MACHINE LEARNING PREDICTS APERIODIC LABORATORY EARTHQUAKES

DANIEL DAVIEAU, OLHA TANYUK

DR. CHARLES SOUTH AND DR. DANIEL W. ENGELS

REGULAR EARTHQUAKES

- CATASTROPHIC STICK–SLIP FAILURE EVENTS

    - STRESS BUILDS BETWEEN TECTONIC PLATES GRADUALLY

    - STRESS EVENTUALLY OVERCOMES FRICTION

    - SLIP OCCURS RELEASING HIGH-FREQUENCY SEISMIC ENERGY

Workers shovel debris off a Mexico City building that collapsed in the 7.1-magnitude earthquake on Sept. 19, 2017. (AP Photo/Rebecca Blackwell)
https://www.washingtonpost.com/news/speaking-of-science/wp/2017/12/14/mexicos-deadly-earthquakes-have-upped-the-chance-of-another-big-one-scientist-says/?noredirect=on&utm_term=.21605c8cdbc1

CLASSICAL EARTHQUAKE FORECASTING

- BASED ON THE RECURRENCE INTERVAL OF EARTHQUAKES THAT REPEAT PERIODICALLY

- MARGIN OF ERROR CAN SPAN DECADES

  "SIMILAR EARTHQUAKES OCCURRING BETWEEN 1857 AND 1966 SUGGESTED A RECURRENCE INTERVAL OF 21.9±3.1 YEARS, AND THUS, AN EARTHQUAKE WAS EXPECTED BETWEEN 1988 AND 1993, BUT ULTIMATELY TOOK PLACE IN 2004"

SLOW SLIP EARTHQUAKES

- **SLOW SLIP EARTHQUAKES:**

  - OCCUR VERY SLOWLY

  - ARE UNDETECTABLE WITHOUT INSTRUMENTATION

  - DO NOT REACH RATES SUFFICIENT TO RADIATE HIGH-FREQUENCY SEISMIC ENERGY

Image from http://www.rocdoctravel.com

https://www.tripadvisor.com/LocationPhotoDirectLink-g32411-d610747-i207184569-Hayward_Fault_Exposed-Fremont_California.html

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REGULAR AND SLOW SLIP

- RELATIONSHIP BETWEEN SLOW SLIP AND REGULAR EARTHQUAKES?
  - EVIDENCE SUGGESTS THAT THERE IS A RELATIONSHIP BETWEEN SLOW SLIP EARTHQUAKES REGULAR EARTHQUAKES.(BAPTISTE ROUSSET, ROLAND BURGMANN)
- MAY PLAY A ROLE IN STRESS TRANSFER AND TRIGGERING OF REGULAR EARTHQUAKES

LANL PREDICTS LABORATORY EARTHQUAKES

- LOS ALAMOS NATIONAL LABORATORY (LANL) PREDICTED <u>LABORATORY</u> EARTHQUAKES WITH 89% ACCURACY

- "*WE SHOW THAT BY LISTENING TO THE ACOUSTIC SIGNAL EMITTED BY A LABORATORY FAULT, MACHINE LEARNING CAN PREDICT THE TIME REMAINING BEFORE IT FAILS WITH GREAT ACCURACY*"

  - ROUET-LEDUC BERTRAND, HULBERT CLAUDIA, LUBBERS NICHOLAS, BARROS KIPTON, HUMPHREYS COLIN J., JOHNSONPAUL A. (2017, JULY 15). MACHINE LEARNING PREDICTS LABORATORY EARTHQUAKES. RETRIEVED FROM HTTPS://DOI.ORG/10.1002/2017GL074677

Training $R^2 = 0.91$
Testing $R^2 = 0.89$

Predictions
Experimental data
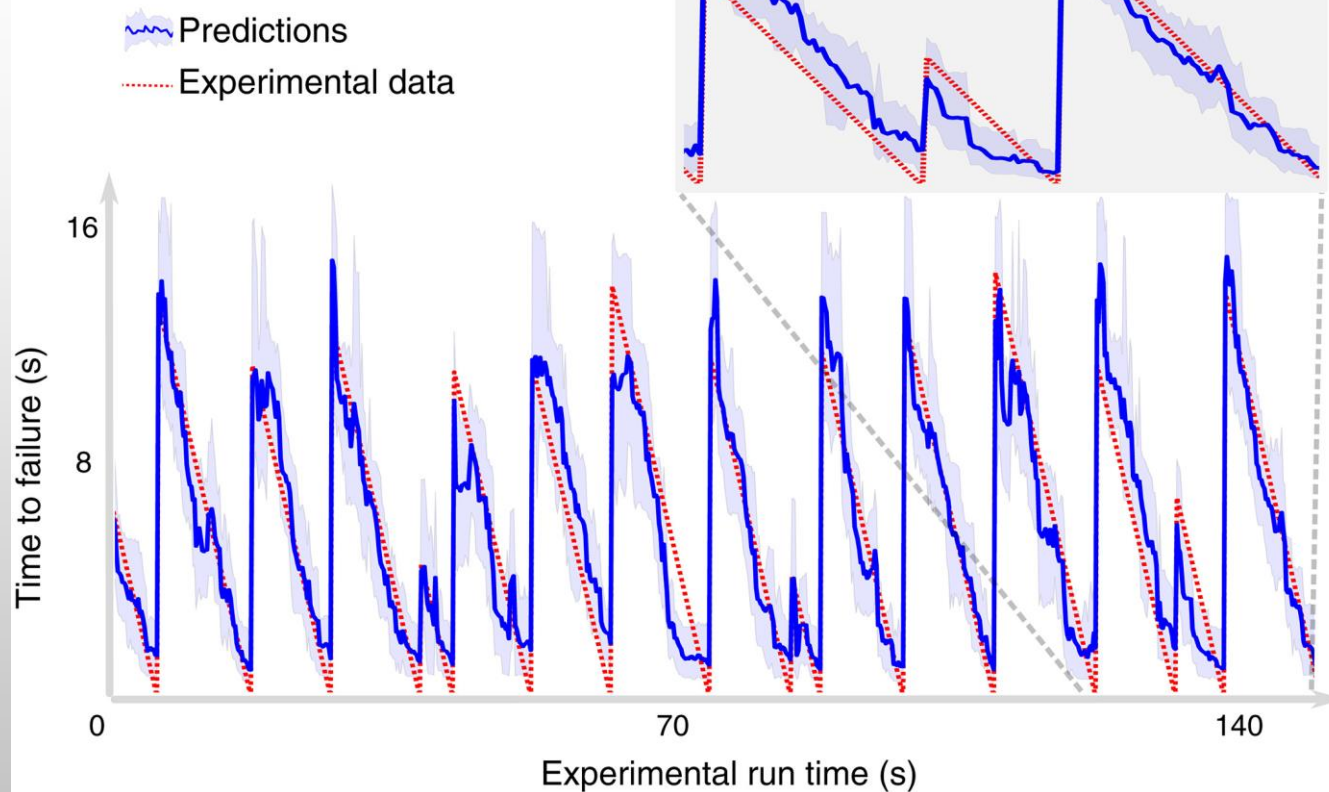
Source: Rouet-Leduc Bertrand, Hulbert Claudia, Lubbers Nicholas, Barros Kipton, Humphreys Colin J., JohnsonPaul A. (2017, July 15). Machine Learning Predicts Laboratory Earthquakes. Retrieved from https://doi.org/10.1002/2017GL074677

ADVANCES IN TECHNOLOGY

- IMPROVEMENT IN THE INSTRUMENTS FOR MEASURING SIGNALS

- IMPROVEMENT IN COMPUTING POWER TO COLLECT DATA

LOS ALAMOS NATIONAL LABORATORY -

"WE SELECTED AN EXPERIMENT THAT EXHIBITS A VERY APERIODIC AND MORE REALISTIC BEHAVIOR COMPARED TO THE DATA WE STUDIED IN OUR EARLY WORK".

"THE DATA FROM THIS CLASSIC EARTHQUAKE MACHINE HAD NEVER BEEN STUDIED USING ML UNTIL OUR EARLY EFFORTS 3 YEARS AGO, AND MUCH REMAINS TO BE EXPLORED AND DISCOVERED."
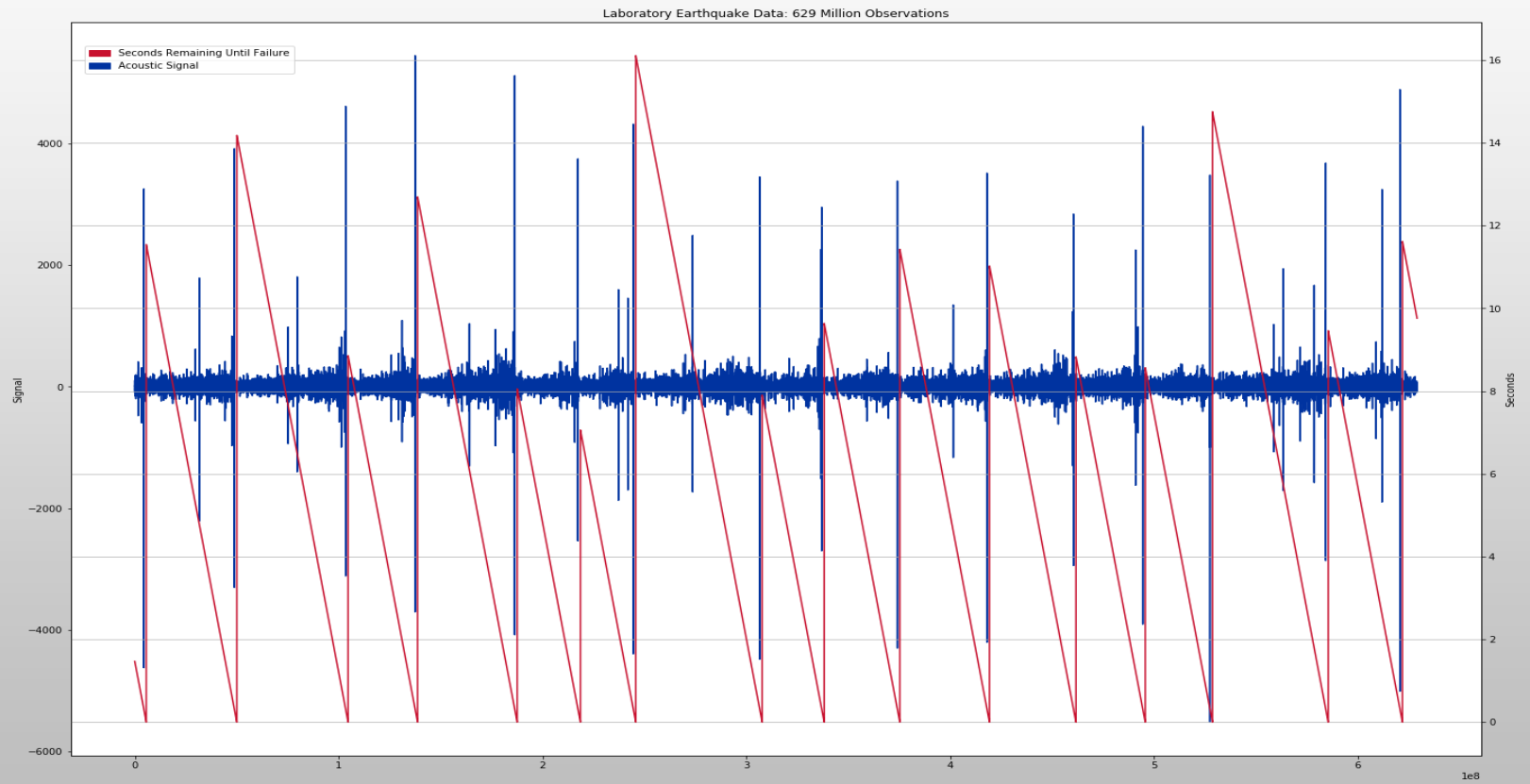
LAB EARTHQUAKE SIMULATION

- LANL COLLECTED A HIGH VOLUME OF MORE REALISTIC AND APERIODIC DATA

- LAB EARTHQUAKES OCCURRING MORE IRREGULARLY
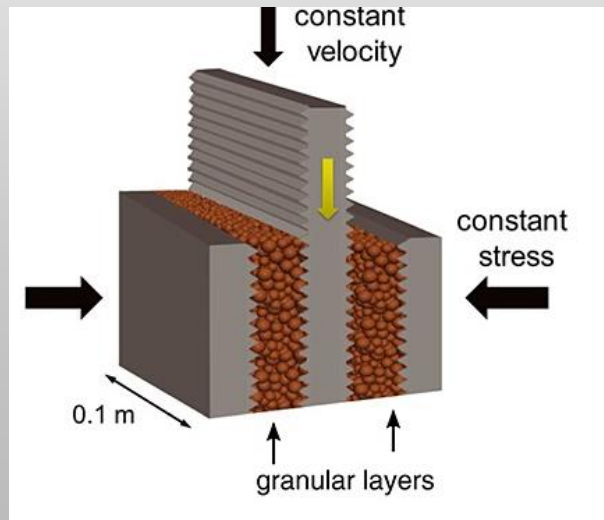
PROBLEM STATEMENT

- GIVEN APERIODIC SLOW-SLIP FAILURES, CAN WE PREDICT LABORATORY EARTHQUAKES?
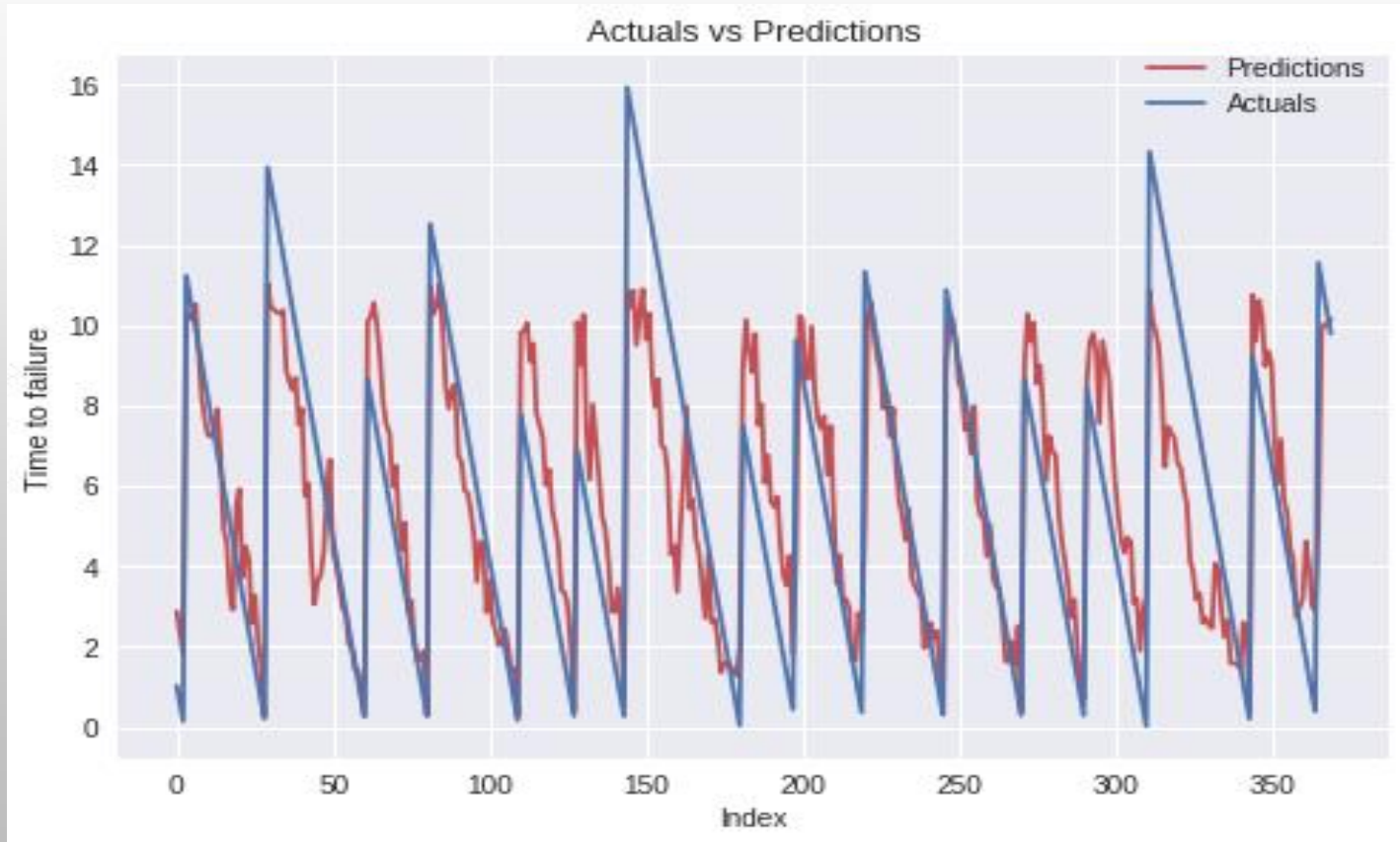
DATA

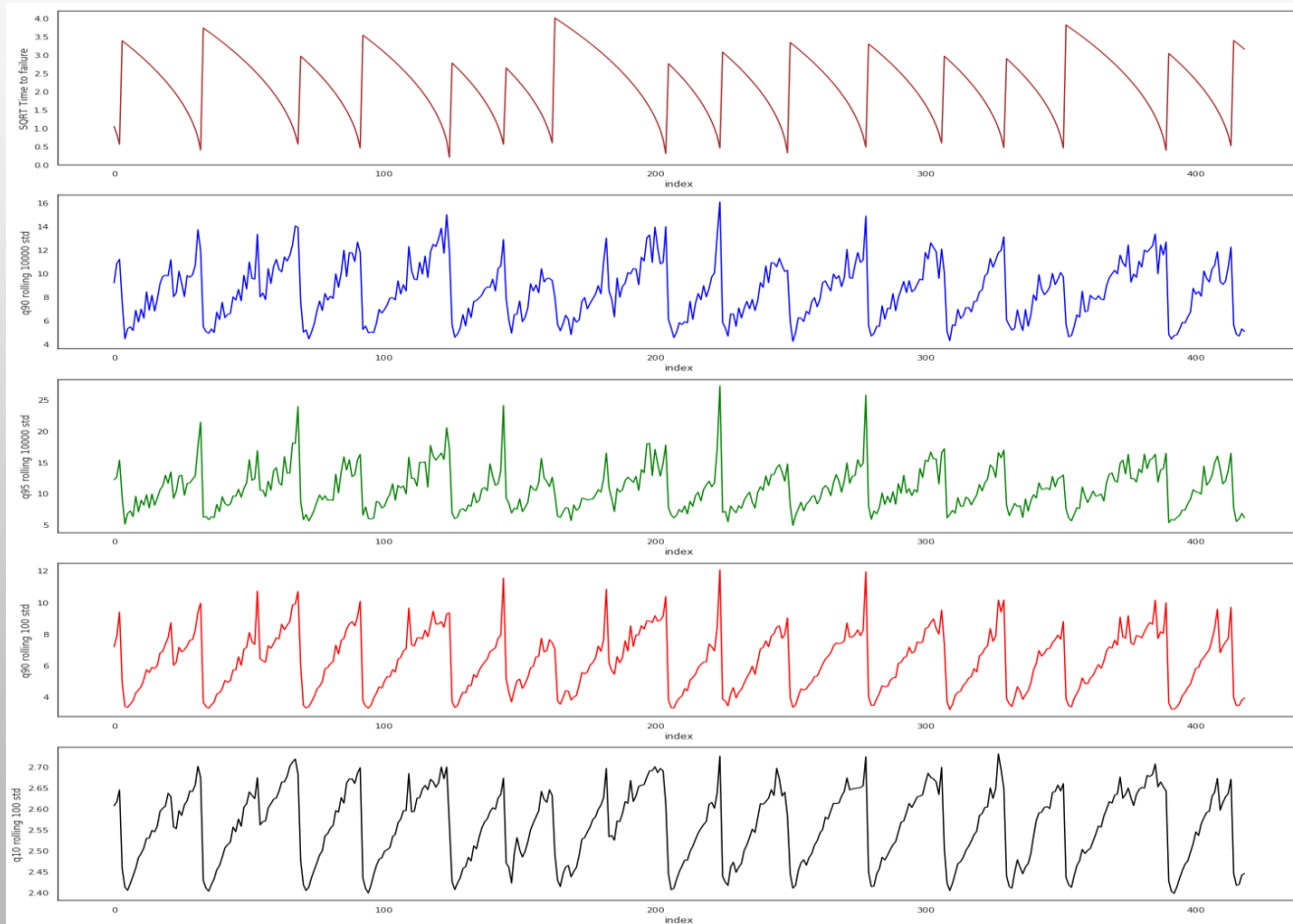Laboratory Earthquake Data: 629 Million Observations

METHODOLOGY

- PREDICT USING ONLY ACOUSTIC SIGNAL DATA

    - EXCLUDE HISTORICAL RECURRENCE INTERVAL

- 629,000,000 OBSERVATIONS WERE DIVIDED BY TIME WINDOWS

- CREATED ADDITIONAL STATISTICAL INPUT FROM THE ACOUSTIC DATA (VARIANCE, SKEWNESS, KURTOSIS…)

- 50/50 TRAIN TEST SPLIT

RESULTS

RESULTS

RESULTS

- RANDOM FOREST (EXTRA TREES REGRESSOR)

  - MEAN ABSOLUTE ERROR : 1.61 SEC

  - COEFFICIENT OF DETERMINATION (r^2): 0.65

- MEAN ABSOLUTE ERROR MEASURE ACCOUNTS FOR DIFFERENCE BETWEEN POSITIVE AND NEGATIVE ACOUSTIC SIGNAL IN PREDICTED VERSUS ACTUAL

CONCLUSION

- THE EVIDENCE SUGGESTS THAT GIVEN THE MORE REALISTIC DATA, MACHINE LEARNING CAN PROVIDE FAILURE FORECASTS WITH 65 % COEFFICIENT OF DETERMINATION.

- HAVING DATA JUST FROM 0.3 SEC PERIOD OF TIME, WE CAN PREDICT THE FAILURE AT ANY MOMENT OF THE QUAKE CYCLE.

- THE RESULTS ARE ENCOURAGING MACHINE LEARNING ANALYSIS OF SEISMIC SIGNALS IN EARTH.

FROM LAB TO REAL WORLD

"IF THIS CHALLENGE IS SOLVED AND THE PHYSICS ARE ULTIMATELY SHOWN TO SCALE FROM THE LABORATORY TO THE FIELD, RESEARCHERS WILL HAVE THE POTENTIAL TO IMPROVE EARTHQUAKE HAZARD ASSESSMENTS THAT COULD SAVE LIVES AND BILLIONS OF DOLLARS IN INFRASTRUCTURE."

- LOS ALAMOS NATIONAL LABORATORY, GEOPHYSICS GROUP

FROM LAB TO REAL WORLD

THE EXPERIMENT CLOSELY MIMICS EARTH FAULTING, SO THE SAME APPROACH MAY WORK IN PREDICTING TIMING, BUT NOT SIZE, OF AN EARTHQUAKE. THIS APPROACH COULD BE APPLIED TO PREDICT AVALANCHES, LANDSLIDES, FAILURE OF MACHINE PARTS, AND MORE

- LOS ALAMOS NATIONAL LABORATORY, GEOPHYSICS GROUP

ETHICAL CONSIDERATIONS

- IF PEOPLE BELIEVE US AND WE ARE WRONG, IT MAY HAVE HIGH COST

- SCIENTISTS' RESPONSIBILITY TO INFORM THE PUBLIC ABOUT THEIR RESULTS MAY CONFLICT WITH THEIR RESPONSIBILITY NOT TO CAUSE SOCIAL DISTURBANCE BY THE COMMUNICATION OF THESE RESULTS.

REFERENCES

BERTRAND ROUET-LEDUC, CLAUDIA HULBERT, *MACHINE LEARNING PREDICTS LABORATORY EARTHQUAKES*

KAGGLE, R.: *LANL EARTHQUAKE PREDICTION*

IKARI MATT J, MARONE CHRIS, : *SLIP WEAKENING AS A MECHANISM FOR SLOW EARTHQUAKES*

BAPTISTE ROUSSET, ROLAND BURGMANN, M.C.: *SLOW SLIP EVENTS IN THE ROOTS OF THE SAN ANDREAS FAULT*

USGS: *WHAT IS AN EARTHQUAKE AND WHAT CAUSES THEM TO HAPPEN?* (MARCH 2019)

ROUET-LEDUC, B.: *LOS ALAMOS MACHINE LEARNING DISCOVERS PATTERNS THAT REVEAL EARTHQUAKE FAULT BEHAVIOR*

AYHAN SOL, HALIL TURAN: *THE ETHICS OF EARTHQUAKE PREDICTION.* VOLUME 10, ISSUE 4, PP 655–666 (DECEMBER 2004)