Seismic Activity in the Inglewood Oil Field

Paul Segall
November 9, 2016

1 Data

Seismic data was provided to me from the USGS Southern California catalog, and separated into two groups: one 0 to 4 km from the center of the field (here labeled as near) and a second group from 4 to 10 km from the center of the field (here labeled as far).

The first step in the analysis is to determine the magnitude of completeness for these data sets. Lower magnitude events are not sufficiently well recorded to have statistically significant properties. The standard method for determining the completeness magnitude is to compare the observed frequency magnitude distribution with the Gutenberg-Richter distribution, as in Figure 1. This figure shows the size distribution of earthquakes (for the full time period) for the near-in and farther away earthquakes on semi-log plot. Earthquake distributions universally follow a linear trend on such a plot, as seen here for magnitudes between approximately $M = 1.75$ and 3. From this we can conclude that (averaged over the full time period) the earthquake catalog is missing events of $M < 1.75$. (Note that the network’s ability to detect smaller events undoubtedly improved with time, thus the catalog may be complete at smaller magnitude level, since for example 2000.) The negative slope on this plot, is known as the b-value; values near 1 are typical. The b-value for the inner zone is roughly 1.2, while for the outer region it is 0.99; these are within the standard range for tectonic earthquakes. The linear trend on a the semi-log plot breaks down at larger magnitudes (roughly magnitude 3), as there are few events of this size in the data set.

Figure 2 shows $M > 1.75$ events as a function of time for both the near (top) and far (bottom) catalogs. Focussing on the top plot, there is a $M = 3.8$ event in 2015, and what appears to be an increase in activity around that time, but it turns out that these events are fairly deep compared to oil-field operations. This can be
Figure 1: Frequency magnitude distribution of earthquakes in and near the Inglewood Oil Field. Red: 0 to 4 km from the center of the field. Blue: 4 to 10 km from center.

Figure 2: Magnitude vs time for events greater than 1.75, in the near (top) and far (bottom) zones. All depths.
seen by considering only events shallower than 4 km, as in Fig. 3. 4 km was chosen as it is roughly the depth of the deeper Sentous formation at the margin of the field. There are relatively few shallow (less than 4 km) events, and they appear somewhat clustered in time. Significantly, there does not appear to be an obvious trend of increasing shallow earthquakes with time that might indicate effects of oil-field operations. The rate of activity for the more distant group of earthquakes (4-10 km) is fairly uniform in time (Figure 2b). Perhaps the first 5 years or so are lacking in $M > 3$ events but that may be due changes in the network detection capability with time.

I did not have available to me time series of injected volumes within the Inglewood Oil Field during this time interval. Thus, it was not possible to compare such a data set with the earthquake data. However, there are no obvious trends in these subsets of data that indicate an influence of oil-field operations. That does not prove that they do not exist. Simply there is no evidence (such as a increasing rate of shallow earthquakes) that is suggestive of human induced impact in the data.

## 2 Poisson Test

I tested whether or not the data are consistent with a Poisson process. A Poisson process is random in time, and is commonly used as a null hypothesis for natural, background seismicity. For this test I used the data from the ‘inner’ region with

![Figure 3: Magnitude vs time for events greater than 1.75, and depth shallower than 4 km, for the near field events.](image-url)
Figure 4: Blue histogram: Observed number of earthquakes per year within inner region and depths less than 4 km. Red stars: Predicted Poisson distribution given the observed frequency of events in this category.

depths less than 4 km, shown in Figure 3. I found that one cannot reject the Poisson distribution for these data at the 95% confidence level. That is the data are consistent with the Poisson distribution at this confidence level. Figure 4 illustrates this, comparing the observed and predicted number of earthquakes per year. The figure shows that the observations are quite consistent with the expected Poisson distribution – there is an 80% chance of no earthquakes within this region with depth less than 4 km and magnitude greater than 1.75 in a given year, exactly as observed.

Thus, while we cannot prove that the earthquakes are all due to natural tectonic processes, there does not seem to be anything based on this evaluation of the data that would indicate an unusual pattern of earthquakes with time.
Paul Segall

People (Profile) Paul Segall has been updated.

Education

1981 | Ph.D. Geology Stanford University
1976 | B.A./M.S. Earth Sciences Case Western Reserve University

Professional Experience

2000 Visiting | Professor Institute de Physique du Globe, Paris
1998 - Present | Professor Stanford University
1993 - 1998 | Associate Professor Stanford University
1991 | Visiting Associate Professor University of Grenoble
1989 - 1993 | Associate Professor (Research) Stanford University
1987 - 1989 | Consulting Professor Stanford University
1983 - 1993 | Project Chief Mechanics of Faulting and Fracturing, USGS
1981 - 1983 | Geologist USGS

Honors & Awards

2011 | William Smith Lecturer, Geological Society of London
2009 | Stanford Postdoctoral Mentoring Award (Honorable Mention)
2002 | Citation for Excellence in Refereeing, American Geophysical Union
1997 | Fellow, Geological Society of America
1990 | J.B. Macelwane Medal, American Geophysical Union
1990 | Fellow, American Geophysical Union
1984 | USGS Special Achievement Award

University Service

2013-2014 | Freshman Advisor
2010-2012 | Office of Judicial Affairs – Internal Review Panel
2005 - 2013 | Instructor, Stanford (Summer) Engineering Academy
2011 - 2012 | School of Earth Sciences Space Committee
Professional Activities

2013 | U.K. National Centre of Earth Observation Assessment Panel
2013 | Invited Speaker, Hawaiian Volcano Observatory
2013 | Invited Speaker, Earthquake Research Institute, University of Tokyo
2013 | Invited Speaker, Oberlin College
2013 | NSF Panel: Frontiers of Earth System Dynamics
2012 | Earth and Ocean Sciences Colloquium, University of British Columbia.
2011 | Keynote speaker, Seismic and aseismic deformation workshop, Strasbourg France.
2011 | Invited speaker, USGS Workshop on Great Cascadia earthquakes, Eugene Oregon.
2011 | Invited Speaker, University of Kyoto, Disaster Prevention Research Institute.
2011 | Invited Speaker, Royal Society Workshop, Magma Migration, Storage and Eruption.
2011 | Chair Reid Medal Committee, Seismological Society of America
2011 | Invited Participant - USGS New Madrid Workshop
2011 | Invited Speaker - Univ. Colorado
2011 | Invited Speaker - J.R. Rice Symposium Caltech
2010 | Invited Speaker - Hawaiian Volcano Observatory
2010 | Invited Speaker - Earthscope Institute: Spectrum of Fault Slip Behavior
2009 | Invited presentation: UC Santa Cruz
2009 | Invited Keynote Speaker: Earthscope National Meeting
2009 | Invited Speaker: Workshop on Numerical Modeling of Crustal Deformation and Earthquake Faulting
2009 | Invited Seminar U.C. Berkeley
2009 | NSF Long Range Science Plan for Geodesy - Discussion Leader
2008 | Chair, U.C. Riverside IGPP External Review
2008 | Invited Presentation: Caltech Geological and Planetary Sciences
2008 | Invited Presentation: US Geological Survey
2008 | Invited Presentation: Volcano Deformation Workshop
2008 | Review Panel: Canadian Institute for Advanced Research
2008 | NSF Long Range Planning for Seismology Workshop
2007 | Invited presentation: IGPP U. C. San Diego
2007 | Invited presentation: Harvard University
2007 - Present | Southern California Earthquake Center Board of Directors
2007 | Invited Speaker: Euro-Conference - Rock Physics and Geomechanic
2006 | USGS working group on National Volcano Early Warning System extramural program
2006 | Invited presentation: SCEC/ERI Workshop
2006 | Chair, UNAVCO Nominating Committee
2005 | Invited Participant, Dahlem Workshop "Dynamics of Fault Zones", Berlin
2005 - 2008 | Donath Medal Committee, Geological Society of America
2005 | Invited presentation Purdue University 2005 Invited participant: Kavli Institute of Theoretical Physics "Fracture and friction from atomic to tectonic scales"
2004 | Newton Institute of Mathematical Sciences, School on physics of granular media
2003 | Invited Presentation, U.C. Riverside
2003 - 2004 | President, Tectonophysics Section, AGU
2003 - 2006 | Chair, Plate Boundary Observatory (Earthscope) Standing Committee
2003 | Coconvener, NSF/USGS sponsored workshop "volcanic processes in Long Valley Caldera - Mono Craters volcanic field"
2002 - 2006 | Department of Interior's Scientific Earthquake Advisory Committee
2002 | Invited Seminar, I.G.P.P., Scripps Institute of Oceanography
2002 | Invited Presentation, Academica Sinica, Taipei, Taiwan
2002 - 2009 | Member CEPEC, California Earthquake Prediction Evaluation Council
2002 | Invited Seminar, University of Southern California
2001 | Invited presentation: Caltech
2001 | Invited presentation: University of Utah, Rate Debate Workshop
2001 | Invited Presentation: University of Hawaii
2001 | Invited Presentation: Hawaiian Volano Observatory
2001 | Invited Presentation: Whole Earth Seminar, U.C. Santa Cruz
2001 - 2003 | UNAVCO, Inc. Board of Directors
2000 - 2001 | UNAVCO (University Navstar Consortium) Steering Committee
2000 - 2002 | President Elect, American Geophysical Union, Tectonophysics Section
2000 - 2002 | American Geophysical Union Meetings Committee
2000 - 2001 | Invited Presentation: D.O.E. Workshop, Gaithersburg Md.
2000 - 2001 | Invited Presentation: E.G.S. Nice, France
2000 - 2001 | Invited Presentation: Institute de Physique du Globe, Paris, France
2000 - 2001 | Invited Presentation: Universite de Bretagne Occidentale, Brest, France
2000 - 2001 | Invited Presentation: Ecole Normale Superieur, Paris, France
2000 - 2001 | Invited Presentation: Observatoire du Midi Pyrenees, Tolouse, France
2000 - 2001 | Invited Presentation: Stress Interactions Workshop, Erice, Italy
2000 - 2001 | Invited Presentation: 2nd Plate Boundary Observatory Workshop
2000 - 2001 | Invited Presentation: Southern California Earthquake Center (SCEC) Annual Meeting
2000 | CNRS review committee of Laboratoire de Tectonique-Mechanique de la Lithosphere, Institute de Physique du Globe, Paris
2000 - 2003 | UNAVCO (NSF GPS Facility) Board of Directors
1999 | Invited presentations: UNAVCO Annual Meeting
1999 | Invited presentations: AGU (Spring) | Meeting
1999 | Invited presentations: UCLA
1999 | Invited presentations: UNAVCO workshop on Volcano Deformation
1999 | Invited presentations: Plate Boundary Observatory Workshop, Snowbird, Utah
1999 | Invited presentations: GPS 99, Tsukuba, Japan
1999 | Invited presentations: Stanford University Statistics Department
1999 - 2002 | Member, Plate Boundary Observatory Steering Committee
1999 - 2000 | Member, NAS Committee to review the Volcano Hazards Program of the U.S. Geological Survey
1999 | Chair, UC Santa Cruz Tectonics Advisory Committee
1998 | Invited lectures: IRIS Annual Meeting
Courses Taught

2014 (Winter) | 288B Crustal Deformation [Enrolled 8]
2014 (Winter) | 385L Earthquake Seismology, Deformation, and Stress [Enrolled 12]
2014 (Spring) | 385L Earthquake Seismology, Deformation, and Stress [Enrolled 9]
2014 (Spring) | 289 Global Positioning System in Earth Sciences [Enrolled 7/10]
2014 (Spring) | 20N Predicting Volcanic Eruptions [Enrolled 12/15]
2013 (Fall) | 385L Earthquake Seismology, Deformation, and Stress [Enrolled 11]
2013 (Fall) | 288A Crustal Deformation [Enrolled 9]

2012 (Spring) | 385L Quake Seismology & Stress [Enrolled 9]
2012 (Winter) | 288B Crustal Deformation [Enrolled 6]
2012 (Winter) | 385L Quake Seismology & Stress [Enrolled 6]
2011 (Fall) | 288A Crustal Deformation [Enrolled 13]
2011 (Fall) | 385L Quake Seismology & Stress [Enrolled 10]
2010 (Summer) | 400 Geophysics Research [Enrolled 1]
2010 (Spring) | Sabbatical
2010 (Winter) | 385L Quake Seismology & Stress [Enrolled 10]
2010 (Winter) | 400 Geophysics Research [Enrolled 4]
2010 (Winter) | 802 TGR Dissertation [Enrolled 2]
2010 (Winter) | GP 113 Earthquakes and Volcanoes [Enrolled 3]
2010 (Winter) | Earth Systems 113 Earthquakes and Volcanoes [Enrolled 16]
2010 (Fall) | 385L Quake Seismology & Stress [Enrolled 9]
2010 (Fall) | 400 Geophysics Research [Enrolled 3]
2010 (Fall) | 802 TGR Dissertation [Enrolled 2]
2010 (Fall) | 281 Inverse Problems [Enrolled 14]
2010 (Fall) | Earth Sciences 117 Earth Sciences of Hawai‘i [Enrolled 14]
2009 (Summer) | 802 TGR Dissertation [Enrolled 2]
2009 (Summer) | 400 Geophysics Research [Enrolled 2]
2009 (Fall) | 288A Crustal Deformation [Enrolled 11]
2009 (Fall) | 385L Quake Seismology & Stress [Enrolled 7]
2009 (Fall) | 400 Geophysics Research [Enrolled 3]
2009 (Fall) | 802 TGR Dissertation [Enrolled 1]
2009 (Winter) | 385L Quake Seismology & Stress [Enrolled 8]
2009 (Winter) | 288B Crustal Deformation [Enrolled 6]
2009 (Winter) | 400 Geophysics Research [Enrolled 2]
2009 (Winter) | 802 TGR Dissertation [Enrolled 2]
2009 (Spring) | 385L Quake Seismology & Stress [Enrolled 8]
2009 (Spring) | 400 Geophysics Research [Enrolled 3]
2009 (Spring) | 802 TGR Dissertation [Enrolled 2]
2009 (Spring) | 113 Earthquakes and Volcanoes [Enrolled 1]
2009 (Spring) | 113 Earthquakes and Volcanoes [Enrolled 13]
2008 (Fall) | 400 Geophysics Research [Enrolled 4]
2008 (Winter) | 802 TGR Dissertation [Enrolled 1]
2008 (Winter) | 400 Geophysics Research [Enrolled 2]
2008 (Winter) | 289 GPS in EarthScience (note 19 enrolled in AA272C) [Enrolled 2]
2008 (Fall) | 281 Inverse Problems (w/ Beroza) [Enrolled 11]
2008 (Fall) | 180 Inverse Problems (w/ Beroza) [Enrolled 4]
2008 (Fall) | 385L Quake Seismology & Stress [Enrolled 9]
2008 (Winter) | 385L Quake Seismology & Stress [Enrolled 9]
2008 (Spring) | 20Q Predicting Volcanic Eruptions [Enrolled 8]
2008 (Spring) | 113 Earthquakes and Volcanoes (w/Beroza) [Enrolled 45]
2008 (Spring) | 385L Quake Seismology & Stress [Enrolled 9]
2008 (Spring) | 400 Geophysics Research [Enrolled 3]
2008 (Spring) | 802 TGR Dissertation [Enrolled 1]
2008 (Summer) | 400 Geophysics Research [Enrolled 3]
2008 (Summer) | 802 TGR Dissertation [Enrolled 1]
2007 (Winter) | 400 Geophysics Research [Enrolled 3]
2007 (Winter) | 385L Quake Seismology & Stress [Enrolled 5]
2007 (Winter) | 802 TGR Dissertation [Enrolled 1]
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2002 | GP185L Quake Seismology and Stress (with Beroza, Zoback) [Enrolled 3]
2002 | GP400 Geophysics Research [Enrolled 17]
2002 | GP399 Teaching Experience [Enrolled 1]
2002 | GP802 TGR Dissertation [Enrolled 2]
2001 | GP400 Research [Enrolled 4]
2001 | GP802 TGR Dissertation [Enrolled 2]
2001 | GP802 TGR Dissertation [Enrolled 2]
2001 | GP400 Research [Enrolled 4]
2001 | GP385 Earthquake Seismology (with Zoback, Beroza) [Enrolled 5]
2001 | GP004 Natural Hazards (with Beroza) [Enrolled 14]
2001 | GP180 Inverse Problems (with Beroza) [Enrolled 16]
2001 | GP399 Teaching Experience [Enrolled 1]
2001 | GP385 Quake Seismology (with Beroza, Zoback) [Enrolled 4]
2001 | GP185 Quake Seismology (with Beroza, Zoback) [Enrolled 1]
2001 | GP289 Global Positioning [Enrolled 7]
2001 | GP385 Quake Seismology (with Beroza, Zoback) [Enrolled 2]
2001 | GP399 Teaching Experience [Enrolled 1]
2001 | GP400 Research [Enrolled 2]
2001 | GP802 TGR Dissertation [Enrolled 2]
2001 | GP400 Research [Enrolled 4]
2001 | GP185 Quake Seismology (with Beroza, Zoback) [Enrolled 1]
2000 | GP385 Earthquake Seismology (with Zoback, Beroza) [Enrolled 8]
2000 | GP004 Natural Hazards (with Beroza) [Enrolled 27]
2000 | GP288 Crustal Deformation [Enrolled 10]
2000 | GP400 Research [Enrolled 12]
1999 | GP004 Natural Hazards (with Beroza) [Enrolled 29]
1999 | GP289 Global Positioning [Enrolled 9]
1999 | GP385 Earthquake Seismology (with Zoback, Beroza) [Enrolled 5]
1999 | GP400 Research [Enrolled 3]
1999 | GP180 Geophysical Inverse Problems (with Beroza) [Enrolled 15]
1998 | GP004 Natural Hazards (with Beroza) [Enrolled 45]
1998 | GP400 Research [Enrolled 12]
Publications


2006 | Yun, S., P. Segall, and H. Zebker, Constraints on magma chamber geometry at Sierra Negra volcano, Galapagos Islands, based on InSAR observations. Journal of Volcanology and Geothermal Research; Feb 1 2006; v.150, no.1-3, p.232-243


Advisee Degrees

2013 | Noel Bartlow: The physics of slow slip, tremor, and associated seismicity from geodetic and laboratory studies Ph.D. (Postdoc Scripps)


2008 | Emily Montgomery-Brown: Time Dependent Deformation of Kilauea Volcano, Hawaii, Ph.D. (Postdoc)

2008 | Dan Sinnet, M.S. (Graduate Student)

2007 | Sang-ho Yun: A mechanical model of the large-deformation 2005 Sierra Negra Volcanic eruption derived from InSAR measurements (with Zebker), Ph.D. (J.P.L.)

2007 | Kyle Anderson, M.S. (Stanford, Grad student)

2006 | Andy Hooper: Persistent Scatterer Radar Interferometry for crustal deformation studies and modeling of volcanic deformation (with Zebker), Ph.D. (Delft University)

2005 | Emily Desmarais, M.S. (Stanford)

2004 | Kaj M. Johnson: Mechanical Models of Interseismic Deformation in California and Taiwan, Ph.D. (University of Indiana)

2003 | Jessica Murray: Deformation Studies at Parkfield, Ph.D. (U.S.G.S.)

2003 | Sang-Ho Yun, M.S. (Graduate Student)

2002 | Peter Cervelli: Using geodetic data to infer the kinematic and mechanical properties of deformation sources on Kilauea volcano, Hawaii, Ph.D. (U.S.G.S. Hawaiian Volcano Observatory)

2002 | Maurizio Battaglia: Unrest at Long Valley Caldera: GPS and gravity investigations, Ph.D. (U.C. Berkeley)

2002 | Antony Mossop: Seismicity, subsidence, and strain at The Geysers Geothermal field, Ph.D. (Sandia Labs)

2002 | Sigurjon Jonsson: Modeling volcano and earthquake deformation from satellite radar interferometric observations, Ph.D. (ETH, Zurich)
2000 | Jessica Murray, M.S. (Ph.D., Stanford)
2000 | Shelley Kenner: Mechanical modeling of time dependent deformation in the lower crust and its effect on earthquake recurrence, Ph.D. (University of Kentucky)
1999 | Susan Owen: GPS measurements and kinematic models of the surface deformation on Kilauea volcano, Hawaii, Ph.D. (U. of S. California)
1999 | Peter Cervelli, M.S. (Ph.D., Stanford)
1998 | Maurizio Battaglia, M.S. (Ph.D., Stanford)
1998 | Shelley Kenner, M.S. (Ph.D., Stanford)
1998 | David Lessick (with Howard Zebker), M.S. (Unknown)

Advisee Publications


News & Media