An automated method for building non-planar 3D fault models from earthquake hypocenters

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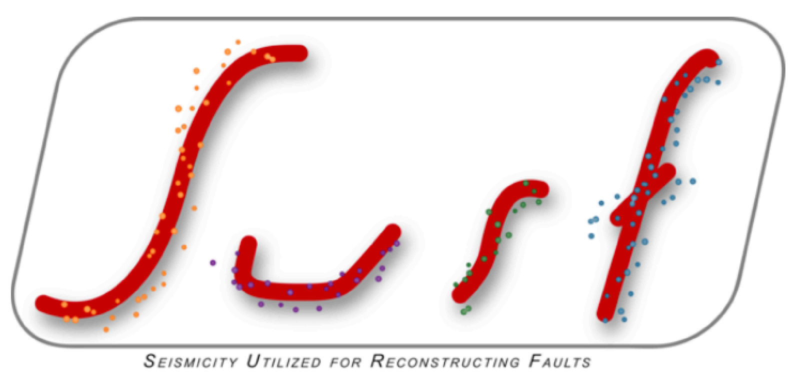
USGS science for a changing world

INTRO

Now available! an open source python package for constructing fault geometries from seismicity patterns.

README.md



SURF: Seismicity Utilized for Reconstructing Faults

SURF is a python-language code for modeling fault surfaces in 3D using hypocentral locations

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Overview

SURF is an algorithm to generate 3D fault models. This algorithm utilizes open-source, well known and documented packages, to generate fault models that require very few user input parameters.

Features

- **Automated event clustering**: Uses network-based clustering to identify fault-related seismicity.
- **Surface merging**: Combines small, coplanar clusters to construct continuous fault surfaces.
- **SVR-based fitting**: Applies support vector regression to estimate fault geometries.
- **3D visualization**: Generates interactive visualizations of fault models.

Try it out!
https://code.usgs.gov/esc/surf

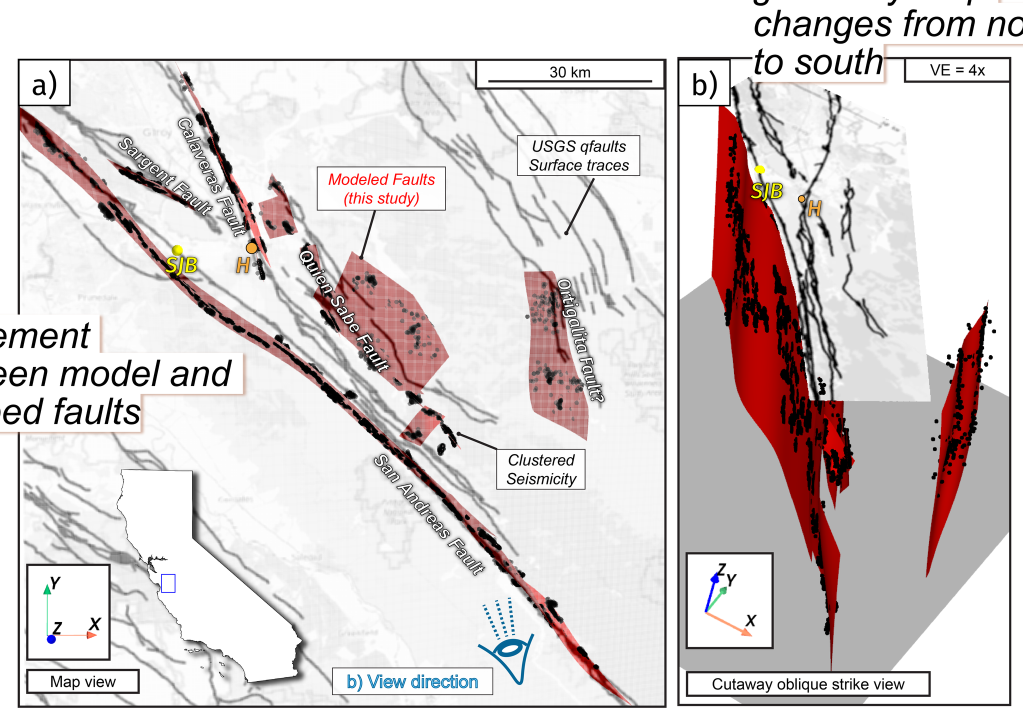
(Alongi et al., 2025 - SRL)

RESULTS

Example - San Juan Bautista

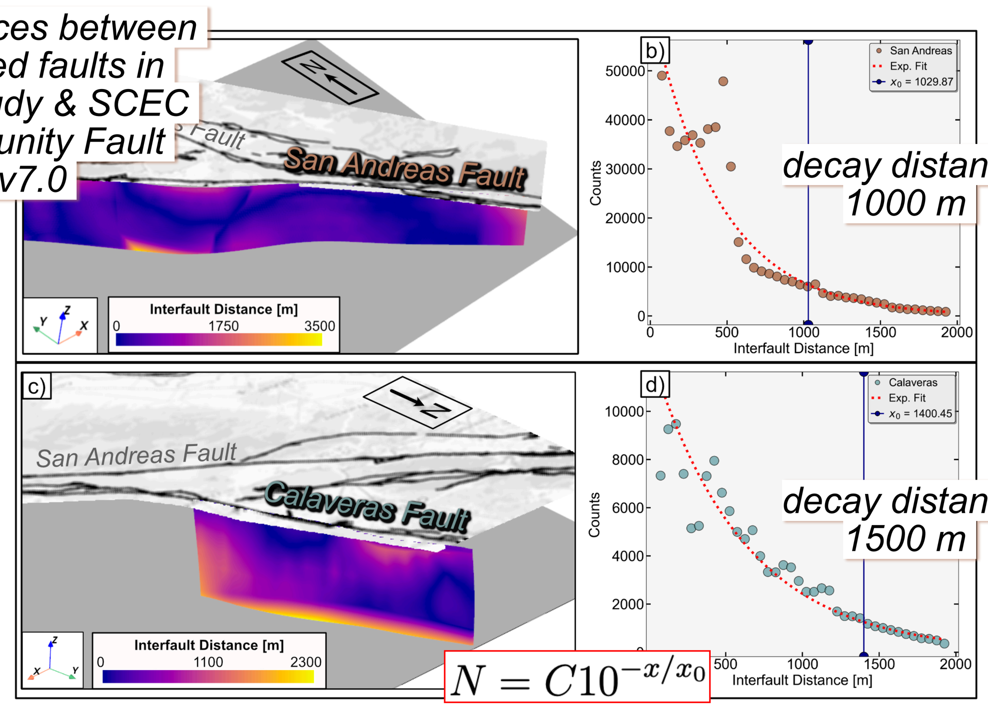
Non-planar fault geometry - dip changes from north to south

Agreement between model and mapped faults



How do results compare to existing fault models?

Distances between modeled faults in this study & SCEC Community Fault Model v7.0



$$N = C10^{-x/x_0}$$

NEW!

Hazards application

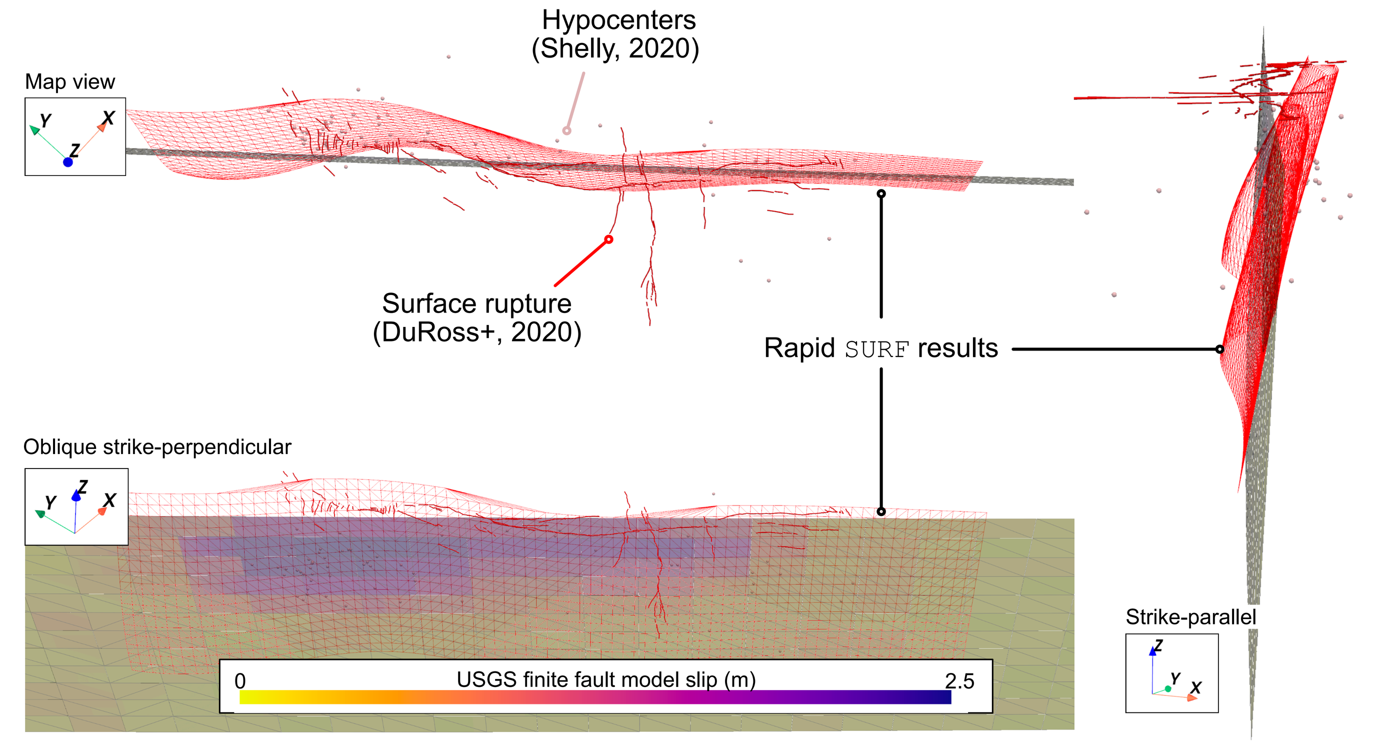
Rapid fault geometry calculation with early aftershocks

We can speed up the finite fault inversion process using early aftershocks to help define the fault geometry and build the mesh with SURF

15 minutes of data after the mainshock
N events = 66

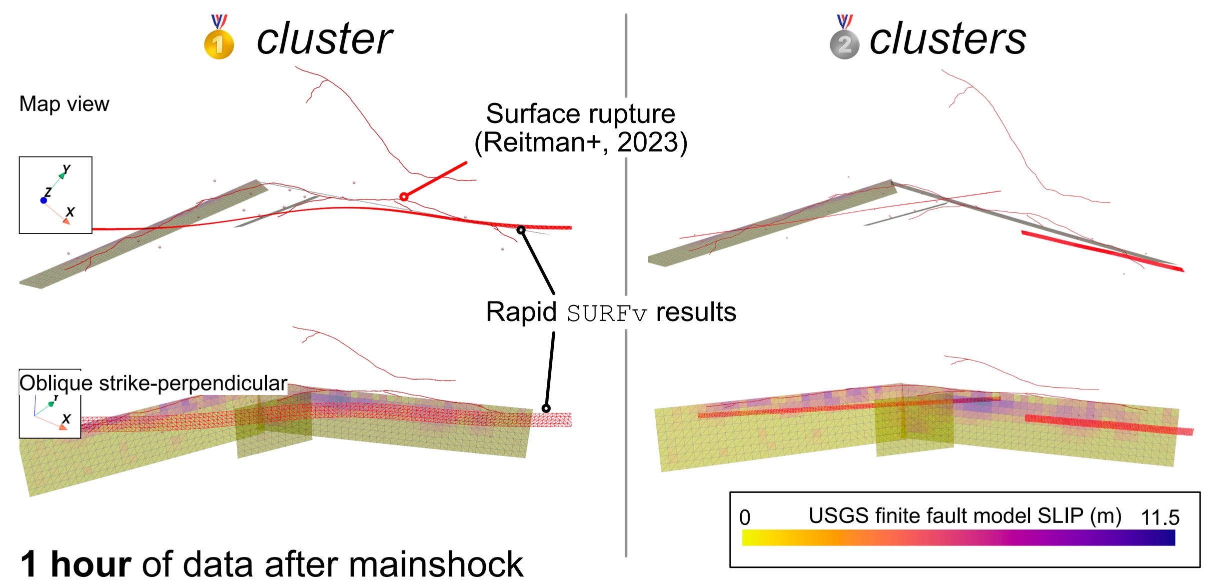
Note- agreement between the USGS finite fault result & the rapid SURF results

Test 1 - M 7.1 Ridgecrest



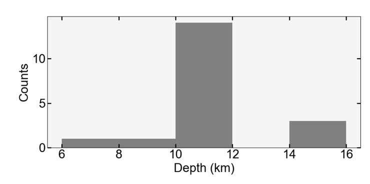
Test 2 - M 7.8 Pazarcik, Kahramanmaras

In some cases, multiple fault surfaces may be generated for longer and more complex fault geometries

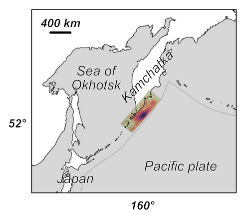


1 hour of data after mainshock
N events = 22

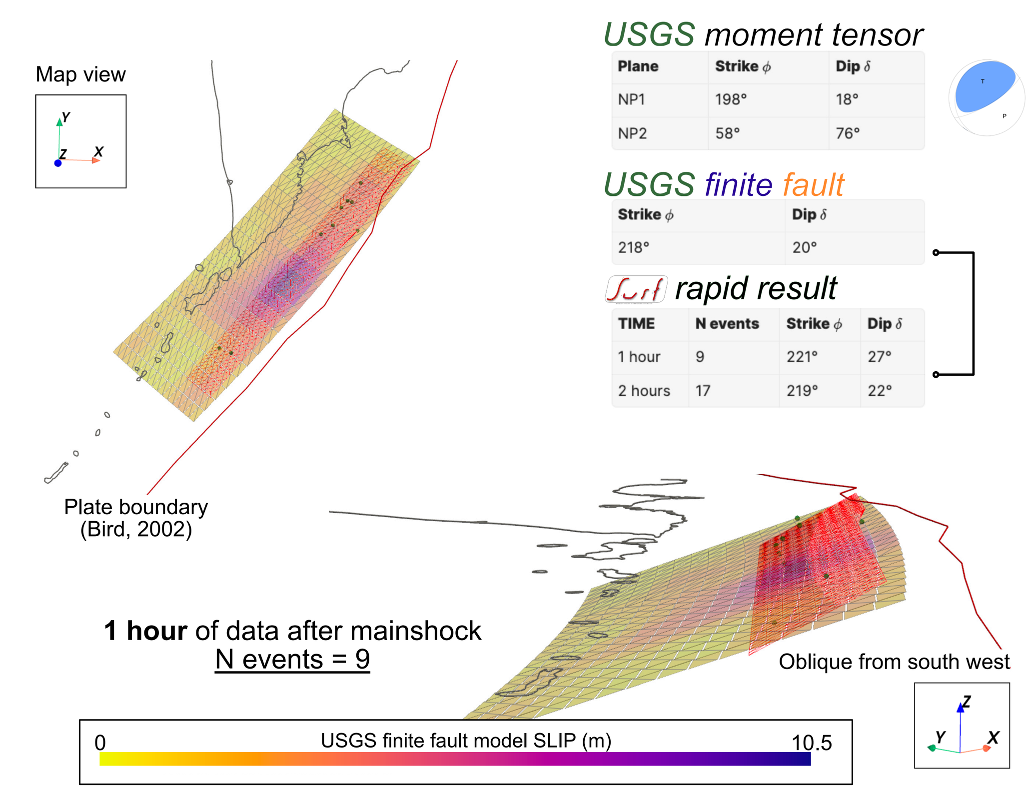
Potential limitation? - in some locations, hypocentral depth resolution may limit geometry confidence



Test 3 - M 8.8 Kamchatka

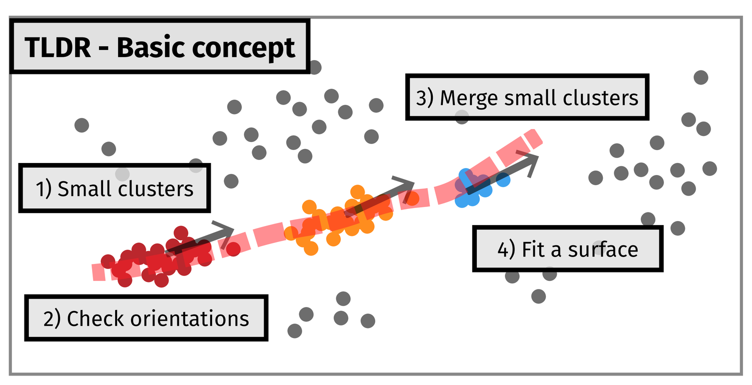


Works well for dipping subduction zone events.
Note- comparable geometry in 1 to 2 hours (~ 15 events)



1 hour of data after mainshock
N events = 9

HOW IT WORKS

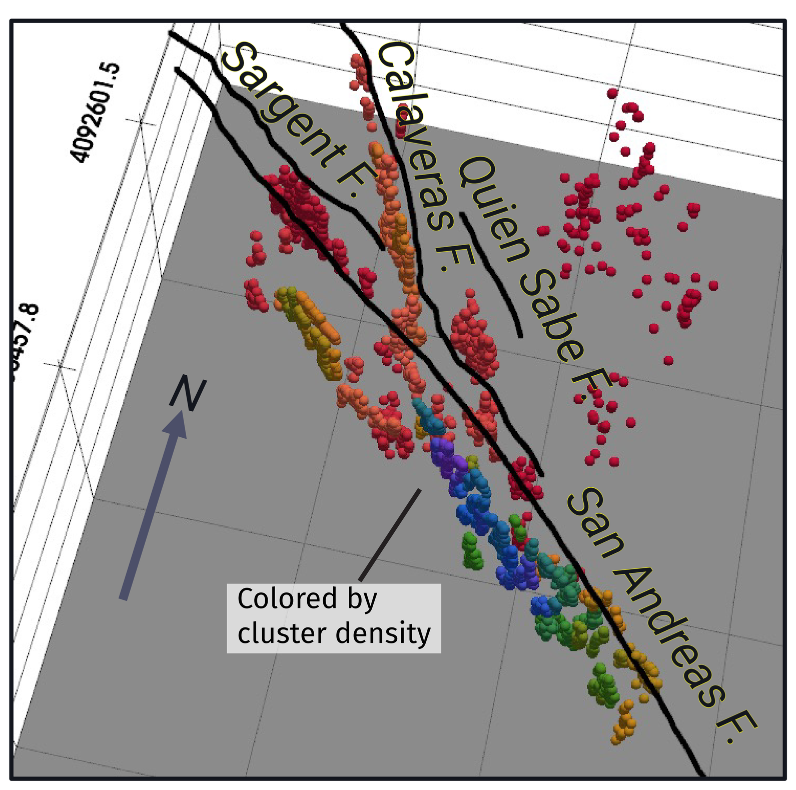


1. clustering

Hierarchical Density Based Spatial Cluster Applications with Noise **HDBSCAN**

Requires only one parameter- the minimum number of events to be considered a cluster

We set this to 40 events allowing orientations to be determined and remain small



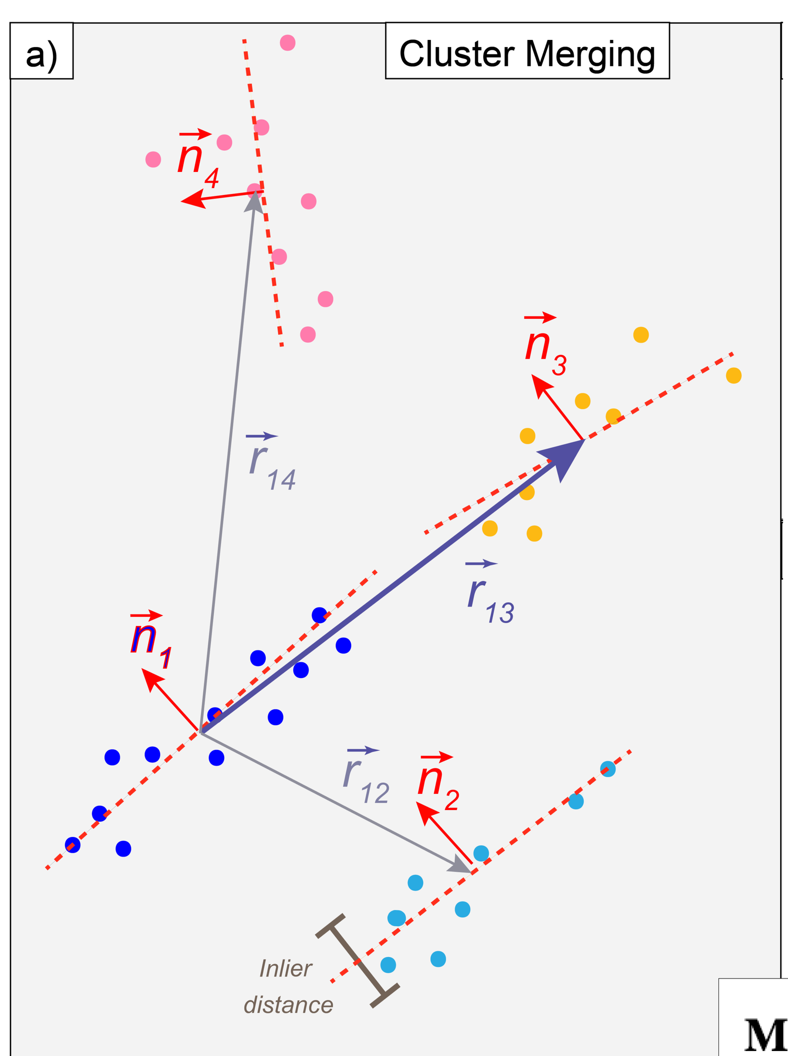
2. a) measure coplanarity

Earthquake cluster merging process.

1. Fit clusters with a plane using RANdom SAmpling Consensus to determine its normal vector, n.

2. Next, the k, nearest neighbor clusters are identified and the direction vector is calculated.

3. normal vectors and direction vectors are used to construct the measurement matrix **M,** that quantifies coplanarity of neighboring clusters



$$\vec{N} = \vec{n_i} \cdot \vec{n_{jk}}$$

$$\vec{D} = \vec{n_i} \cdot \vec{r_{jk}}$$

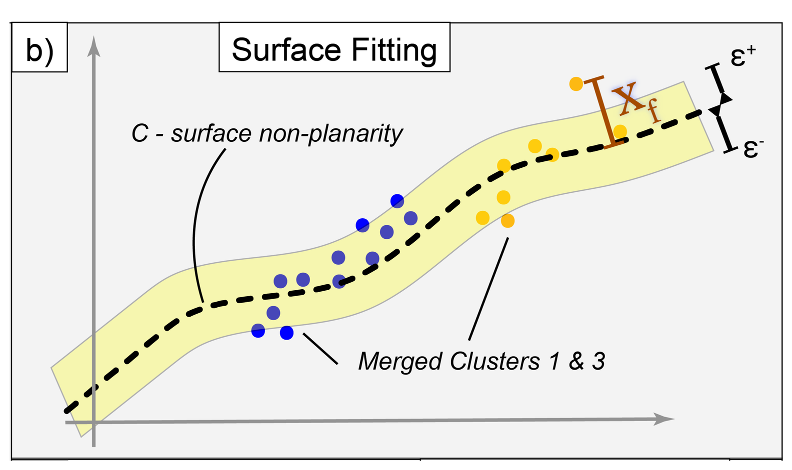
$$\mathbf{M} = |\vec{N}| \cdot (1 - |\vec{D}|)$$

3. b) surface fitting

A cartoon illustration to help build intuition about the support vector regression (SVR) surface fitting parameters, C and ϵ.

C describes how non-planar the modeled fault surface is, with higher values indicating greater non-planarity.

ϵ describes the length scale near the surface where points do not impact the fit.



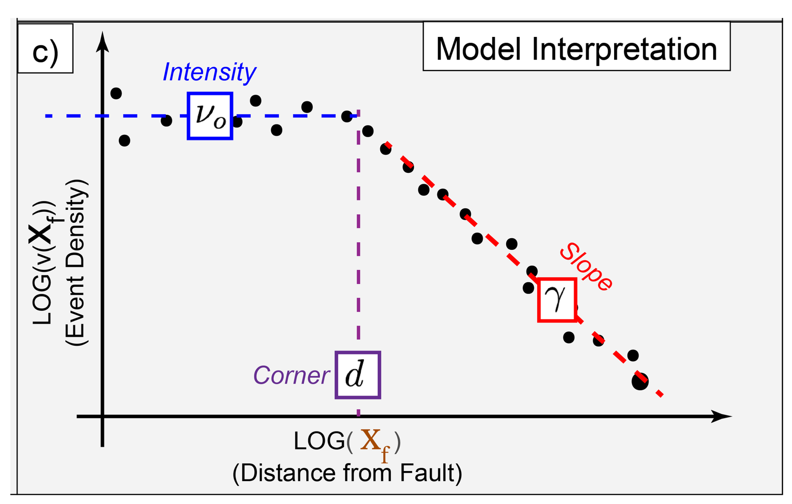
4. c) quality indicators

To assess the reliability of the algorithm's outputs, we measure the spatial distribution of earthquake density around the modeled fault surface.

The relationship between earthquake density and distance is an inverse power law relationship. We fit the following equation,

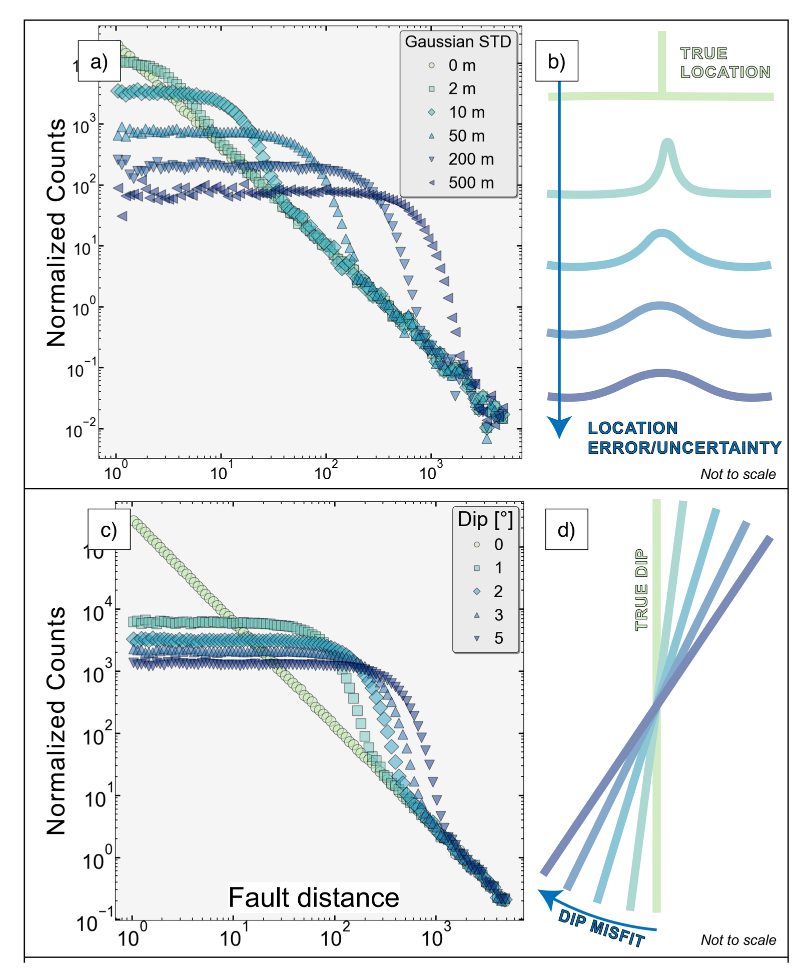
$$\nu(x) = \nu_o \left(\frac{d^m}{|x|^m + d^m}\right)^{\frac{\gamma}{m}}$$

Schematically



5. Impact of misfit and unmodeled complexity on a power law distribution of earthquakes

The points (green circles) are prescribed an idealized distribution around the fault with lateral distances being power law distributed from a line.



Note, examples feature a similar result of moving the corner of the power law further from the fault with increasing unaccounted for fault complexity or fit errors.