Spatial Mapping of b-value of earthquakes at Salton Trough and Imperial Valley, Southern California

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1 Introduction

The Imperial Valley, situated to the south of the Salton Sea in southern California (Figure 1), is a region characterized by transtensional tectonics. This involves a complex interplay between the Cerro Prieto fault in the south, which is part of the main plate boundary, and the San Jacinto fault in the west. Additionally, there is a significant right step between the Cerro Prieto fault and the southern San Andreas fault (Fuis, Mooney, & Wallace, 1990). The Salton trough is the host of two of the largest fluid-dominated geothermal energy fields in the world: the Salton Sea geothermal production field in southern California and the Cerro Prieto field in Mexico. The geothermal production in these fields has inadvertently led to an increase in seismic activity in the region (White, Nakata, Tribaldos, Nayak, & Dobson, 2022).

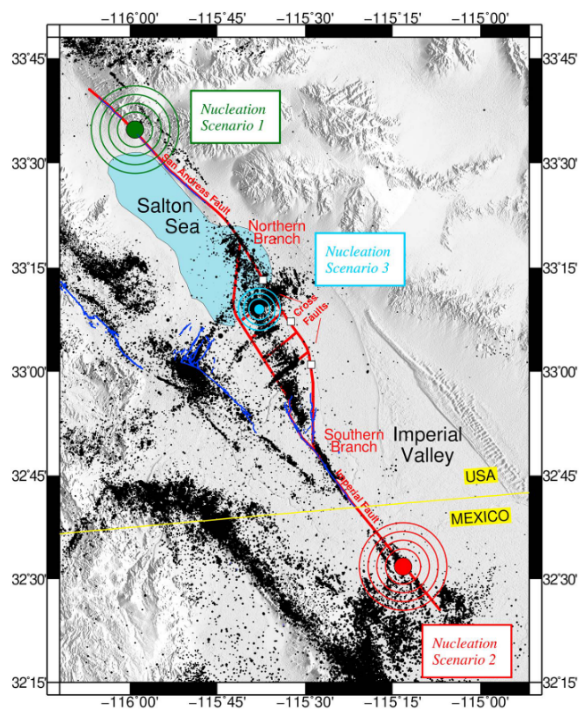

Figure 1: Fault traces (blue curves, USGS, 2006 and microseismicity lineaments (black dots) from relocated seismicity of Hauksson et al. (2012) of Salton Trough and Imperial Valley area in Southern California (adopted from (Kyriakopoulos et al., 2019))

Detailed analysis of seismic data has greatly contributed to advancements in seismology and earthquake forecasting. The recent series of earthquakes in the geothermal field of Mexico, which consisted of three events with a magnitude above 4.0, highlights the immediate requirement for improved evaluation of seismic risks in the Salton Trough/Imperial Valley area. This region is especially worrisome because it is located close to the San Andreas Fault, where a significant earthquake could result in catastrophic outcomes.

The b-value in Gutenberg-Richter relation is a crucial parameter in earthquake seismology that is obtained from the Gutenberg-Richter frequency-magnitude distribution. The b-value is the defined by the slope of magnitude frequency distribution of earthquakes and is independent of whether global, regional or local seismicity in analyzed (Fiedler, Hainzl, Zöller, & Holschneider, 2018-10-01). The b-value offers valuable information about the stress conditions of the Earth's crust and can serve as an indicator of areas with an elevated risk of experiencing significant earthquakes. Schorlemmer et al. (2004) showed that by mapping b-values in both space and time, it is possible to identify patterns that are associated with earthquake events and the distribution of stress. The objective of this project is to create a Python Jupyter Notebook that will use the techniques described by Schorlemmer et al. (2004) to generate a space-time b-value map for the Salton Trough/Imperial Valley.

2 Method and Data

2.1 b-value Estimation

The earthquake size distribution can be described by a power-law with an exponent b, which shows the Gutenberg-Richter relationship (Gutenberg & Richter, 1944):

$$\log(N) = a - bM \tag{1}$$

Where b is the slope of the number of events (N) with greater than magnitude M provides the seismic activity and a provides productivity. b-value will be computed using the maximum-likelihood estimator (Aki, 1965; Bender, 1983; Utsu, Ogata, S, & Matsu'ura, 1995):

$$b = \frac{1}{\bar{M} - M_c} \log_{10}(e) \tag{2}$$

Where $\bar{M}$ is the mean magnitude, $e = \exp(1)$, and M_c is the magnitude of completeness adjusted for bin size to account for potential bin size biases (Guo & Ogata, 1997; Utsu et al., 1995). We will estimate the magnitude of completeness using the maximum curvature method. The statistical uncertainty for maximum likelihood b-value estimates can be determined from (Shi & Bolt, 1982).

$$\sigma_b = \frac{b^2}{\log(e)} \sqrt{\frac{\sum_{i=1}^{n}(M_i - \bar{M})}{n(n-1)}} \tag{3}$$

Where n is the number of events above M_c, M_i is the magnitude of individual AE events and $\bar{M}$ is the mean magnitude for events greater or equal than M_c.

2.2 Data and Spatial Mapping of b-value.

We will use the Southern California Earthquake Data Center (SCEDC) relocated high quality catalog spanning the period 1977 - present. From the catalog we will separate the events of the Salton Trough and Imperial Valley region. We will cut the catalog at a depth of 20 Km. The processing steps for spatial mapping of b-vlaue will be adopted from (Schorlemmer, Wiemer, Wyss, & Jackson, 2004). The authors presented earthquake statistics from the Parkfield section of the San Andreas Fault.

The data for this project can be accessed using following python script:

```python
import obspy
from obspy.clients.fdsn import Client
from obspy import UTCDateTime
import csv

# Initialize the FDSN client for the Southern California Earthquake Data Center (
    SCEDC)
```

```python
client = Client("SCEDC")

# Define the parameters for the catalog search
start_time = UTCDateTime("2022-01-01")
end_time = UTCDateTime("2022-12-31")
min_magnitude = 3.0
max_magnitude = 6.0
min_latitude = 32.0
max_latitude = 36.0
min_longitude = -120.0
max_longitude = -114.0
min_depth = 0.0
max_depth = 30.0

try:
    # Fetch the catalog data from the SCEDC using the specified parameters
    catalog = client.get_events(starttime=start_time, endtime=end_time,
                                minmagnitude=min_magnitude, maxmagnitude=max_magnitude,
                                minlatitude=min_latitude, maxlatitude=max_latitude,
                                minlongitude=min_longitude, maxlongitude=max_longitude,
                                mindepth=min_depth, maxdepth=max_depth)

    # Print the number of events in the catalog
    print(f"Number of events in the catalog: {len(catalog)}")

    # Define the output CSV file name
    output_csv = "seismic_event_catalog.csv"

    # Write the event details to the CSV file
    with open(output_csv, mode='w', newline='') as csv_file:
        csv_writer = csv.writer(csv_file)
        # Write the header
        csv_writer.writerow(["Event ID", "Origin Time", "Magnitude", "Latitude", "Longitude", "Depth (km)"])

        # Iterate over the events and write the details for each event
        for event in catalog:
            # Extract the event ID by splitting the URI
            event_id = event.resource_id.id.split('=')[-1]
            origin = event.origins[0]
            magnitude = event.magnitudes[0].mag
            csv_writer.writerow([event_id, origin.time, magnitude, origin.latitude, origin.longitude, origin.depth / 1000])

    print(f"Seismic event catalog has been saved to {output_csv}")

except Exception as e:
    print(f"An error occurred: {e}")
```

Listing 1: Example Python code to access catalog from SCEDC

3 Outcomes of the project

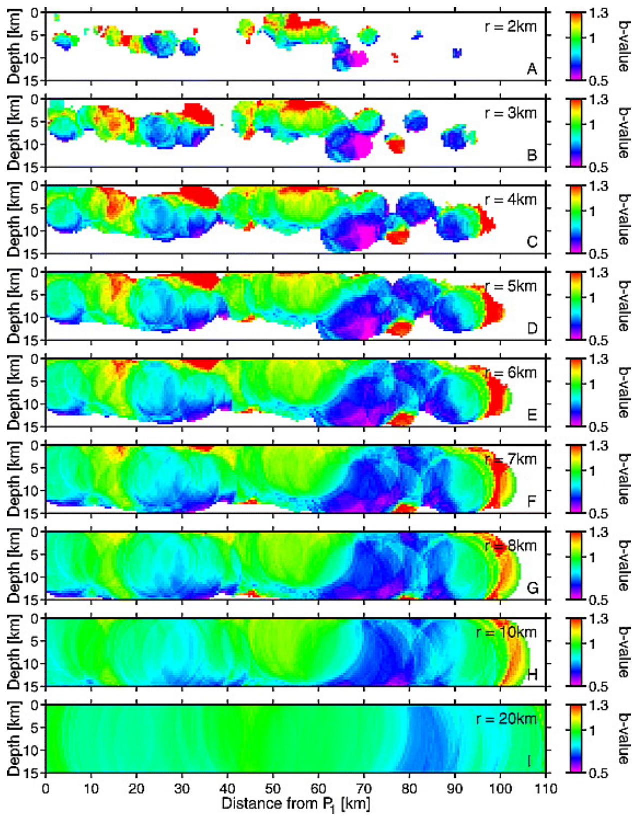

Figure 2: Distribution of b values in the Parkfield segment of the San Andreas fault computed with the NCSN catalog from 1981 to 2003 using different radii r and Nmin = 50. (a) r = 2 km. (b) r = 3 km. (c) r = 4 km. (d) r = 5 km. (e) r = 6 km. (f) r = 7 km. (g) r = 8 km. (h) r = 10 km. (i) r = 20 km. (Schorlemmer et al., 2004)

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