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C A U
Kiel University
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MARDATA HELMHOLTZ SCHOOL FOR MARINE DATA SCIENCE

GEOMAR

Links between climate and volcanism

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Motivation

Does climate affect volcanism?

- Increased volcanic activity following last glacial cycle
- Coinciding periodicities between eruptions and climate cycles
- **Limited statistical methods**


Photograph courtesy Árni Sæberg, Icelandic Coast Guard http://news.nationalgeographic.com

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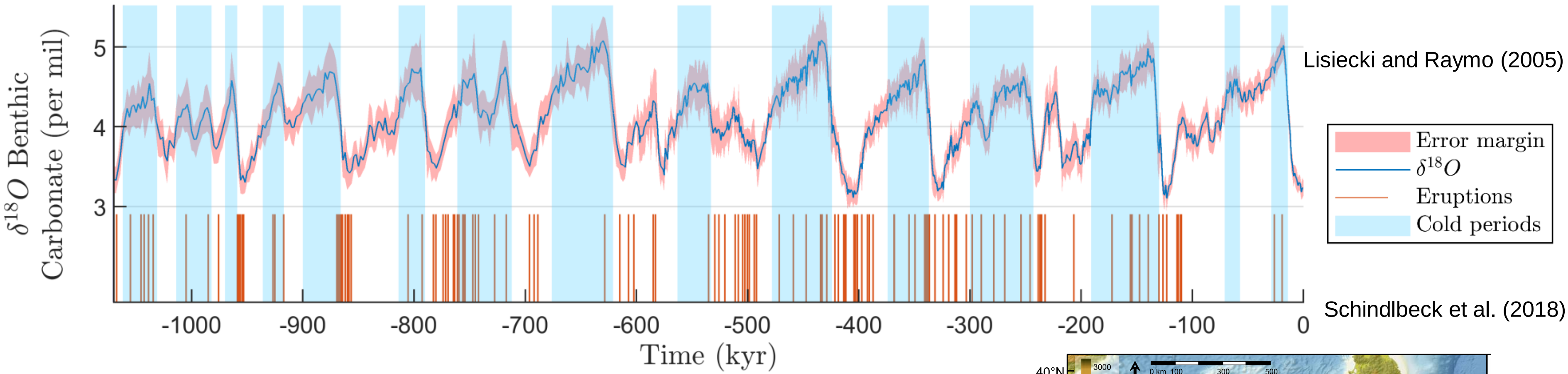
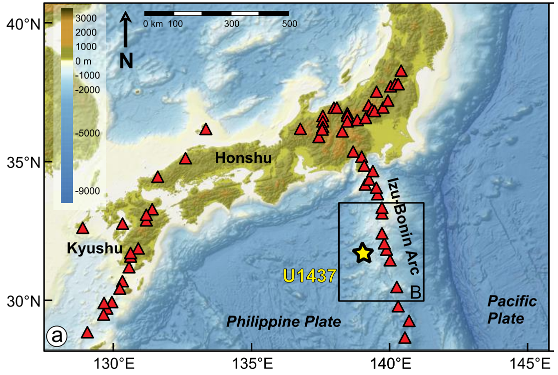
Data



Lisiecki and Raymo (2005)

Schindlbeck et al. (2018)



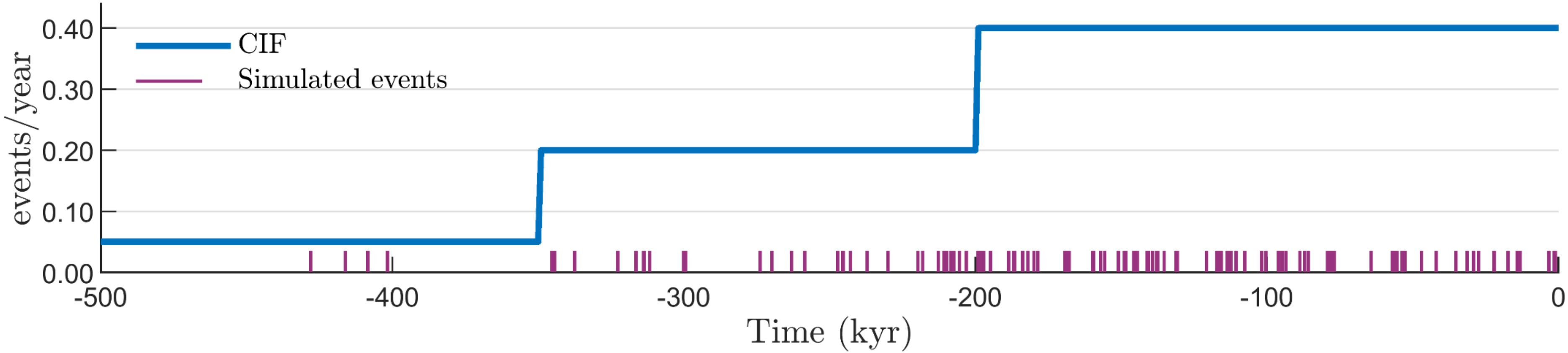
- ➢ 1.1 Myr tephra record from IODP hole 350-U1437B
- ➢ Climate proxy – $\delta^{18}O$ global reference stack

Influence of continuous time series on binary events?

Modeling

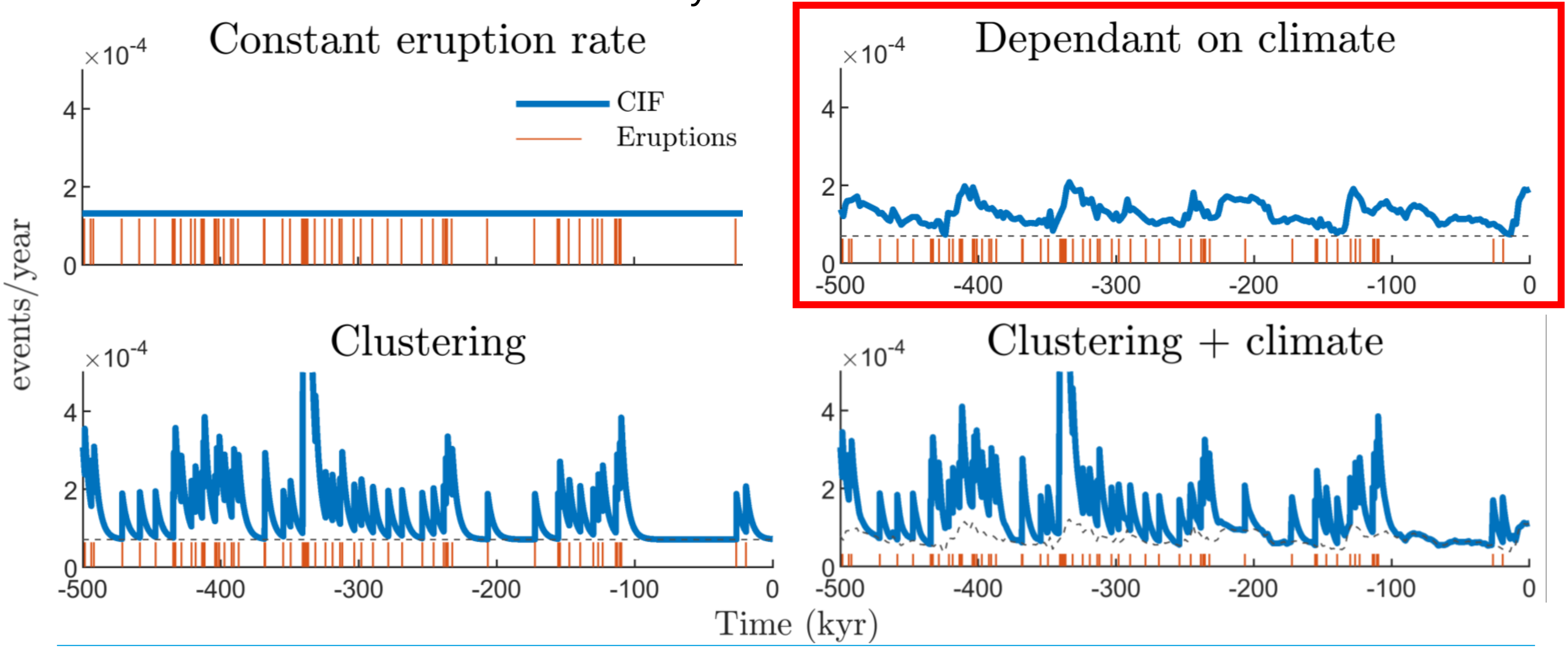
Point processes

- Random events $(t_1, t_2, t_3, \ldots)$ on the time interval $[-T, 0]$
- Conditional Intensity Function (CIF) – Eruption rate at each point in time

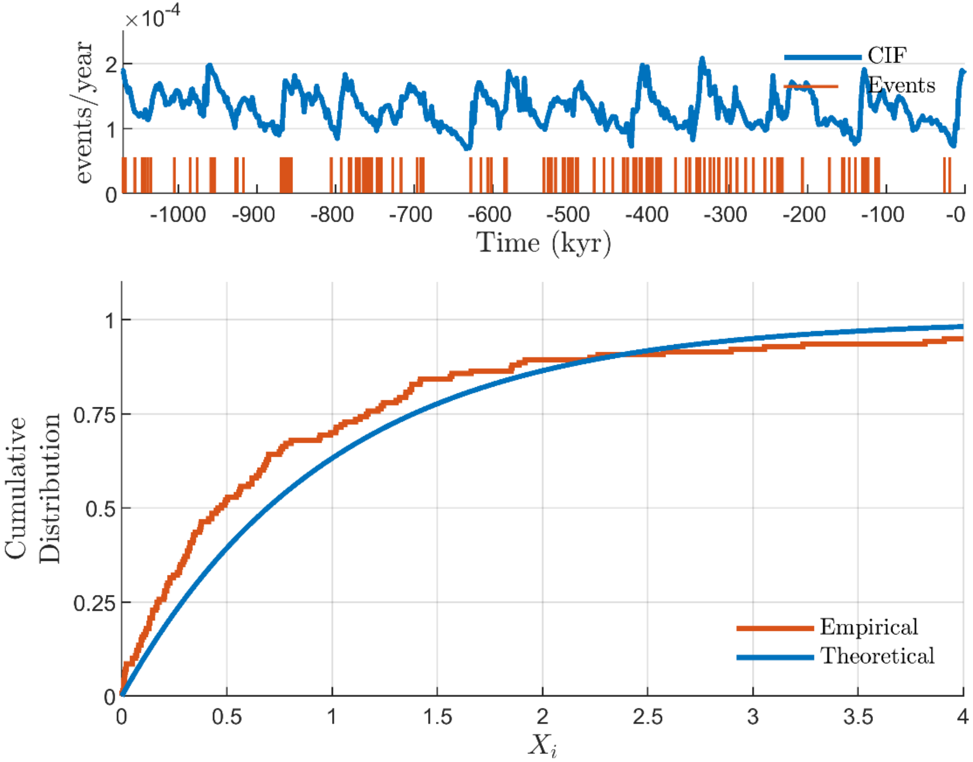


Four Hypotheses

- What is the true conditional intensity function?



Hypothesis testing – known parameters



Hypothesis – True parameters θ_0

Key result – If $(t_1, \dots, t_N)$ are events generated from $\lambda(\cdot;\theta)$, then

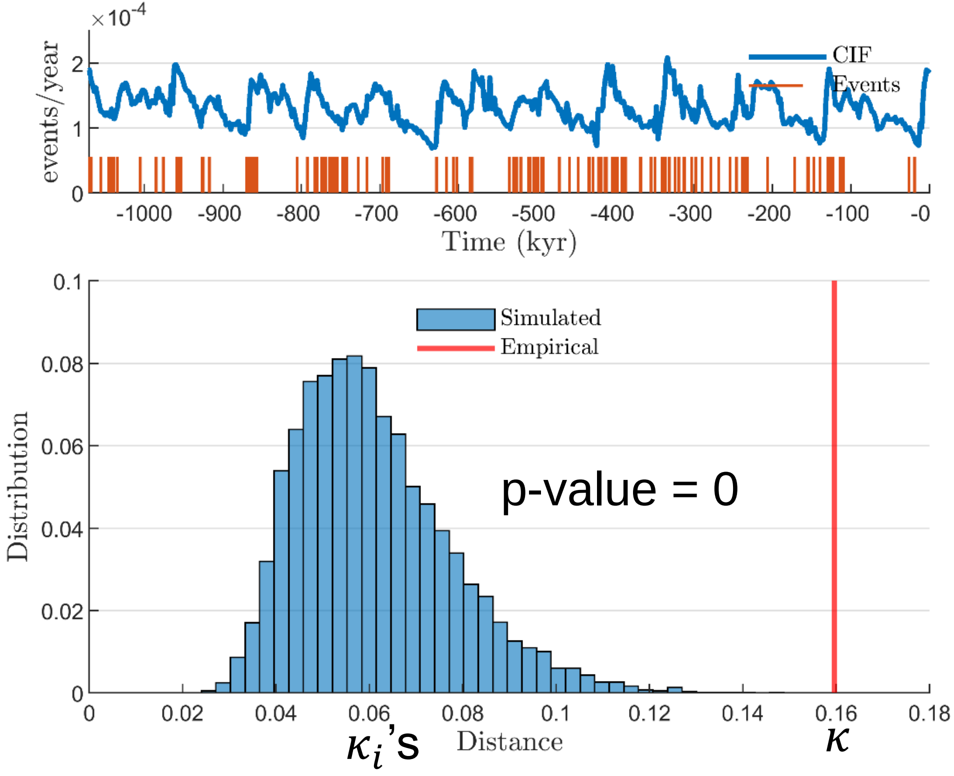
$$X_i = \int_{t_i}^{t_{i+1}} \lambda(s;\theta)ds$$

are i.i.d. unit exponential r.v.'s

Distance - $KS\big(\theta, (t_1, \dots, t_N)\big)$

Idea – Compare $KS\big(\theta_0, (t_1, \dots, t_N)\big)$ with $KS\big(\theta_0, (s_1, \dots, s_N)\big)$ where $(s_1, \dots, s_N)$ where $(s_1, \dots, s_N)$ are known to come from $\lambda(\cdot, \theta_0)$

Hypothesis testing – unknown parameters



Hypothesis – There is some θ_0 such that $\lambda(\cdot;\theta_0)$ is the true intensity

Current procedure

1. Estimate θ_0 from data as $\hat{\theta}$
2. Replace θ_0 by $\hat{\theta}$ in previous slide

Correct procedure

1. Estimate θ_0 from data as $\hat{\theta}$
2. Calculate $\kappa = KS(\hat{\theta}, (t_1, \dots, t_N))$
3. Simulate 1000 events from $\lambda(\cdot;\hat{\theta})$
4. For each simulation, calculate κ_i as in steps 1 and 2, with $\hat{\theta}$ replacing θ_0
5. Compare κ with the κ_i's

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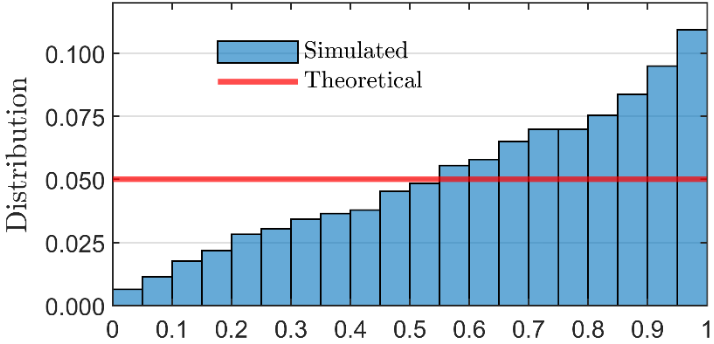
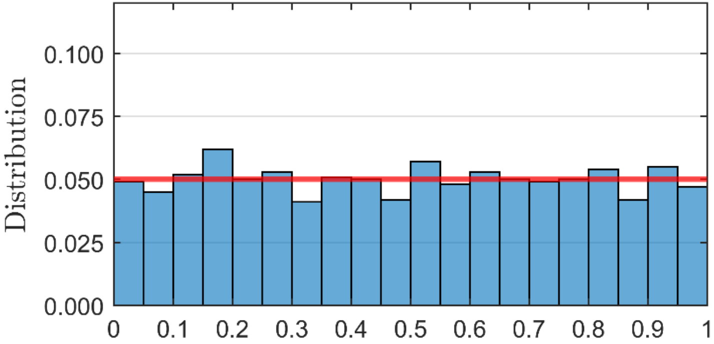
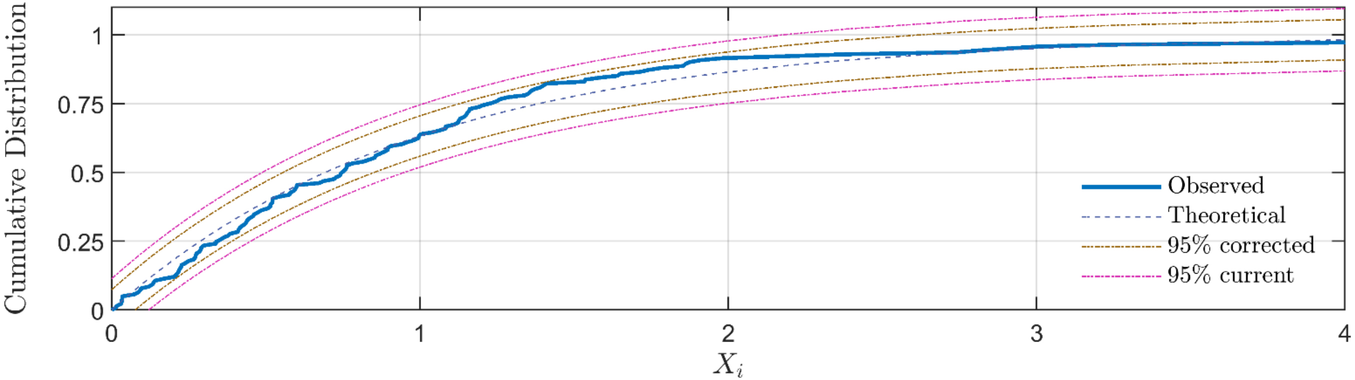
Hypothesis testing – comparison

Current procedure

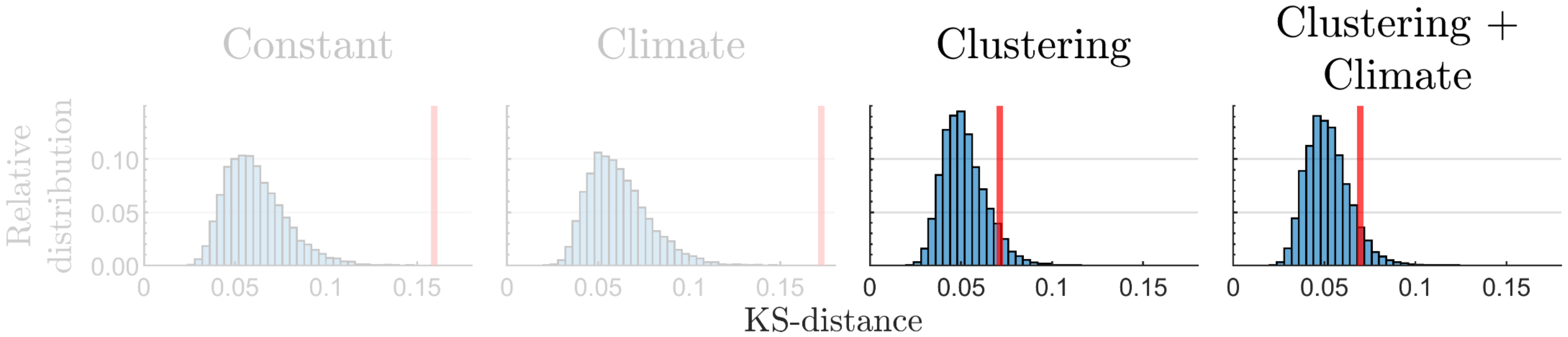


Correct procedure





Results – complete eruption record

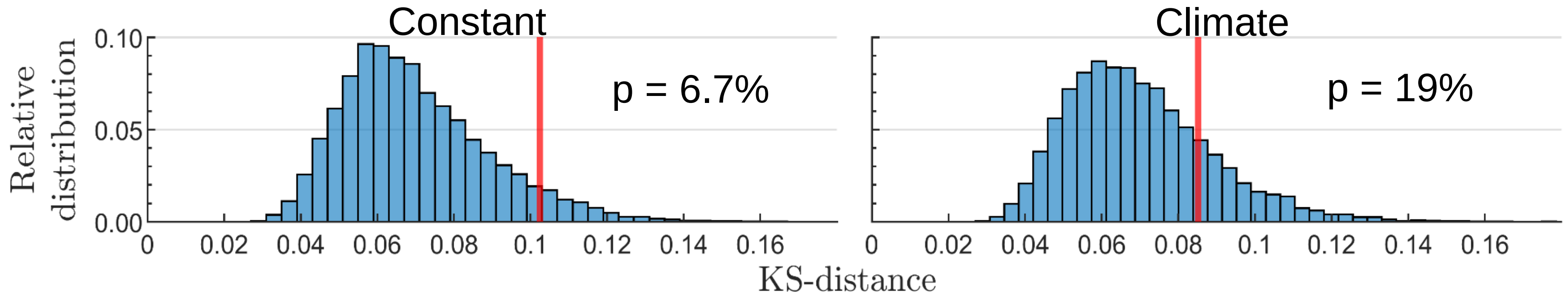


p = 0%   p = 0%   p = 6%   p = 8%

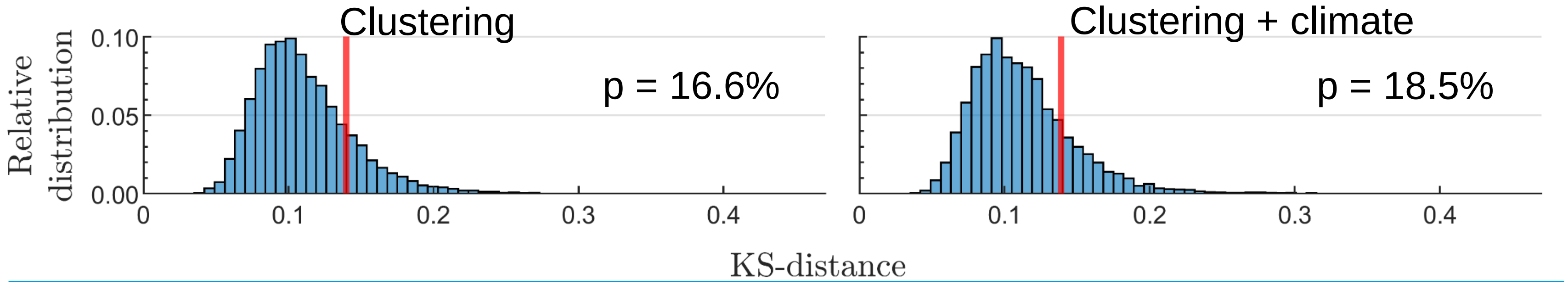
- First two hypotheses rejected
- Last two not rejected at a 95% level

Results – different magma composition

Felsic eruptions



Mafic eruptions



Conclusions

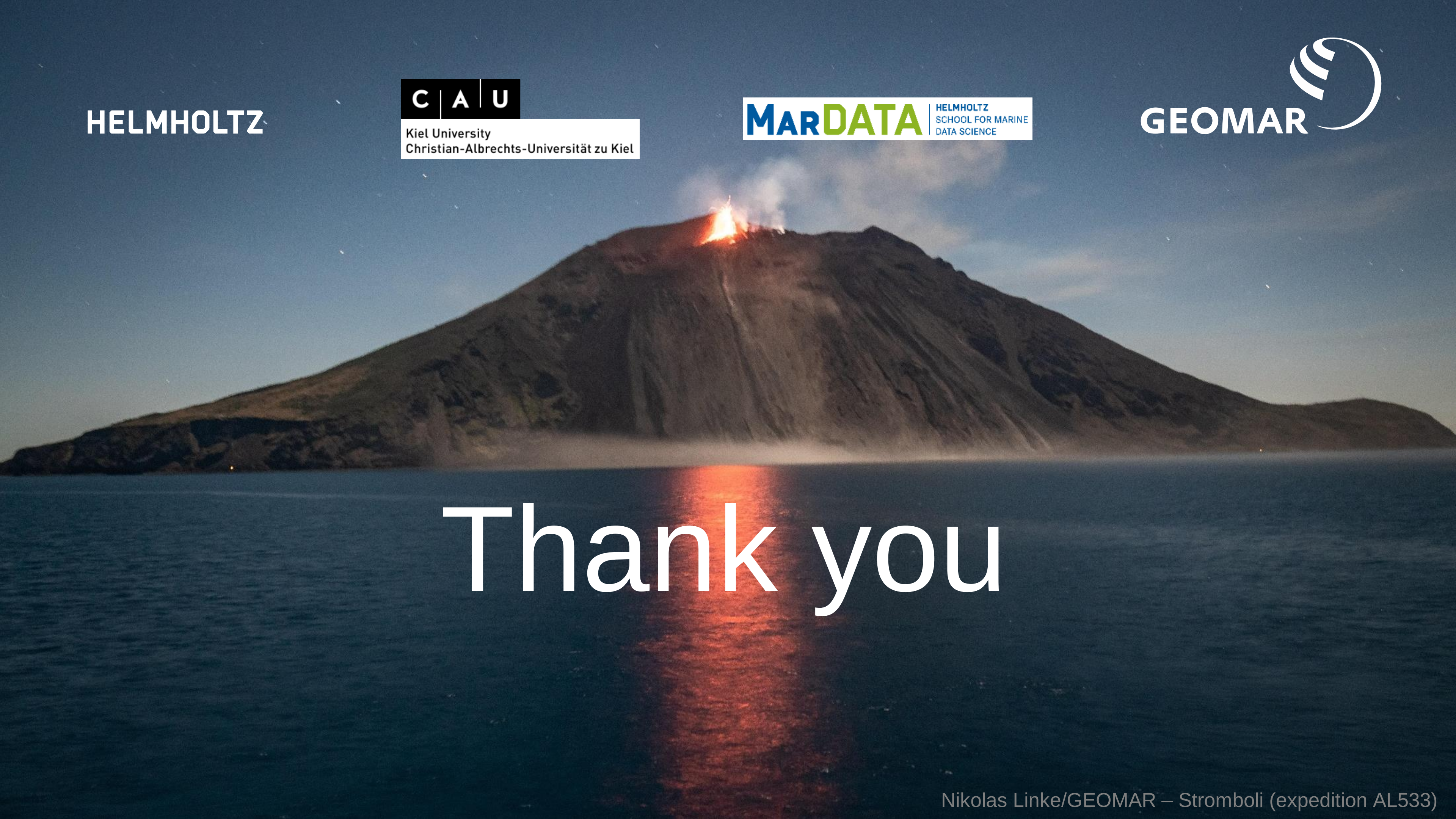
Analysis of the data

- Eruption rate is not constant
- Clustering due to mafic eruptions – Felsic eruptions dependent on climate

Advantages of the method

- Sound statistical procedure. Reliable even for small datasets
- Flexibility – Earthquakes and tides. Other applications?

MATLAB code – OceanRep, Point Process Tools (DOI: 10.3289/SW_5_2023)
Kling et al. (2023) - Under review process for Frontiers of Earth Science



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Thank you

Nikolas Linke/GEOMAR – Stromboli (expedition AL533)

Four hypotheses - Parametrization

1. Constant eruption rate – Poisson process

$$\lambda_{HP}(t;\mu) = \mu$$

2. Dependent on climate – Inhomogeneous Poisson process

$$\lambda_{IP}(t;\mu,\gamma) = \mu + \gamma f(t)$$

3. Clustering – Hawkes process

$$\lambda_{HH}(t;\mu,\alpha,\beta) = \mu + \sum_{t_i<t} \alpha\, e^{-\beta(t-t_i)}$$

4. Clustering + climate – Inhomogeneous Hawkes process

$$\lambda_{IH}(t;\mu,\gamma,\alpha,\beta) = \mu + \gamma f(t) + \sum_{t_i<t} \alpha\, e^{-\beta(t-t_i)}$$