Using the Least-squares Inversion to Find the Best Fitting Fault Plane for the Maacama Fault Near The Geysers

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0.1 Abstract

Determining the plane of a fault is fundamental to understanding the behavior of a fault and the broader role it plays in the surrounding fault system. Using earthquake data from the Double-Difference Earthquake Catalog for Northern California (Waldhauser & Schaff 2008), we write a MATLAB code to preform a least-squares inversion to determine the best fitting plane for a small section of the Maacama Fault nearest to The Geysers geothermal field. We then model the plane in 3 dimensions and calculate the dip of the fault. We find that the calculated dip suggests a near-vertical dipping fault plane, which aligns with trends seen in the seismicity along the fault.

0.2 Introduction

The Maacama Fault is a right-lateral fault in northern California extending from near Laytonville in Mendocino County to Mark West Creek in Sonoma County. It is thought to be a near-vertical fault with an average strike of N28W. The Maacama Fault is creeping along a large portion of its 160 kilometer total length.

The section of the Maacama fault from which earthquake data was used (Figure 1) is the portion nearest to The Geysers geothermal field. The creep rate here is the highest along the entirety of the fault, potentially the result of the changing pore pressure in the subsurface due to the extraction of steam at the geothermal plant. The higher creep rate allows us to infer that there are more repeating earthquakes along this segment, which typically occur directly on the fault plane. This will hopefully result in a better fitting plane from the least-squares inversion.

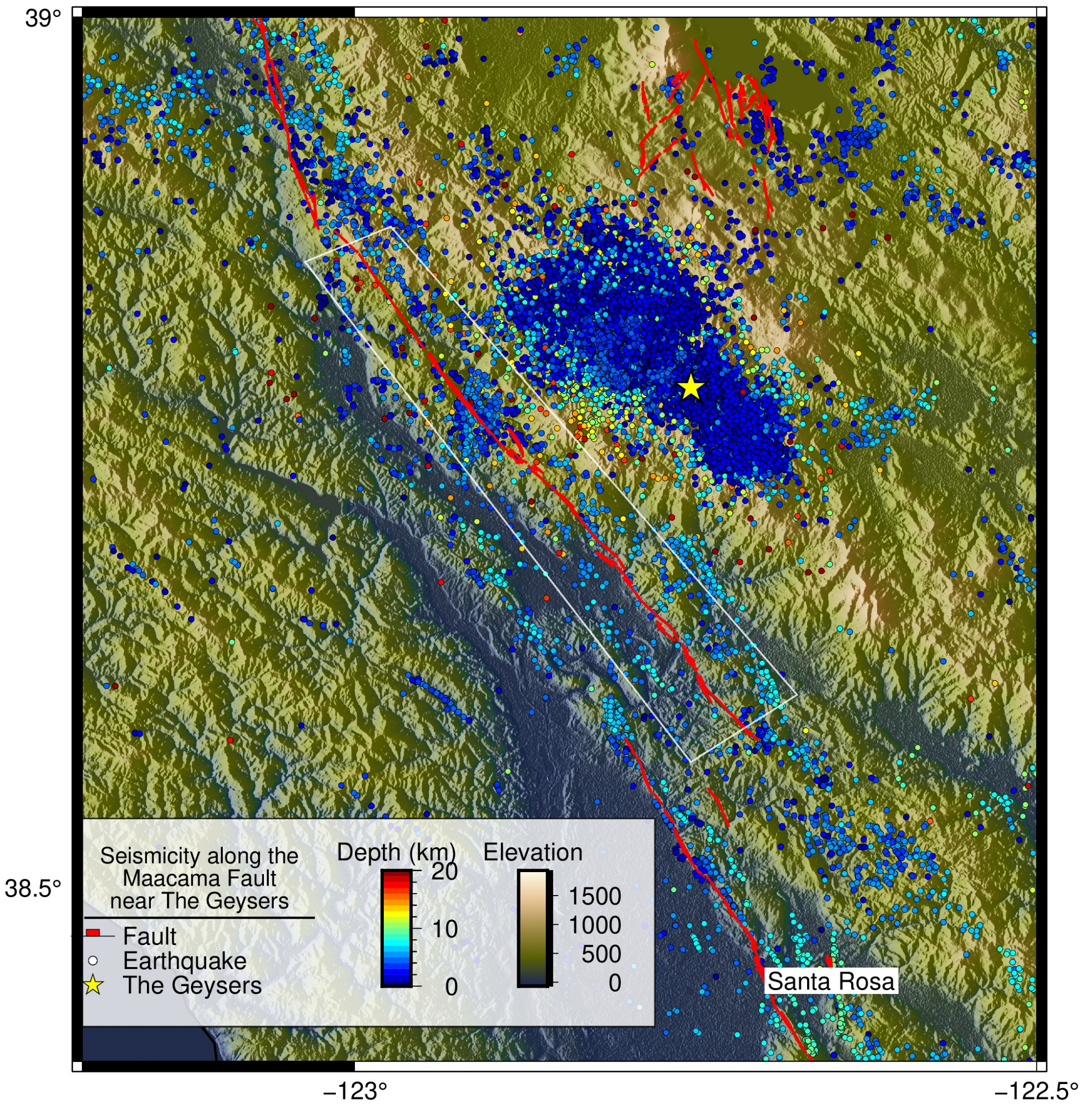

Figure 1: Map of seismicity along the Maacama Fault near The Geysers geothermal field (yellow star). The earthquakes within the white polygon along the fault are the events used as the dataset for the least-squares inversion.

0.3 Methods

The data used for the least-squares inversion was obtained from the Double-Difference Earthquake Catalog for Northern California (1984-2011) (Waldhauser & Schaff, 2008). The data was loaded into MATLAB, where the built-in tool 'inpolygon' was used to select only the data within a drawn polygon (figure 2) around a section of the fault near The Geysers. The latitudes and longitudes of the events were then converted to UTM using the MATLAB function 'deg2utm' prior to preforming the least-squares inversion.

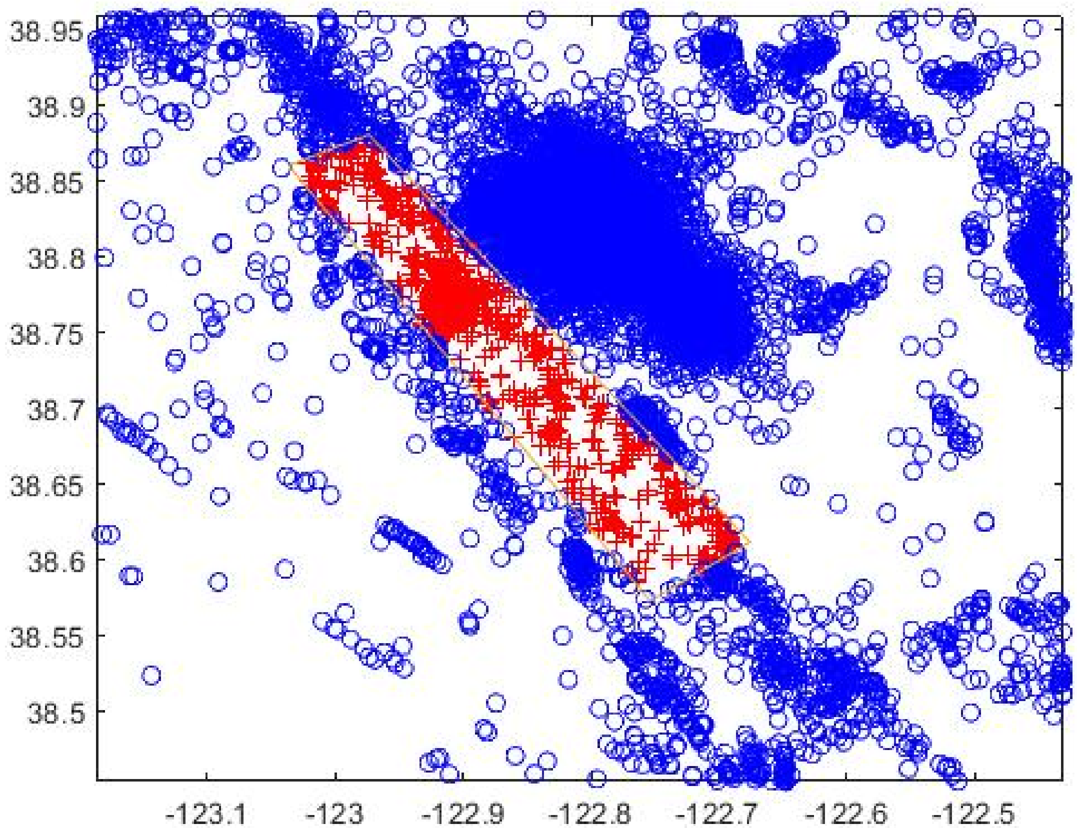

Figure 2: The result of using the built in MATLAB function 'inpolygon' to select the data for the inversion. The red crosses are earthquakes within the drawn polygon around the Maacama Fault. The blue circles are earthquakes outside of the polygon.

To set up the design matrices for the inversion, we start with the equation of a plane:

$$x = ay + bz + c$$

where x are the eastings, y are the northings, and z are the depths (km) of the earthquake locations. We then set up the design matrix for our least-squares inversion:

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} y_1 & z_1 & 1 \\ y_2 & z_2 & 1 \\ y_3 & z_3 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

Using this equation, we set up our least-squares inversion:

$$\vec{x} = A \backslash \vec{b}$$

where our vector 'x' contains our coefficients (a, b, c), our design matrix 'A' includes the depths, eastings, and a column of 1s, and our vector b contains our northings.

The least-squares inversion solves for the coefficients a, b, and c, and then we plug them back into our plane equation to find the best fitting plane for the seismic data along the Maacama Fault.

After doing so with the planar equation, we then tried the same process using the equation of a quadratic surface:

$$x = ay^2 + bz^2 + cyz + dy + ez + f$$

however, when attempting the least-squares inversion with this equation, it was unsuccessful due to the lack of adequate data.

0.4 Results

According to the USGS, the dip of the Maacama Fault is estimated to be near-vertical. This aligns with our results for the best fitting plane shown in Figure 3, from which we calculated a dip of 88.48 degrees.

There appear to be two distinct trends of earthquakes parallel to each other on either side of the fault. Further analysis of the region could be done to fit an individual plane along each of the trends in order to compare the seismicity on both sides of the fault. Extending the polygon to cover a larger section of the fault would also be beneficial, as it may become possible to use the quadratic surface equation to obtain a more accurate fault geometry.

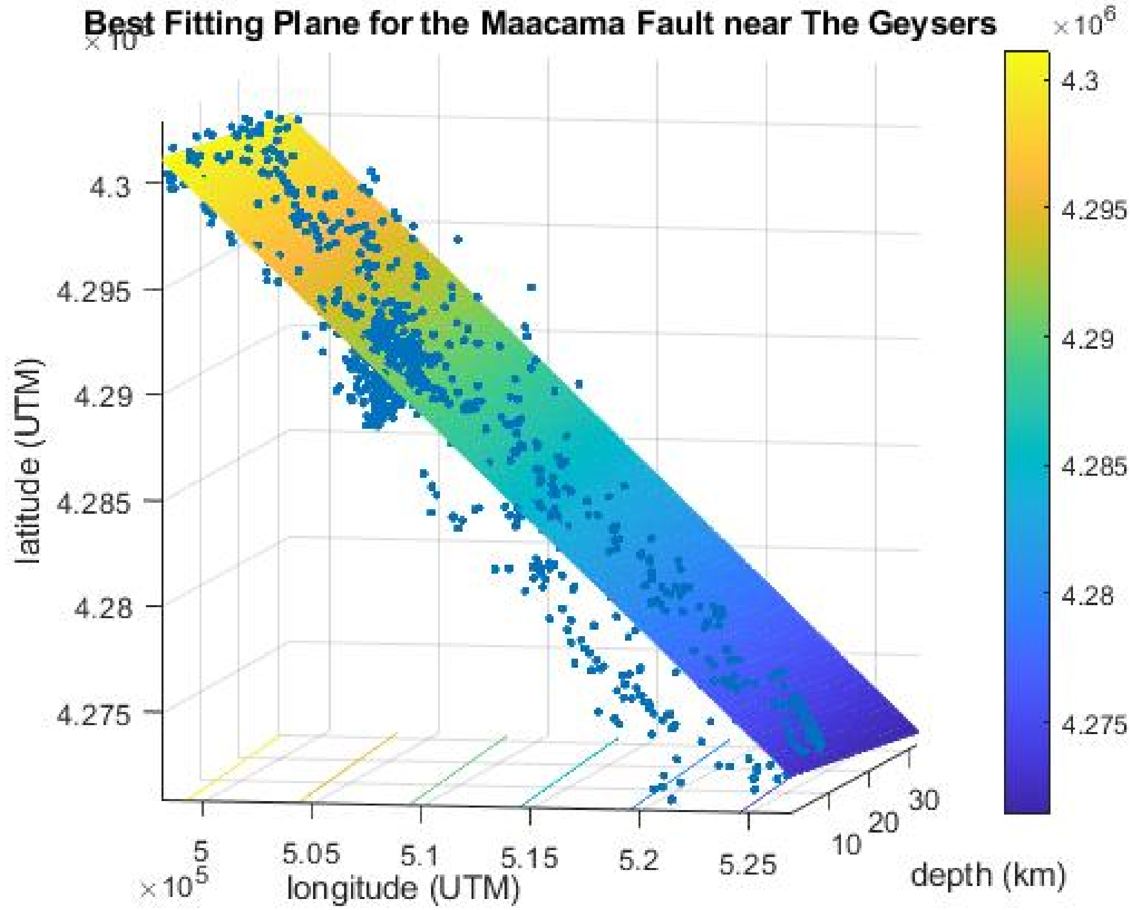

Figure 3: The modeled best fitting fault plane for the section of the Maacama Fault nearest to The Geysers geothermal field calculated by minimizing the eastings. The plane is calculated to be dipping at an angle of 88.48 degrees, confirming the suggestion that the fault plane is near-vertical.

0.5 Discussion

Prior to minimizing the eastings to solve for the coefficients through the least-squares inversion, we attempted to minimize the depths instead. Figure 5 shows the result of this inversion, with the fault plane appearing near horizontal.

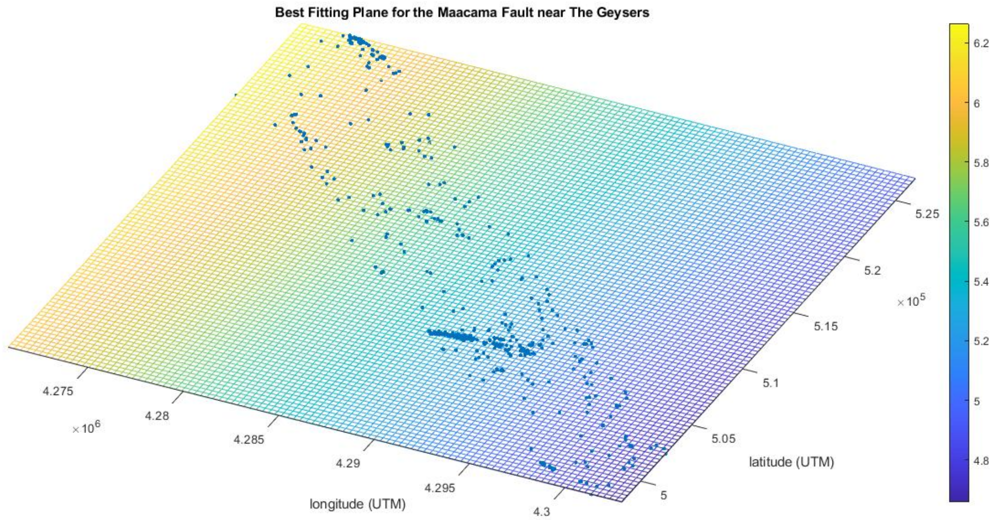

Figure 4: The modeled best fitting fault plane when minimizing the depths. The fault plane is near horizontal, despite being assumed to be near-vertical.

Because the fault plane is near-vertical, minimizing the depths will result in very large values for earthquakes far from the fault plane, and very small values for earthquakes directly on it. These values resulted in the fault plane appearing to be near-horizontal, despite being estimated to have a near-vertical dip.

0.6 References

Waldhauser, F. and D.P. Schaff (2008), Large-scale relocation of two decades of Northern California seismicity using cross-correlation and double-difference methods, J. Geophys. Res., 113, B08311, doi:10.1029/2007JB005479.