Relaxing ETAS' assumptions to better capture the real behavior of seismicity

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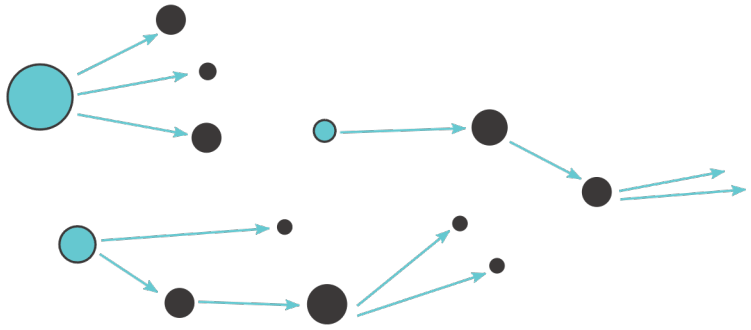
Epidemic-Type Aftershock Sequence (ETAS) Model

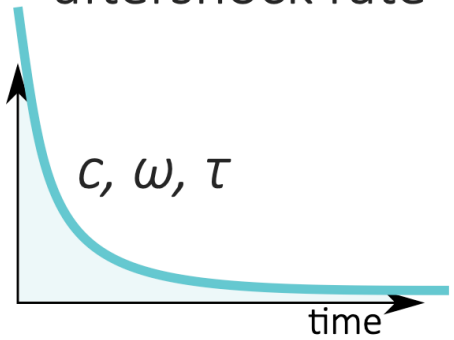
ETAS distinguishes **background events** and **triggered events**

All aftershocks can recursively trigger own aftershocks

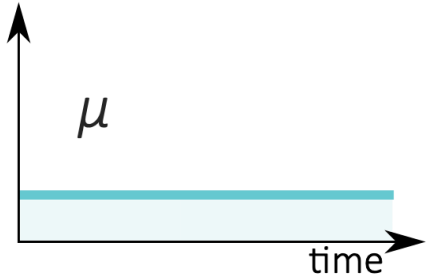


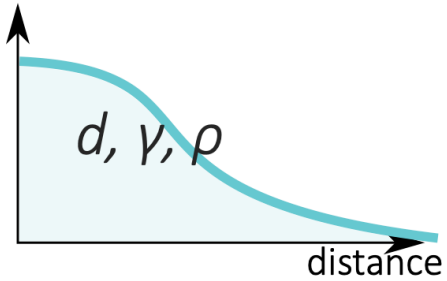
Aftershock triggering is based on few **empirical principles**

aftershock rate

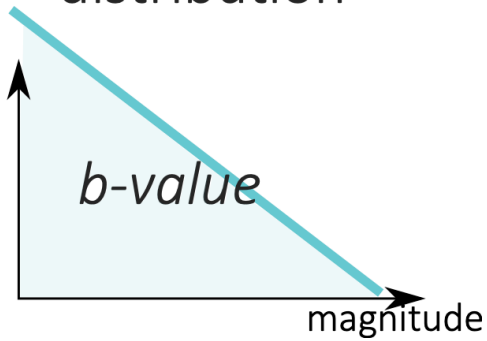


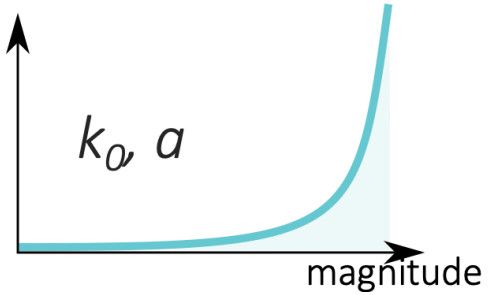
background rate





magnitude distribution





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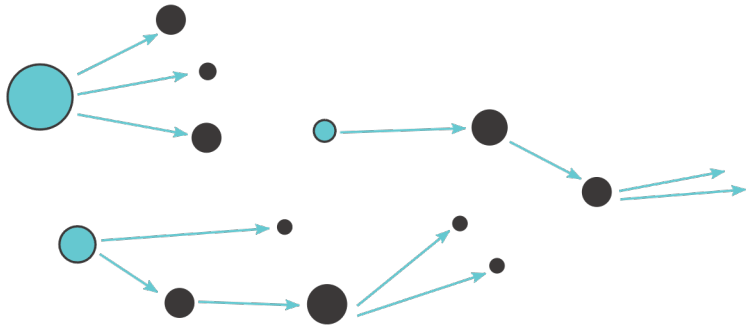
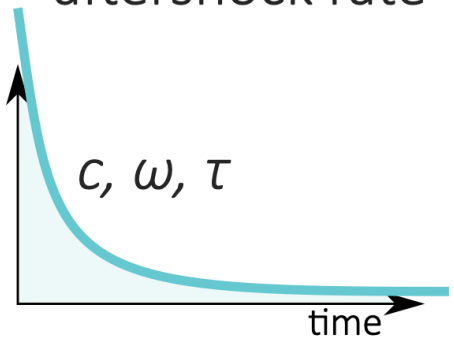
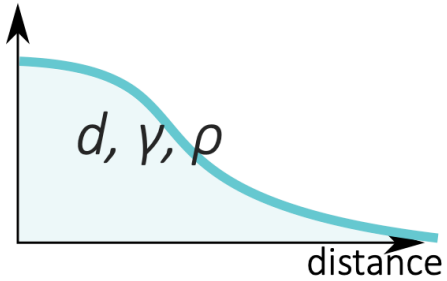


Aftershock triggering is based on few **empirical principles**

Our approach: self-consistent inversion algorithm for **event-specific** background and productivity

aftershock rate



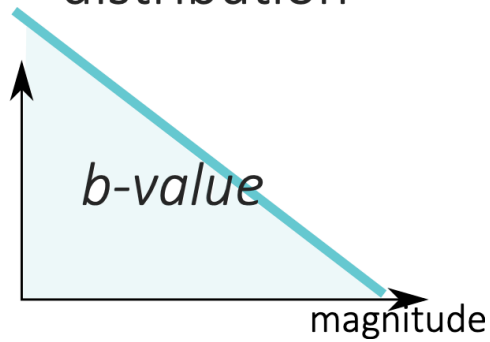


non-parametric productivity

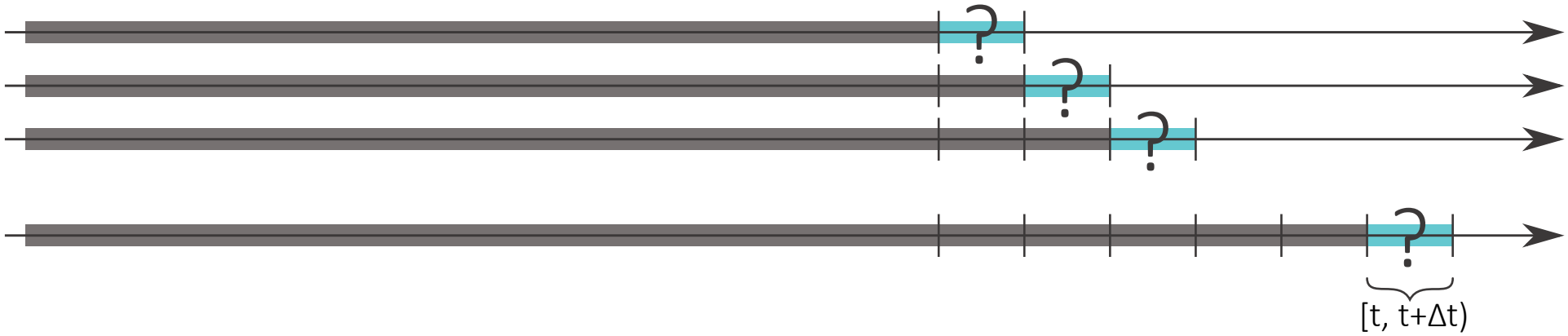
background rate

non-parametric background

magnitude distribution



Pseudo-Prospective Forecasting Experiment



Procedure:

- Calibrate models using data until forecasting start
- Compare forecast to observed data

Evaluation metric:

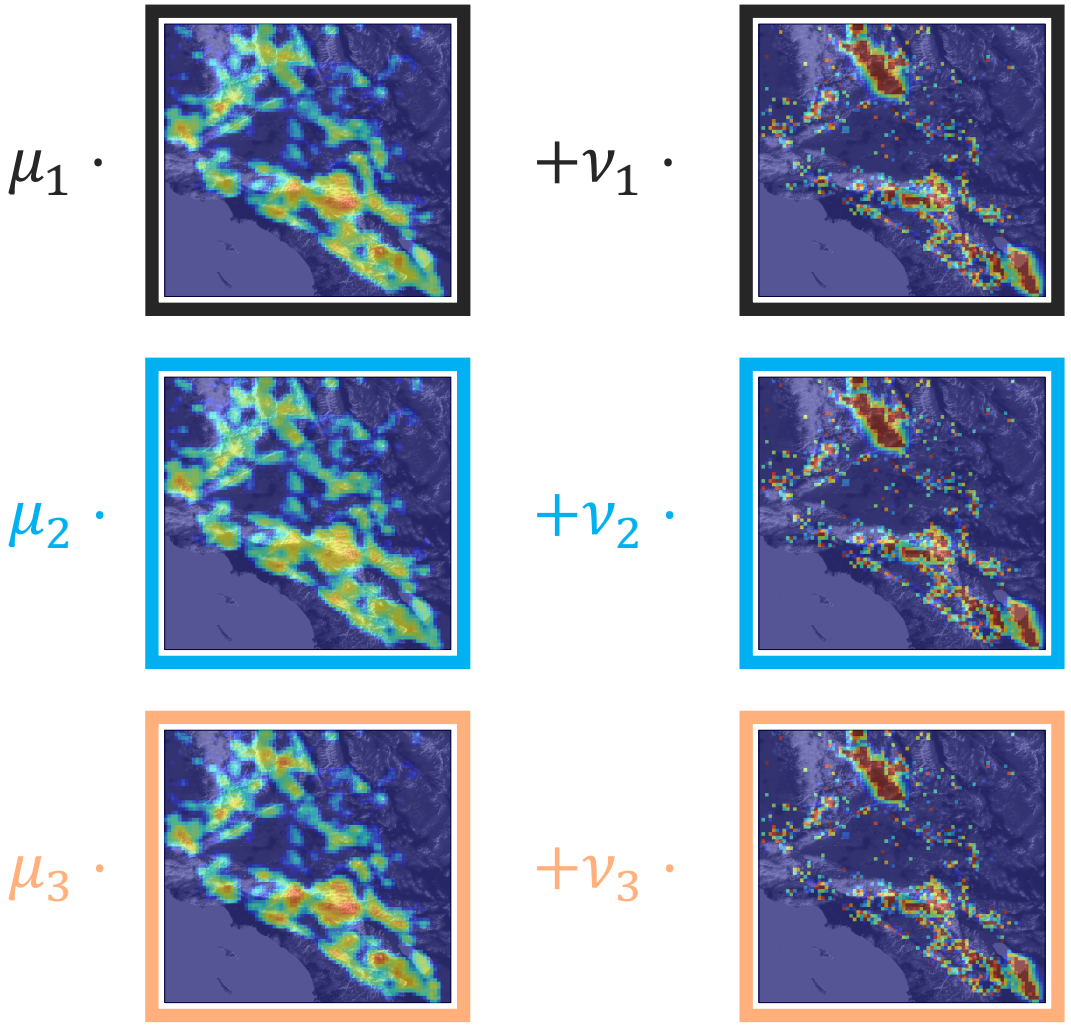
- Information gain based on conditional intensity

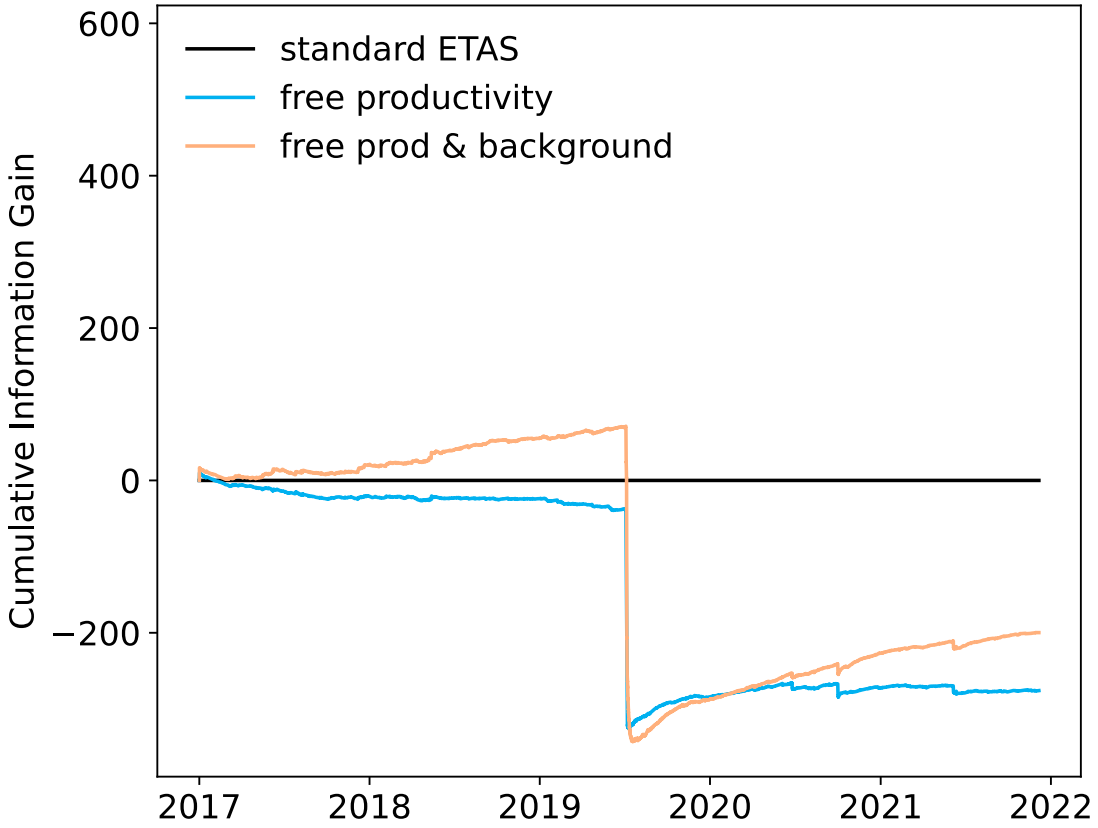
$$\ln \lambda(x, y, t) - \iiint \lambda(x, y, t)\, dx\, dy\, dt$$

Experiment Setup:

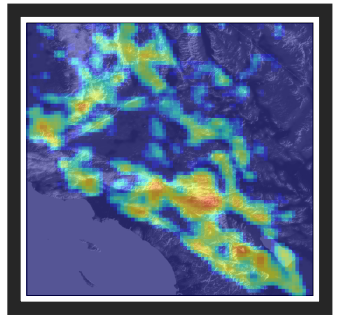
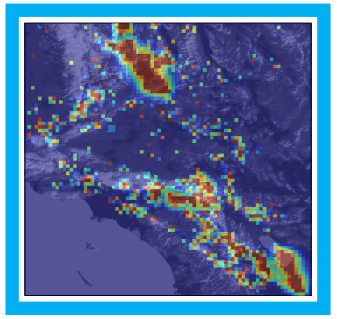
- Southern California, ANSS catalog, 2010 – 2021, M≥2.0
- 5 years of testing, starting on January 1st, 2017

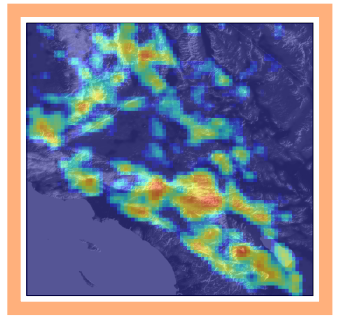
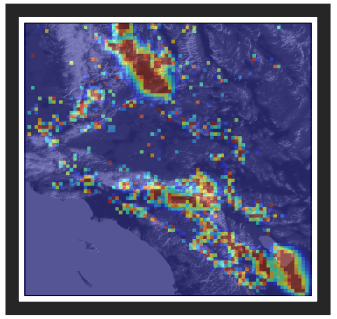
Results of the pseudo-prospective forecasting experiment

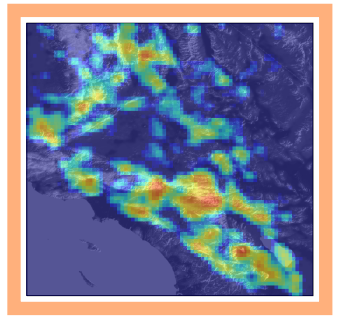
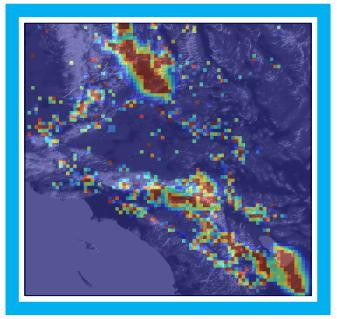




Component-driven ensembling

$\mu_1 \cdot$  $+\nu_1 \cdot$ 

$\mu_1 \cdot$  $+\nu_1 \cdot$ 

$\mu_1 \cdot$  $+\nu_1 \cdot$ 

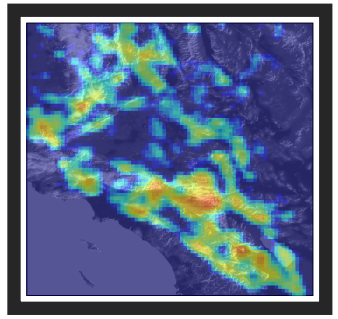
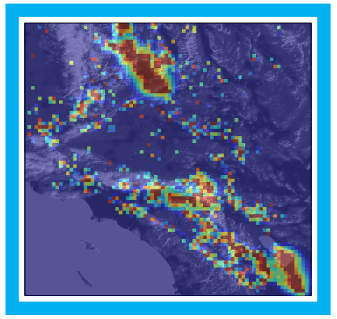
Each model has

- A **number** component
- A **background density** component
- An **aftershock density** component

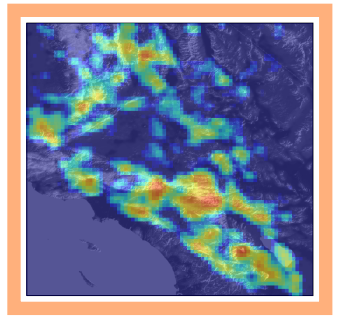
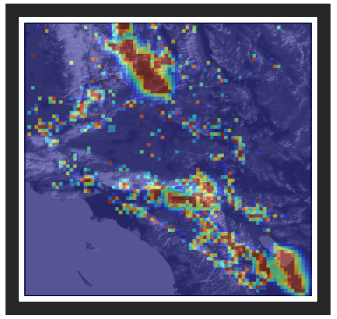
Instead of traditional ensembling, we **combine components** from different models

Component-driven ensembling

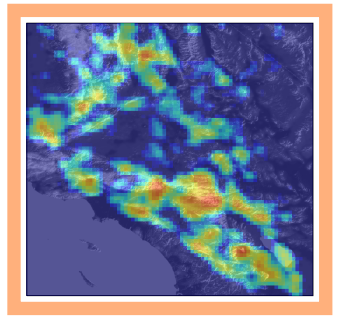
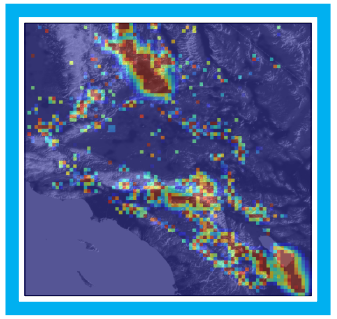
Mix 1

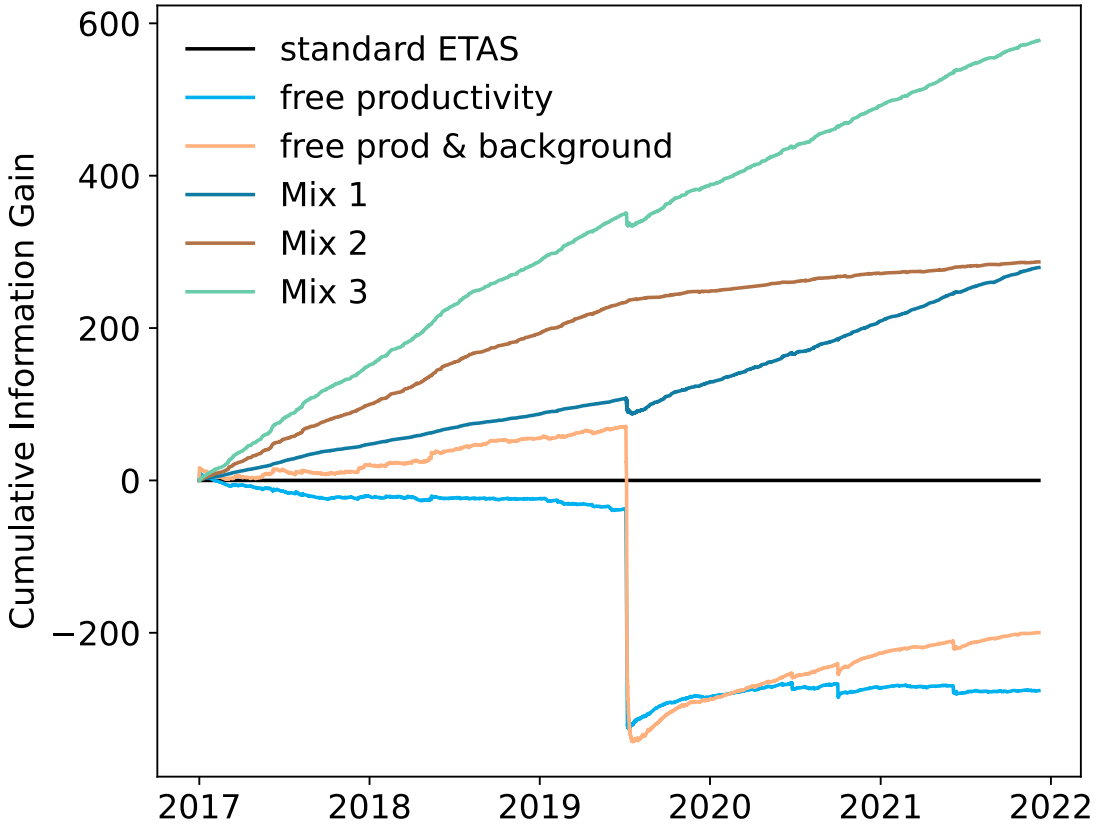
$\mu_1 \cdot$  $+\nu_1 \cdot$ 

Mix 2

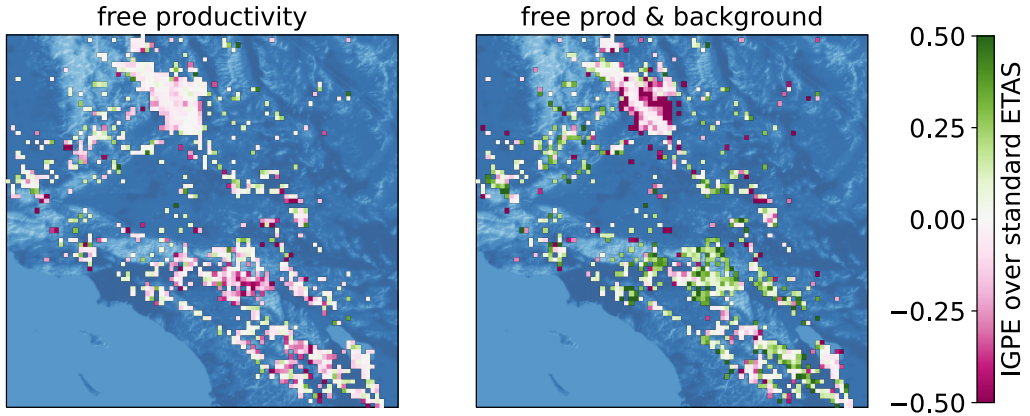
$\mu_1 \cdot$  $+\nu_1 \cdot$ 

Mix 3

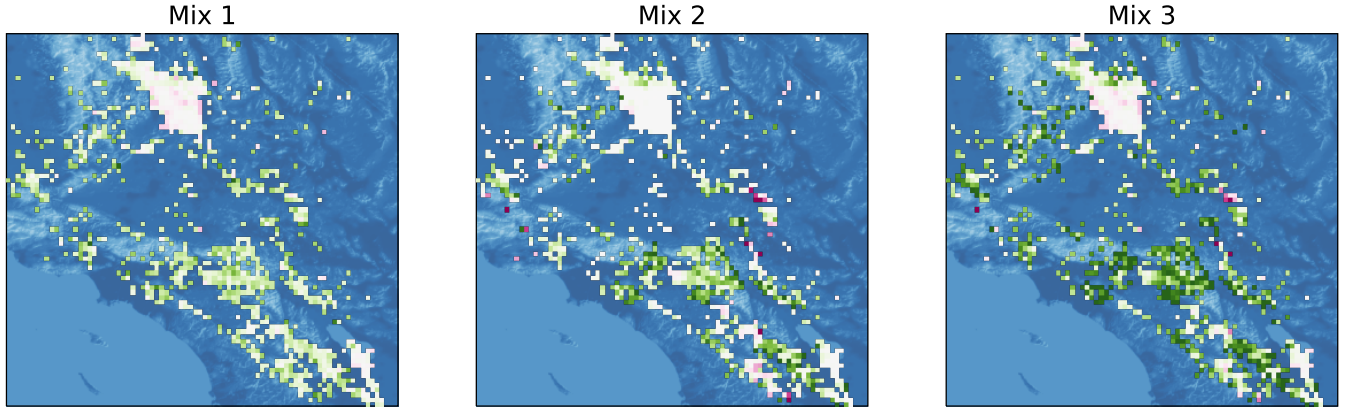
$\mu_1 \cdot$  $+\nu_1 \cdot$ 

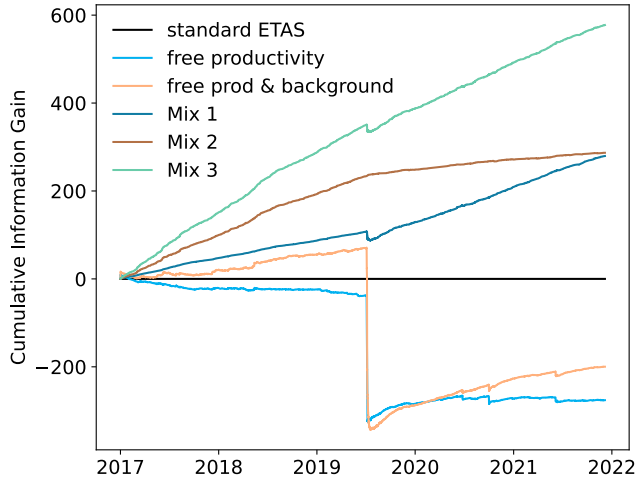


Information gain per Earthquake (IGPE) over standard ETAS

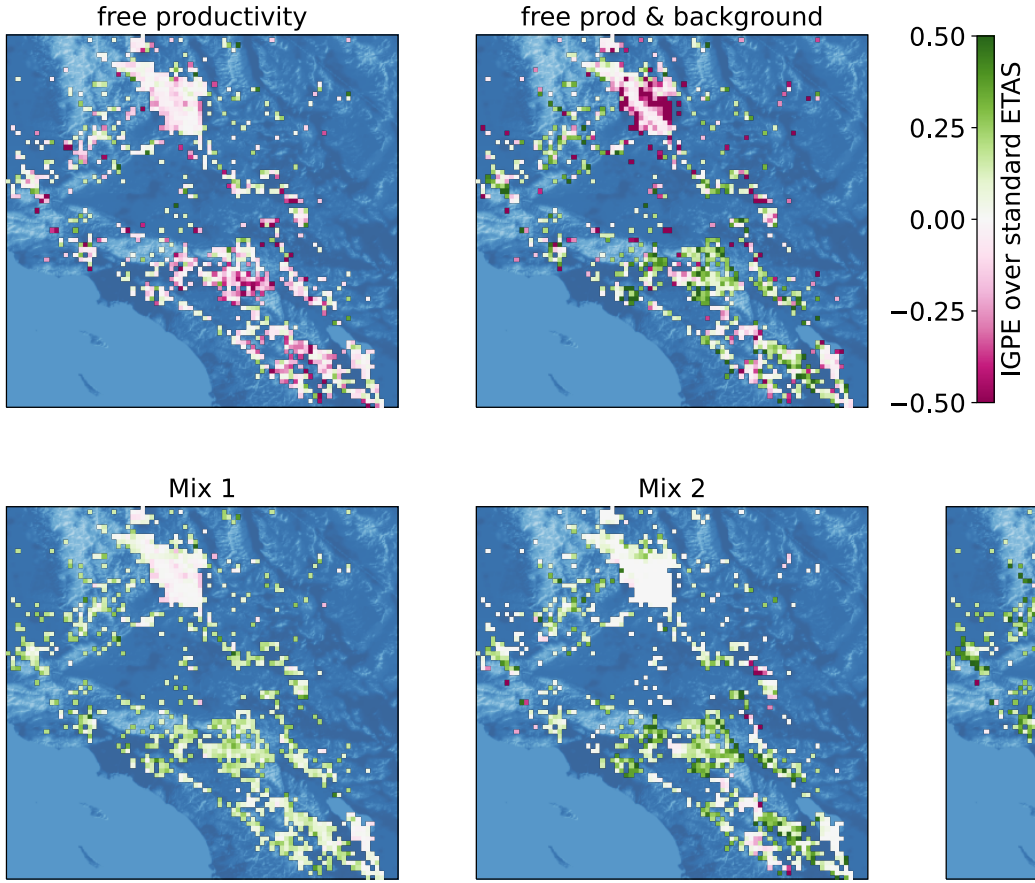


	Free productivity	Free prod & background	Mix 1	Mix 2	Mix 3
IGPE	-0.022	-0.016	+0.022	+0.023	+0.046
p-value	1.000	0.999	0.000	0.000	0.000
Average IGPE per cell (5x5km)	-0.055	+0.008	+0.108	+0.104	+0.215





Conclusions



- **Flexible ETAS** models can outperform standard ETAS, but not consistently
- Component-driven ensembling of different models is a **promising approach** towards better earthquake forecasting
- They **help us understand** what a model captures well and where its weaknesses are
- There are **more ensembles** to test: more ingredient models and more combinations thereof
- We will test them **prospectively** in an upcoming forecasting experiment for Italy

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