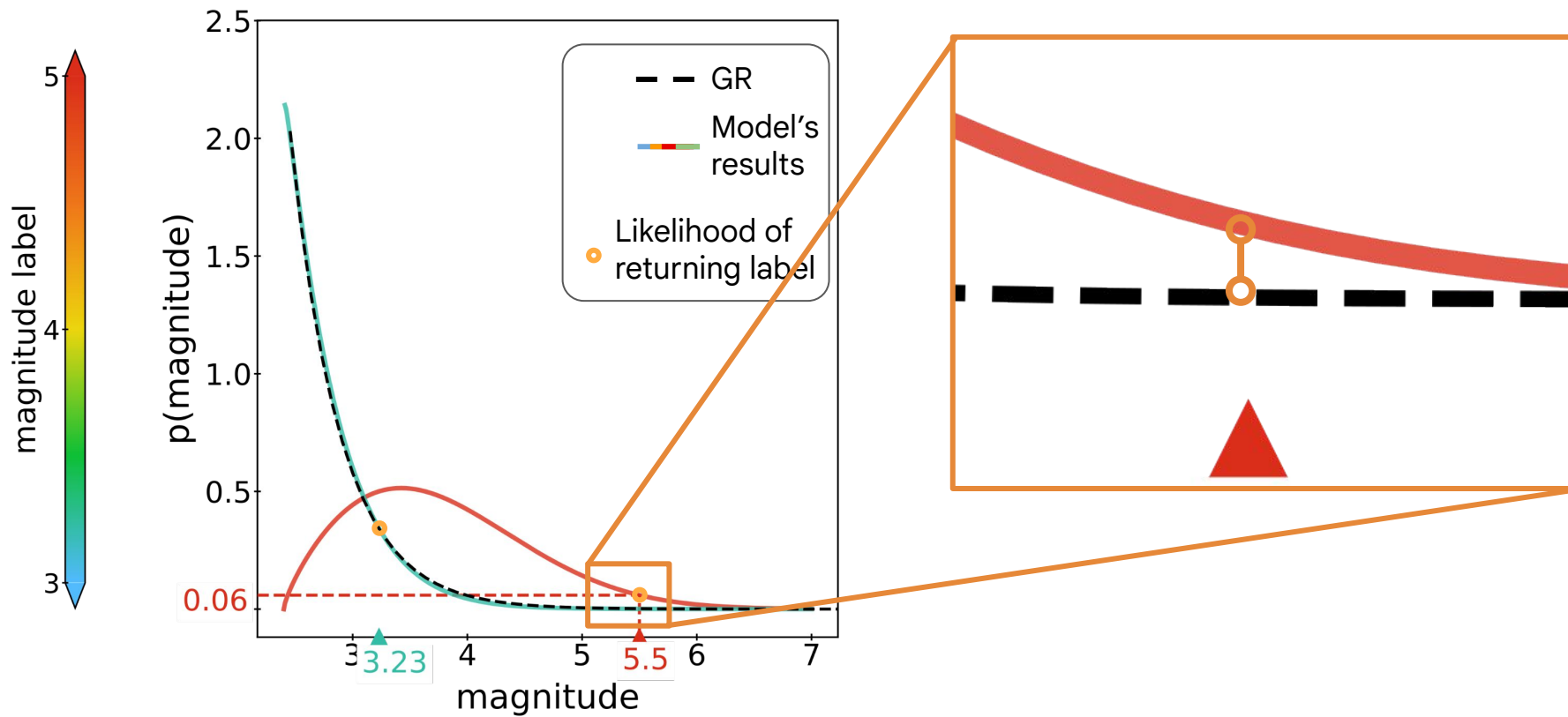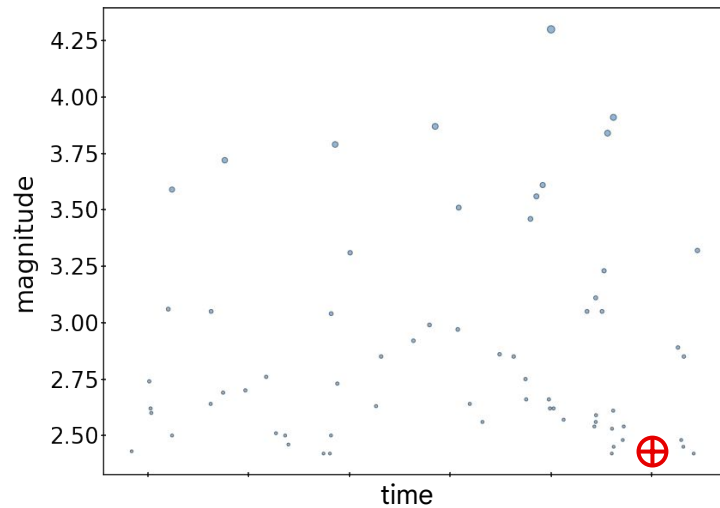
Input data - Hauksson catalog
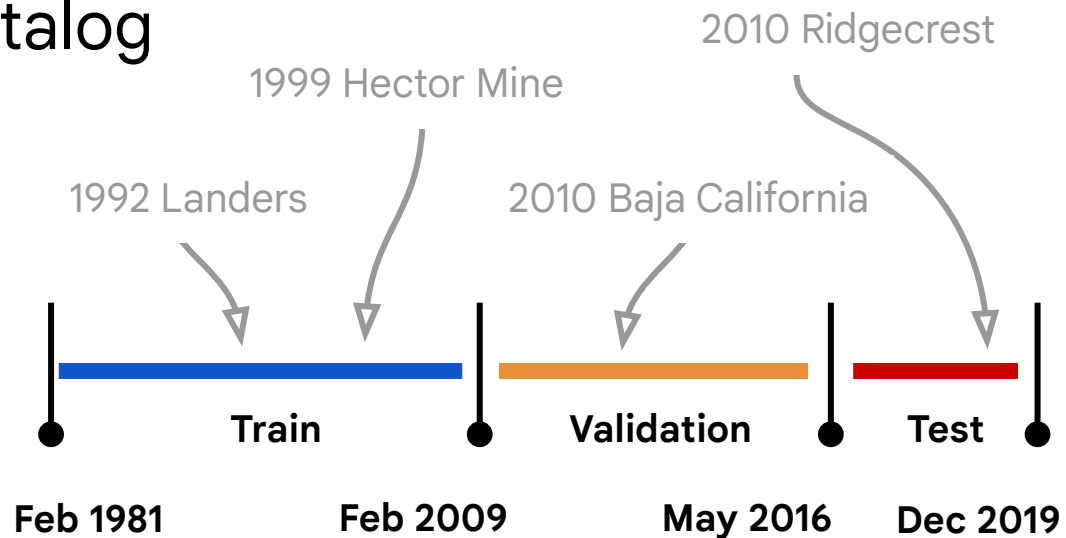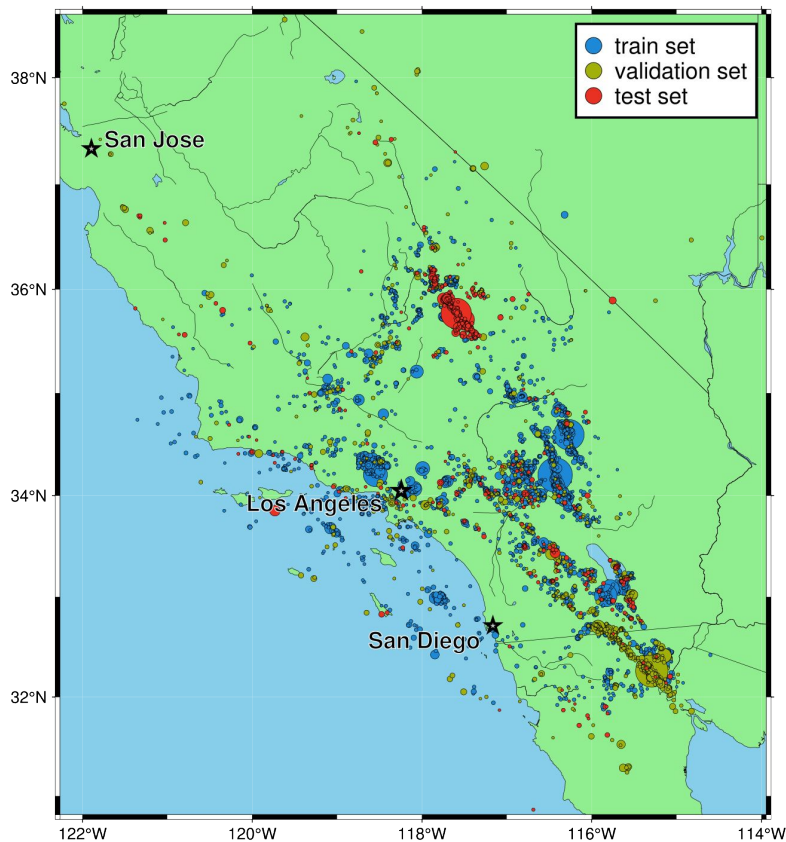
Results - magnitude sampling functions
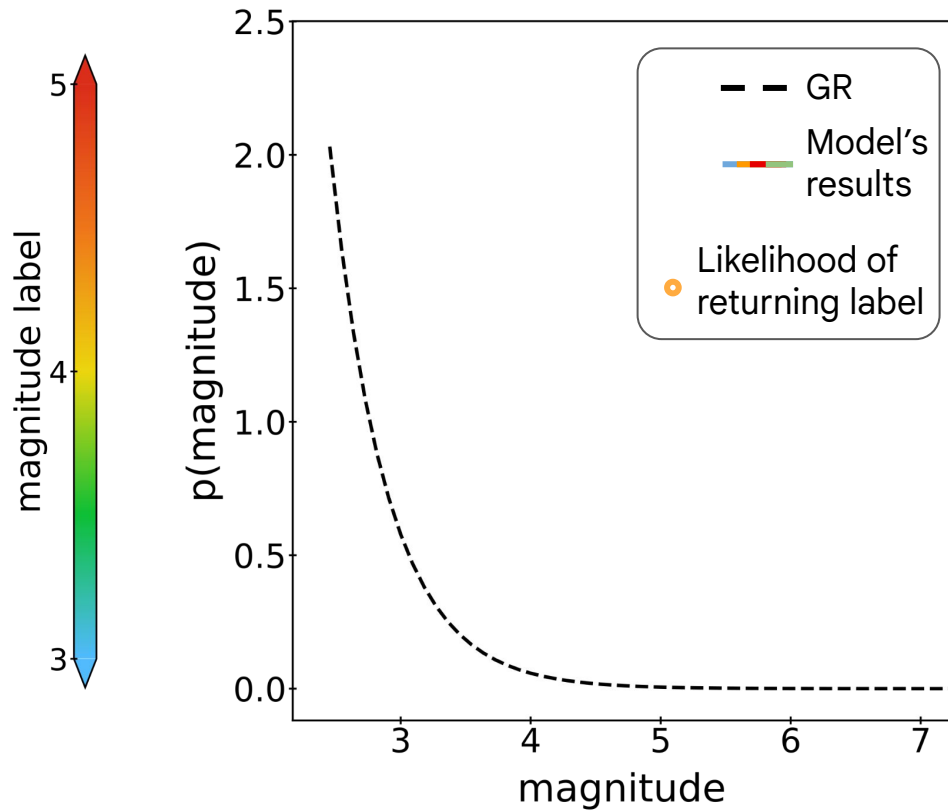
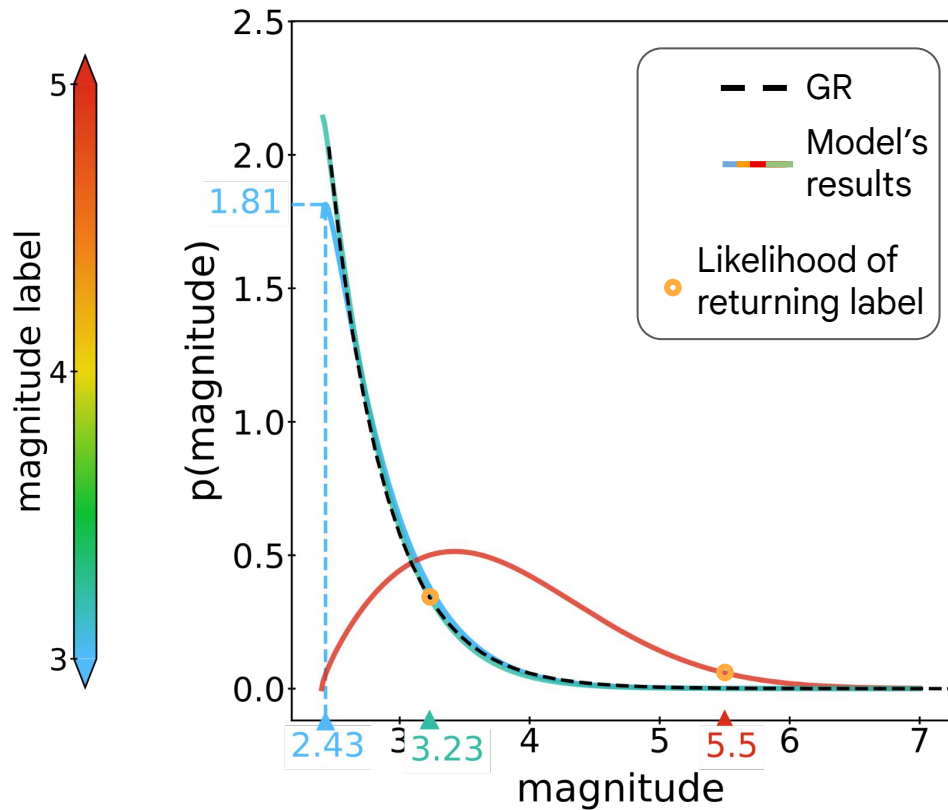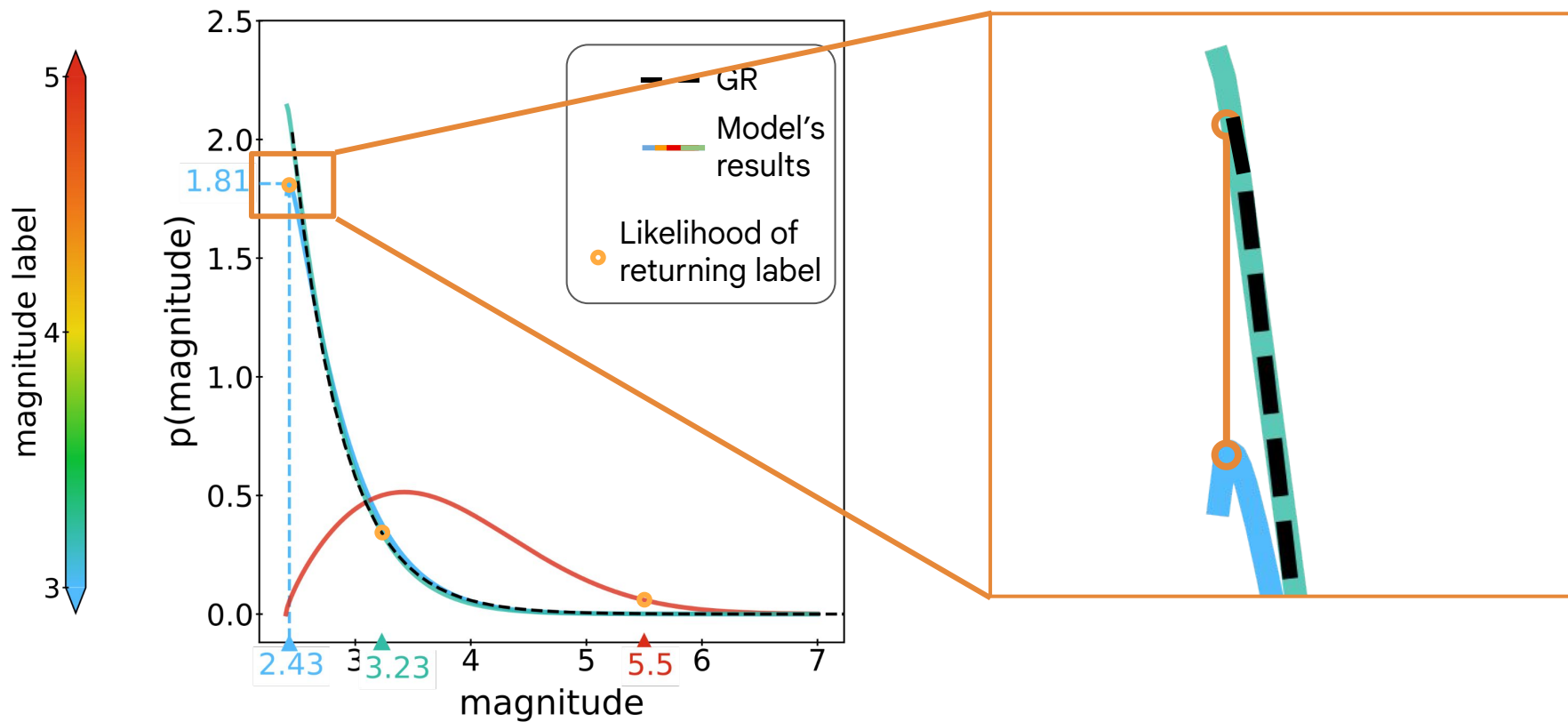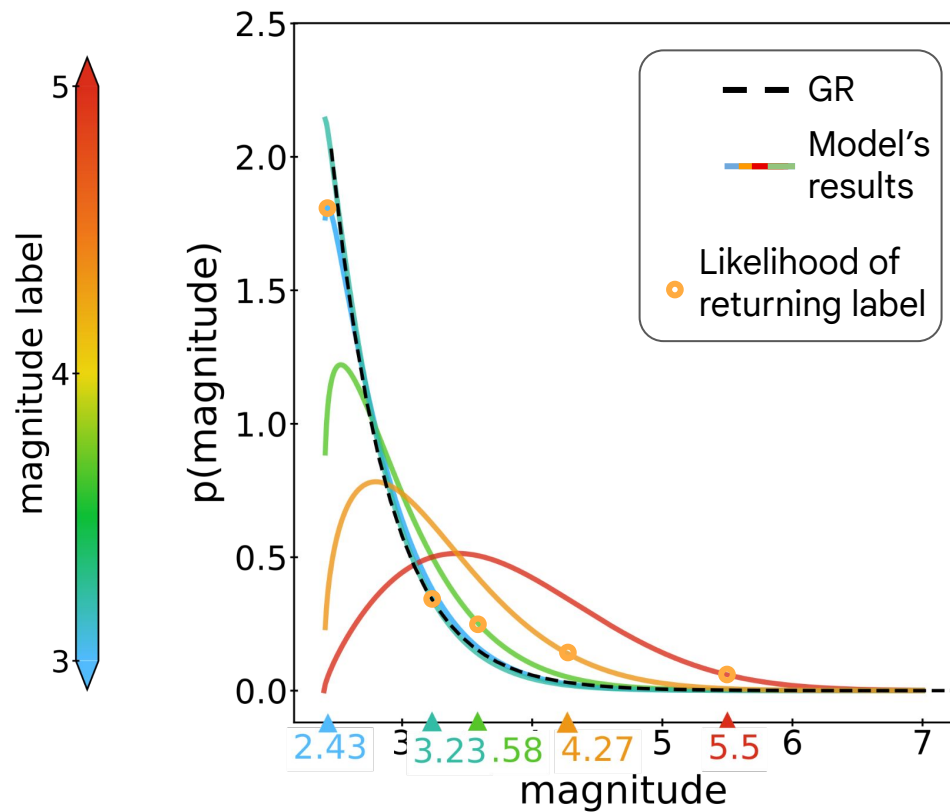# Results - magnitude sampling functions

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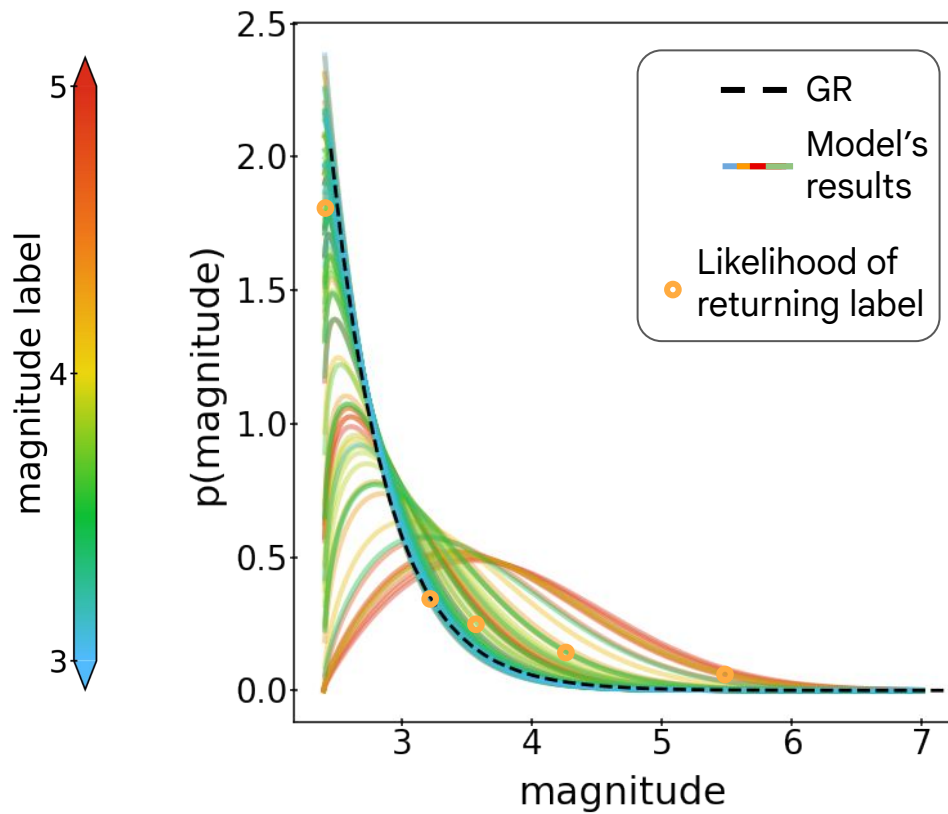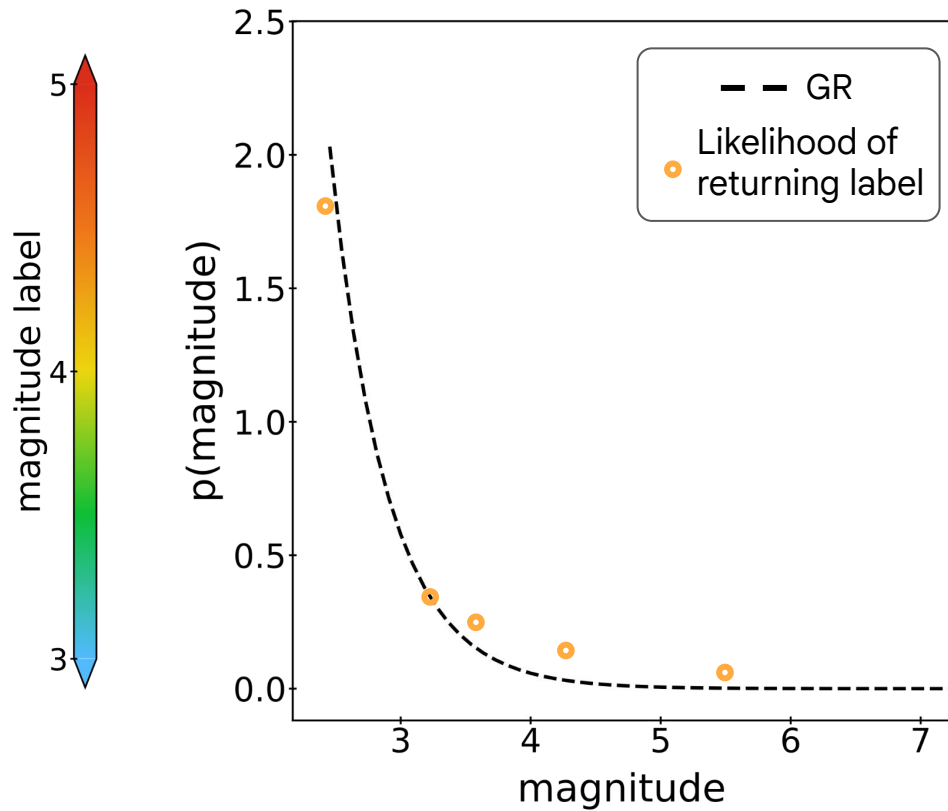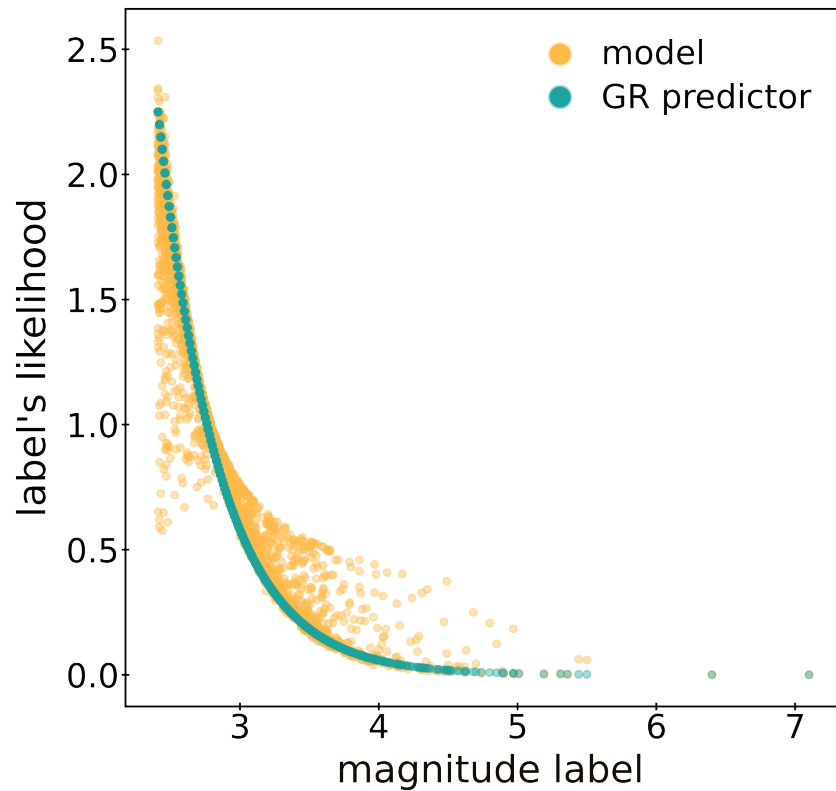# Results - magnitude sampling functions

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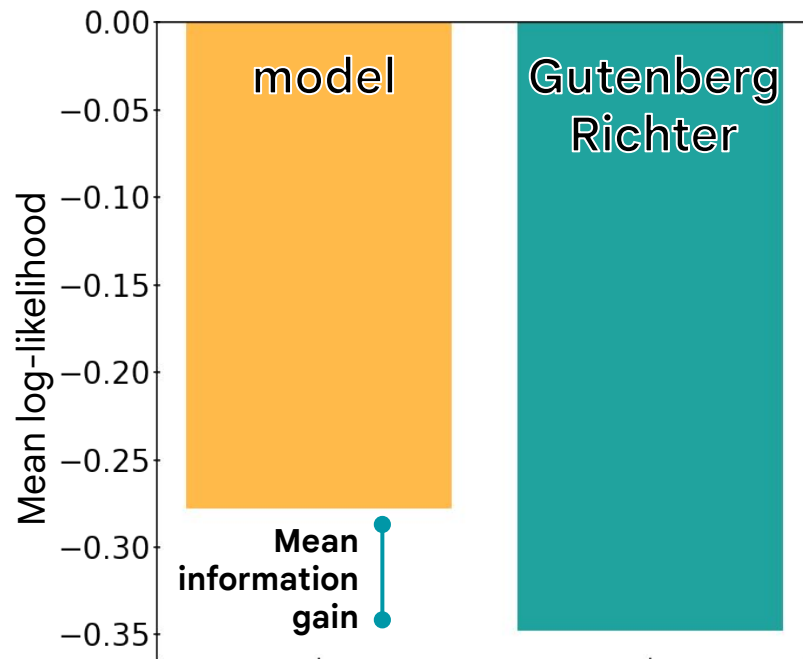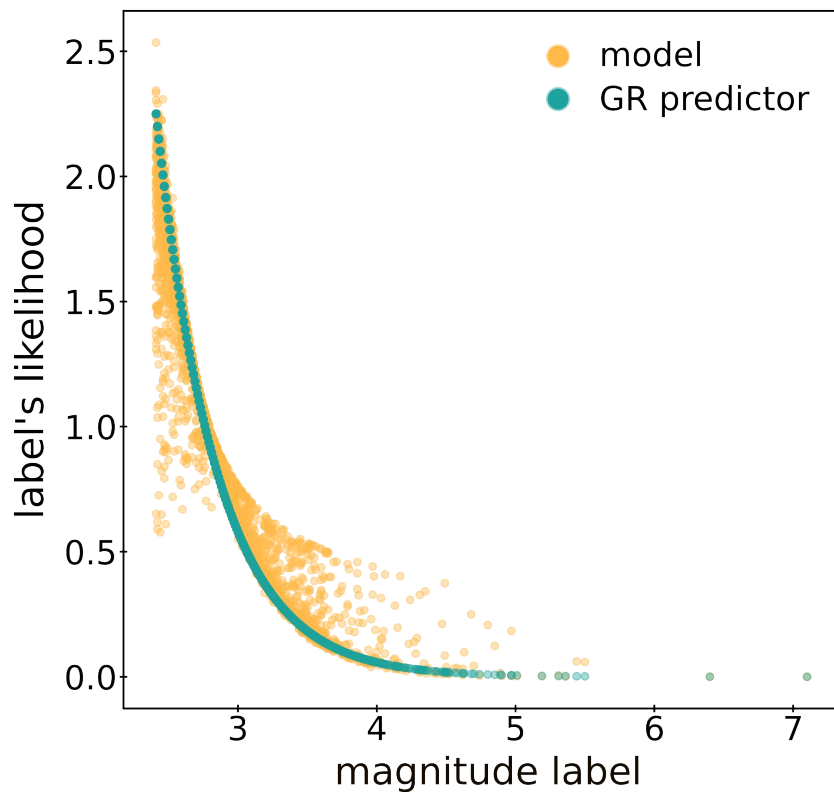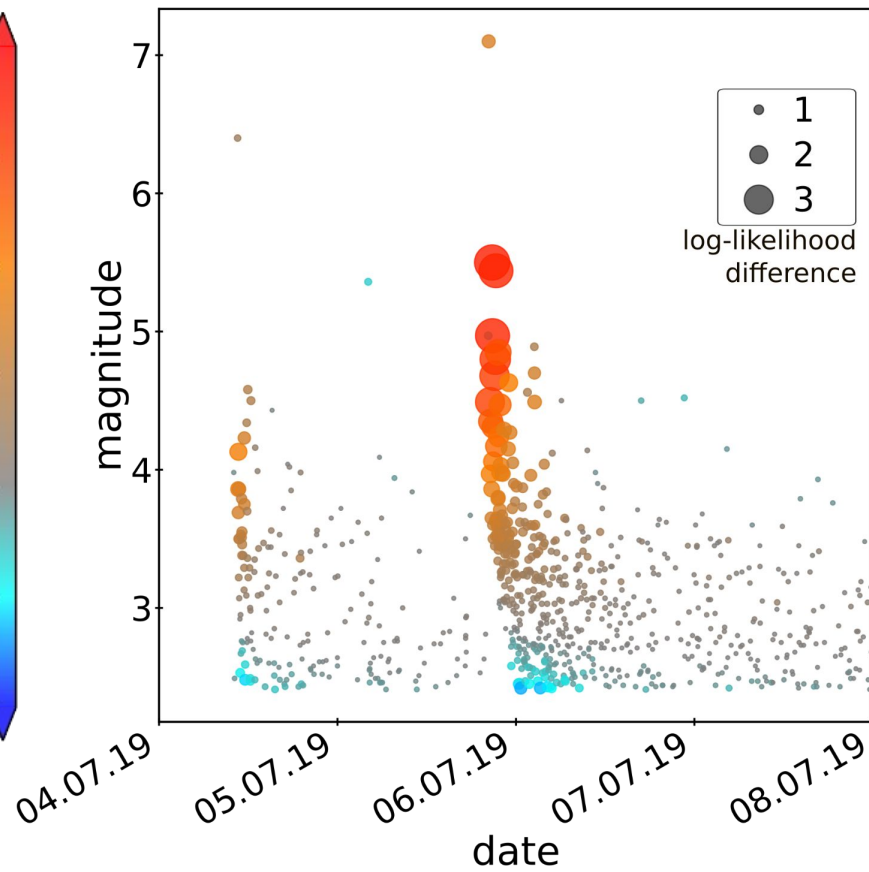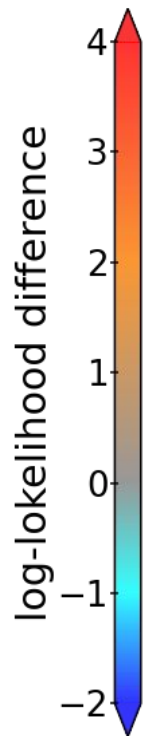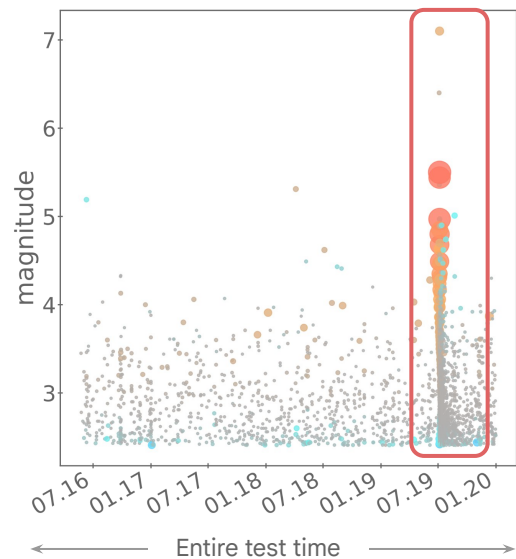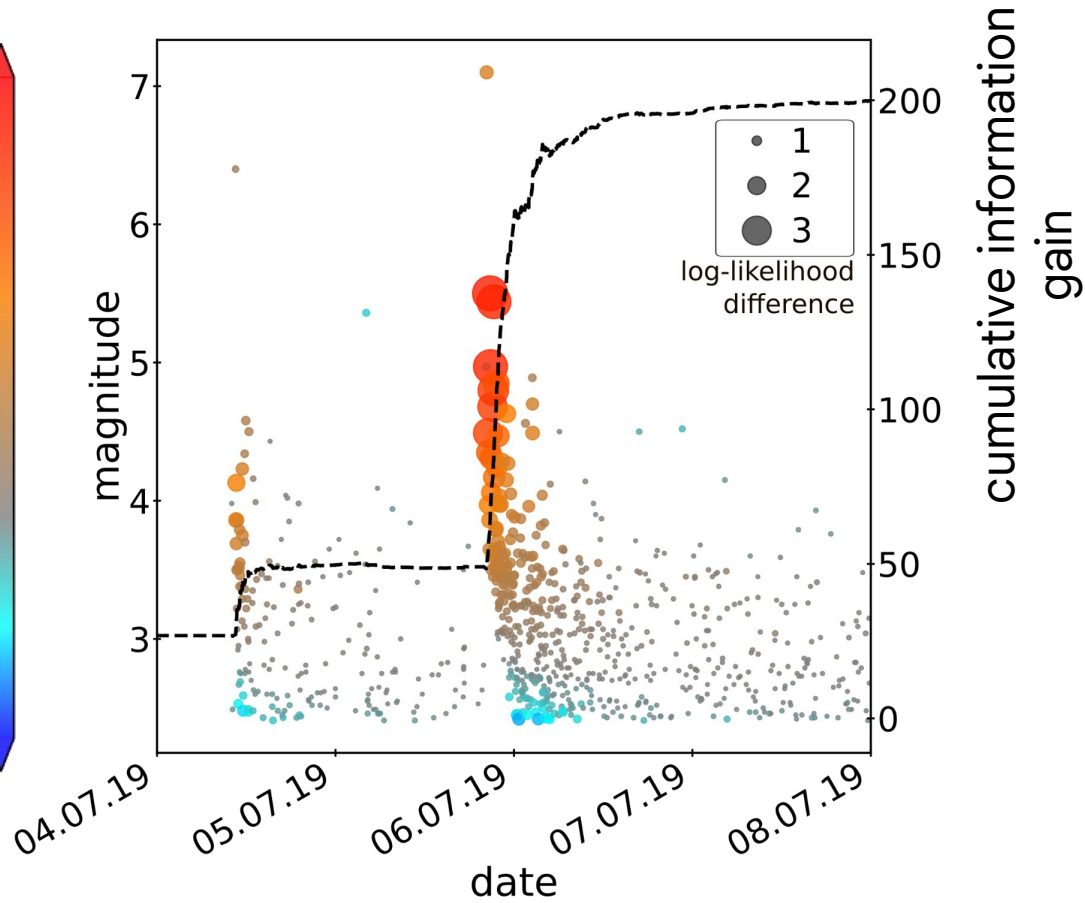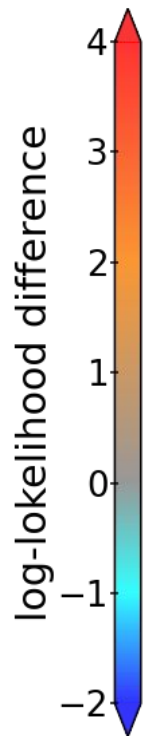
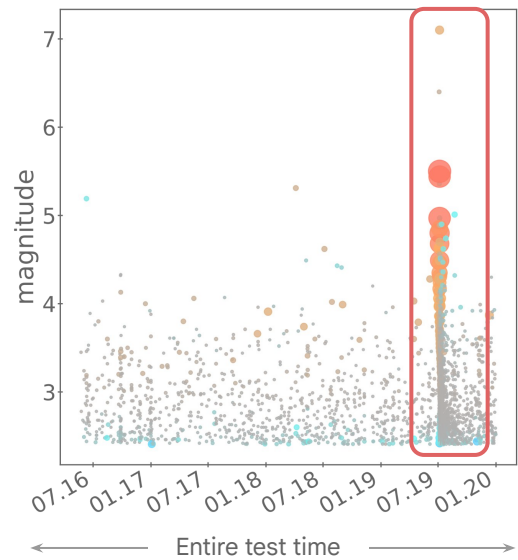# Results - magnitude sampling functions

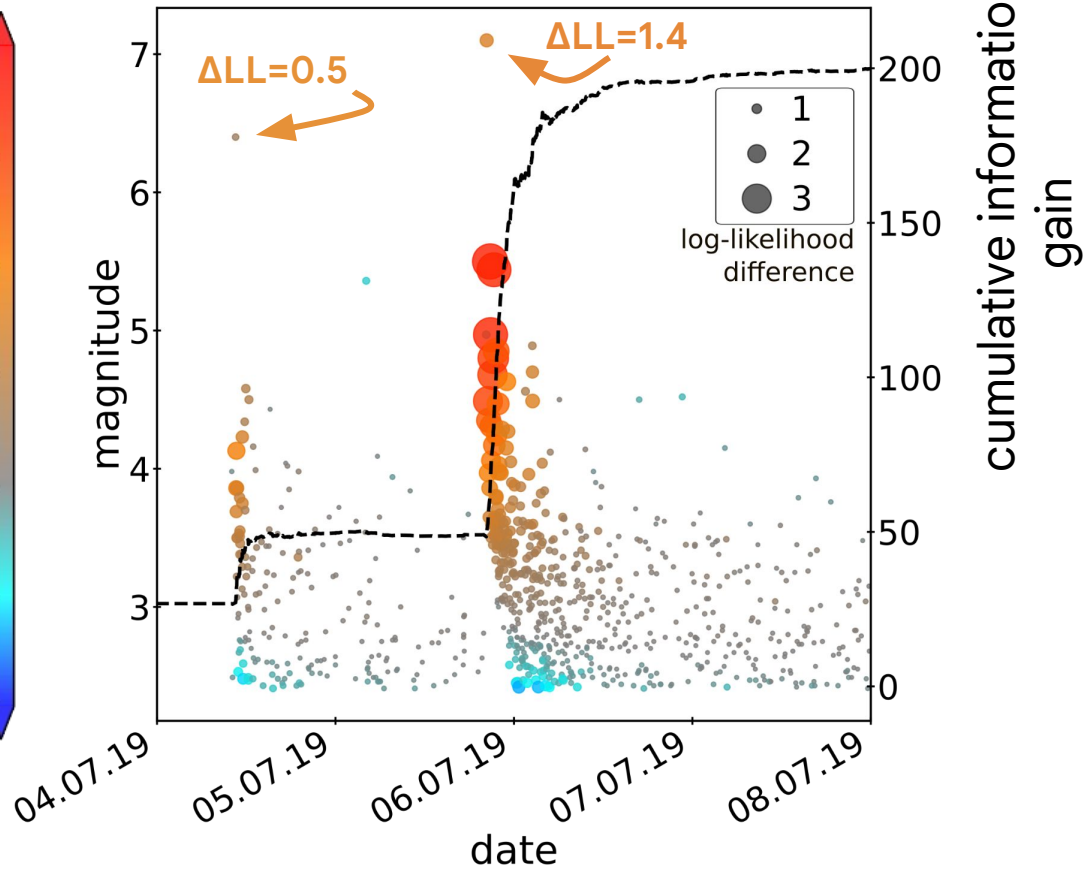# Results - likelihood per example

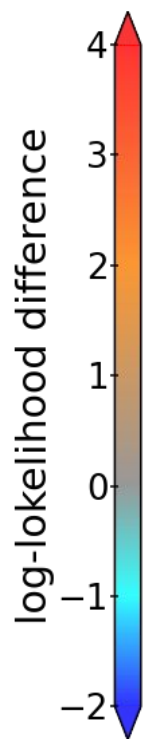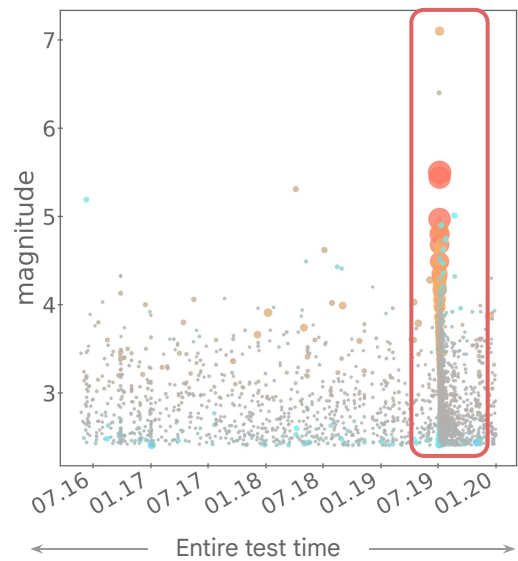# Results - likelihood per example

Model's advantage per event

Model's advantage per event

Model's advantage per event

Conclusion

Improvement in magnitude prediction

— — ➤ **Magnitudes are history dependent**

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Improvement in magnitude prediction

– – ➤ **Magnitudes are history dependent**

Future directions

- Use the model as an oracle
  E.g: "What will be the the probability for m>4 in the next 24 hours?"

- Use as a replacement in an ETAS-like model:

$$\lambda(t, x, y) = \mu(x, y) + \sum_{i:t_i < t} \boxed{\tilde{\kappa}_i(m_i | t - t_i, x - x_i, y - y_i, m_{t_j < t_i})}$$
$$\cdot\, g(t - t_i)$$
$$\cdot\, f(x - x_i, y - y_i; m_i)$$

Thanks!