

TPG is a publication of the American Institute of Professional Geologists

# THE PROFESSIONAL GEOLOGIST

VOLUME 56 NUMBER 1

JAN.FEB.MAR 2019

**Student Edition!**

**Classroom Earth**

*Peer Reviewed Articles:*

**Geoscience Modeling**

**Doppler Radar Estimates of  
Precipitation**



# The Professional Geologist

Volume 56 Number 1

Jan.Feb.Mar 2019

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On the Cover: Shirley Tsootsoo Mensah, SA-7566, from Eastern Illinois University at Yellowstone National Park's Upper Yellowstone Falls during summer field camp. Read about Shirley's experience at field camp on page 19 of this issue.

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The Professional Geologist (USPS 590-810 and ISSN 0279-0521) is published quarterly by the American Institute of Professional Geologists, 1333 W. 120th Avenue, Suite 211, Westminster, CO 80234-2710. Periodicals Postage Paid at Denver, Colorado and additional mailing offices.

POSTMASTER: Send address changes to The Professional Geologist, AIPG, 1333 W. 120th Avenue, Suite 120, Westminster, CO 80234-2710

Subscriptions for all Members and Adjuncts in good standing are included in annual membership dues. Subscription prices are \$20.00 a year for Members' additional subscriptions and \$30.00 a year for non-members for 4 issues (for postage outside of the U.S. add \$10.00). Single copy price is \$5.00 for Members and \$8.00 for non-members. Claims for nonreceipt or for damaged copies are honored for three months.

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Printed in U.S.A. by Modern Litho-Print Company in Jefferson City, Missouri.

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# Assessment of Uncertainty in Doppler-Radar Estimates of Precipitation for Use in Geoscience Studies

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## Abstract

Doppler radar data forms the underpinnings of various applications in hydrometeorology, engineering, floodplain management, and weather forecasting, (among other uses) necessitating the importance of scrutinizing its accuracy, which depends on the accuracy of measured precipitation estimates obtained from gaged monitoring sites. This article explores the collective use of the WRS-88D Doppler radar system, given its long history, from the assemblage of several thousands of published data pairs of Doppler radar precipitation estimates with actual rain gauge precipitation gauge readings. Detailed statistical analysis of these data pairs shows that the evaluation of the uncertainty in the Doppler radar estimated precipitation can be accomplished using standard techniques, and the display of the computational results can be communicated using scatter plot visualization techniques readily available. The resulting distributions depict the degree of uncertainty associated with Doppler radar estimates of precipitation.

## Introduction

Weather radars are playing an important role in predicting precipitation characteristics. The Weather Surveillance Radar (WSR-88D) is a Doppler Radar first introduced in 1988. This is the usual name for the 159 high resolution S-band Doppler weather radars which are part of the NEXRAD (Next Generation Radar) network, and are operated by the National Weather Service. The WSR-88D radar operates by sending and receiving microwave pulses, in the 2-4 GHz range, known as S band. During 1988-2013, many researchers quantified the performance of Doppler Radars by comparing the Doppler radar derived rainfall with the associated relevant gauge observations (considered the “bench mark” data). These comparison studies highlight factors that can affect the reliability of Doppler predictions, including the often used ZR power law relationship, radar miscalibration, signal attenuation and range effect, among others.

Focusing specifically on the data accumulated by the WSR-88D Doppler Radar system, (prior to the completion of the system upgrades to Dual Polarization by 2013), of particular interest is the comparison between the reported precipitation gauge readings and the related Doppler radar estimate of precipitation. In this analysis, published literature in cited references 1-10 contains the data in the form of scatter plots and tables. The data compares the Doppler-radar-derived rainfall estimates with the observed local gauge values, spread across multiple storms and geographical domains with the overwhelming majority categorized via total storm accumulation. We used digitizing software to read the graphs and tabulate the data in each reference for later concatenating.

## Method

The raw data file consists of two columns of rainfall data; namely, Doppler Radar Estimated Precipitation (“DREP”) and Gauge Estimated Precipitation (“GEP”). The DREP column includes radar estimated values (in mm) from the Doppler WSR-88D equipment whereas the GEP column includes precipitation values (in mm) as measured by recording precipitation gauges. Combining the two columns creates a set of ordered pairs resulting in 8846 ordered pairs for the subject Doppler data file.

Below, Table 1 summarizes the data characteristics for the Doppler Radar column. Based on the published graphs and/or tables from the cited references, the compiled radar and gauge precipitation values in the current paper specifically focus on total storm accumulation Doppler Radar data for further analysis, as opposed to the other types of radar data available, e.g. Dual-Polarization data.

**Table 1 - Summary of Doppler (WSR-88D) Data Characteristics**

Radar Type	Paper ID	# of ordered pairs (N)	Radar Data		Gauge Data	
			Mean	SD	Mean	SD
Doppler (WSR-88D)	1-10	8846	20.9	22.8	23.8	28.1

Figure 1 depicts the data in Table 1 in its raw form. Using the standard normalization technique to provide scalability,  $y_i = (x_i - \bar{x})/\sigma$ , these data are normalized with respect to both the DREP and the GEP variables to produce a set of normalized data pairs. Figures 2 and 3 show the DREP and GEP as con-

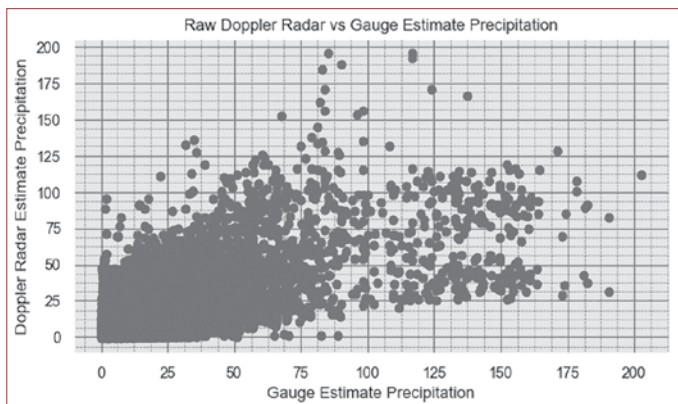


Figure 1 - Raw Doppler Radar (DREP) and Gauge Precipitation (GEP) values collected, arranged, and documented in Table 1.

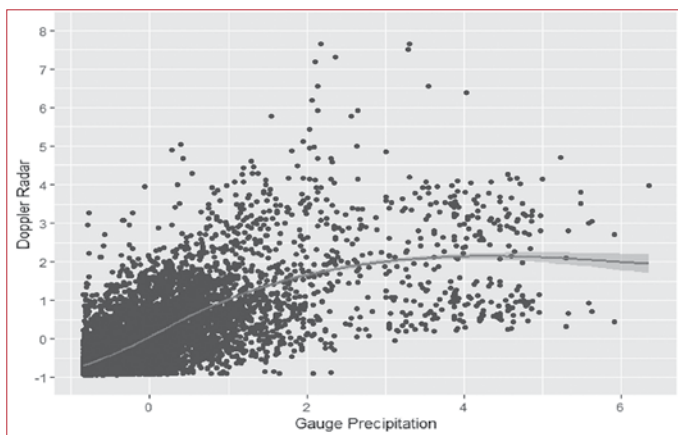


Figure 2 - Spectrum of the normalized Doppler Radar and Gauge Precipitation values with a best fit line in red and uncertainty in surrounding dark grey.

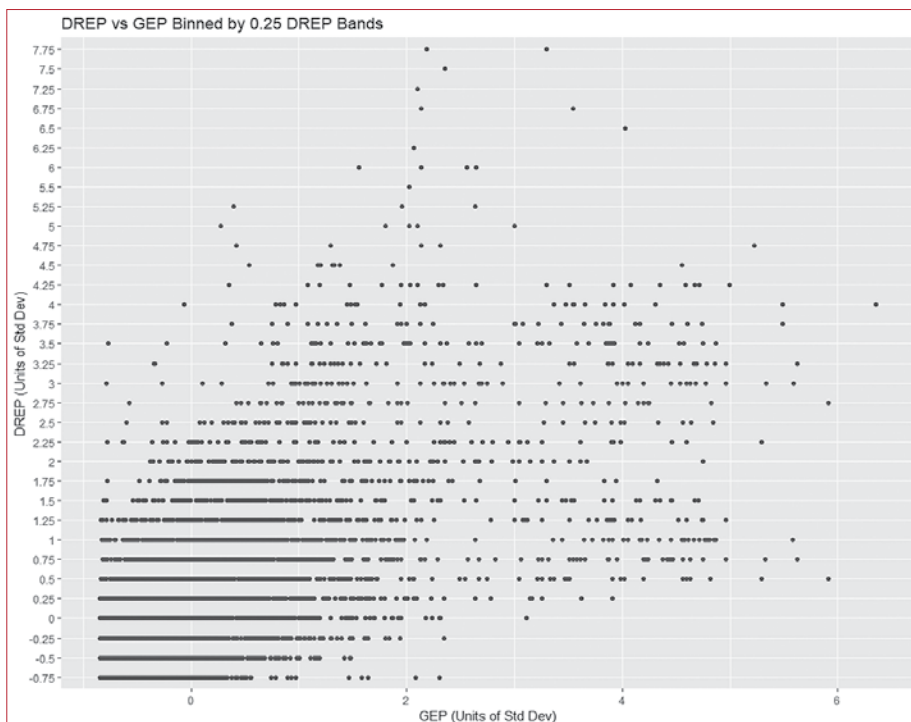


Figure 3 - Spectrum of the normalized Doppler Radar and Gauge Precipitation values binned by increments of 0.25.

tinuous variables plotted against one another using RStudio's "ggplot" (<https://www.rstudio.com>). Applying a best-fit line to the data in Figure 2 aids in showing nonlinearity of the dataset. Figure 3 displays the normalized DREP and GEP variables, and bins them by the DREP variable into 36 bands of 0.25 standard deviation increments. Figure 3 is instrumental in setting up an algorithm that examines each band utilizing various statistical analysis methods.

The Python "Seaborn" (<https://seaborn.pydata.org/>) package wrapped around "matplotlib" also performed relevant statistical analysis in this study. The "joint plot" function in Seaborn creates a multi-panel figure that shows both the bivariate (or joint) relationship between the two variables. Figure 4 on page 24 shows the spectrum of the normalized GEP and DREP together with the probability density plot while Figure 5 on page 24 takes a DREP slice, preset to be a 0.25 standard deviation incremental band, and applies a kernel density estimate, meaning a nonparametric or unspecific distributed way to estimate the probability density function of the target random variable. This cross-section of the data with respect to the independent variable (DREP), given in terms of standard deviation units, yields the outcome of a frequency-distribution of dependent variable precipitation to be determined.

The two software programs each provide a high-level of interface for communicating informative statistical graphics. After normalizing the two variables, use of RStudio and Python was central to the analysis of the data. The "joint plot" option in Seaborn aids in analysis and visualization of singular bands of Radar ranges while RStudio's "ggplot" takes this idea of DREP bands and creates a set of "ridgeline" plots for further analysis and visualization of the entire dataset, consisting of 36 bands of Doppler Radar ranges as seen in Figures 6 and 7 on page 25. In order to accomplish the graphics in these later figures, the first task required is to go back into the original, tabulated data file and conditionally format a new cell that

relates to a data pair and creates a responsive bin. The output of this bin categorizes each data point and allows for future plotting ease by preformatting the previously designated 0.25 band increments. In the excel data file: the final "bin" variables follow the labeling system "Doppler Radar ADJ Band" and "Gauge PPT ADJ Band" relating their effective 0.25o width to the points contained therein. The ggplot function then treats these new "bin" variables as factors and forms the labels for the plotting algorithm to output the useful information as seen previously in the standalone band of Figure 5.

## Results

Treating the Doppler Radar Estimated Precipitation (DREP) variable as the input and the Gauge Estimated Precipitation (GEP) variable as the output, the visualizing of these two variables presents an inverse function when arranging DREP on the vertical axis and GEP on the horizontal axis. This allows for the bands of DREP to present relevant statistical information in the form of kernel density estimates,

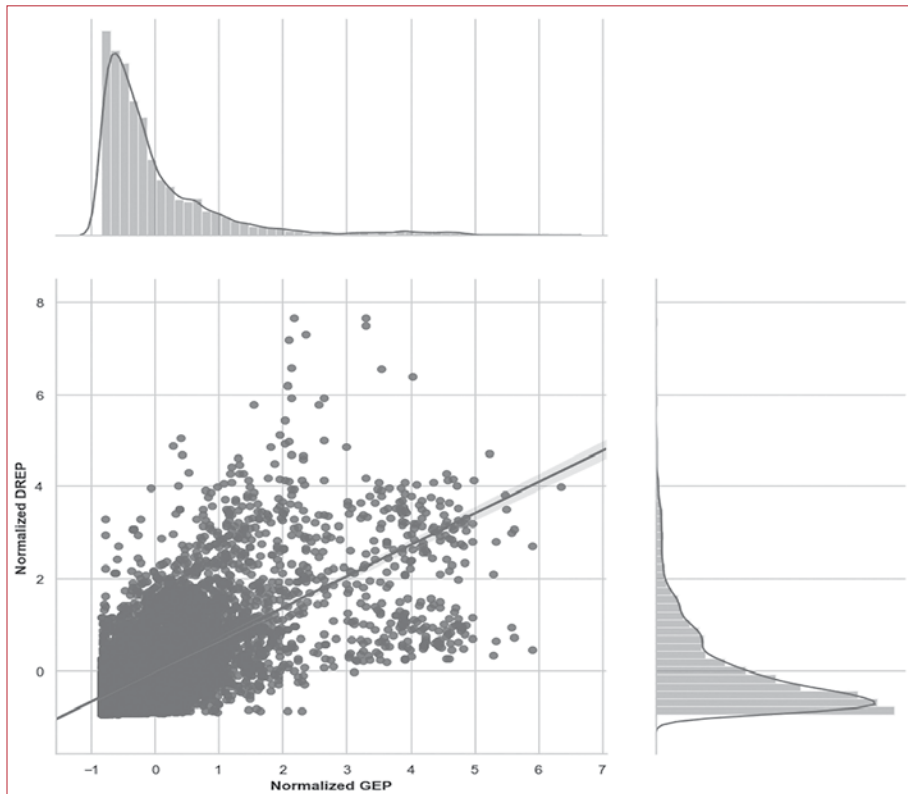


Figure 4 - Spectrum of the normalized Doppler Radar and Gauge Precipitation values with the probability density plot as it applies to each variable as the independent variable.

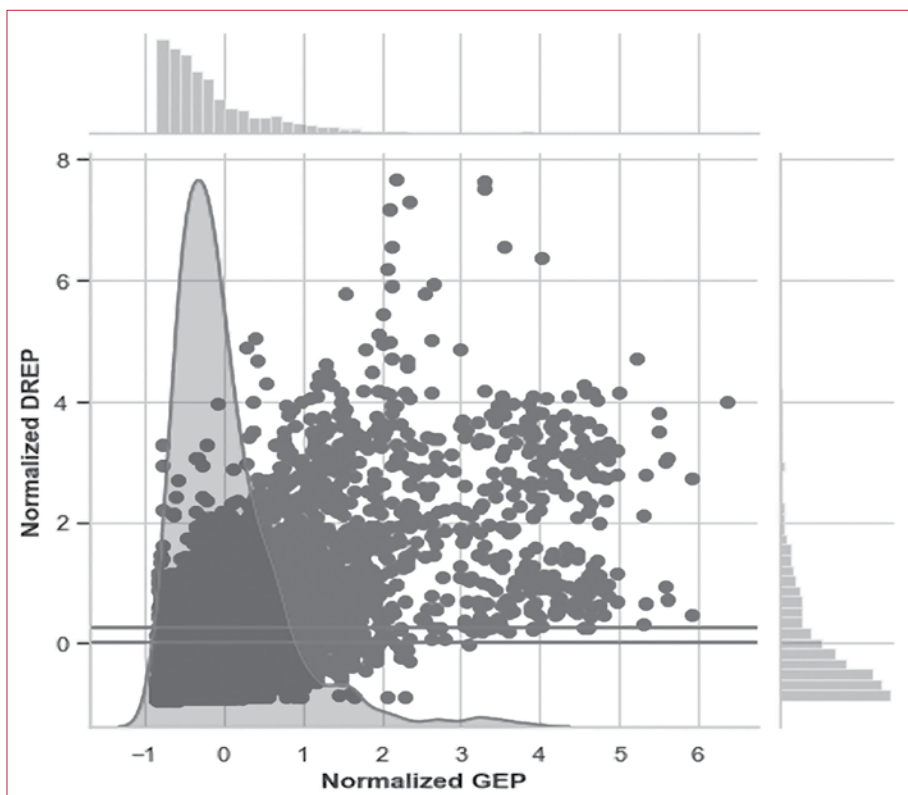


Figure 5 - Spectrum of the normalized Doppler Radar and Gauge Precipitation values with a kernel density function applied to one band of DREP (0 to 0.25).

i.e. a probability density, in increments of 0.25 standard deviation units, a specific increment chosen to adequately visually divide the entire dataset evenly for an appropriately focused analysis. Applying this algorithm of normalizing the data, arranging it to present an inverse function, and binning the vertical axis in 0.25 standard deviation unit increments across the entire range of DREP produces the frequency distributions defined by the normalized data analysis conducted for this study.

These results are now suitable to cascade into other computational models such as hydrologic models for floodplain assessment and dam reservoir assessment, among other topics. The results feed into a probabilistic distribution of likely values that cascades into other uses such as estimation of uncertainty in runoff predictions, uncertainty in soil-water contributions related to landslides, uncertainty in estimates of groundwater recharge from precipitation; among several other uses in Geoscience related investigations.

## Conclusions

The assessment of uncertainty associated with modern Doppler-Radar measurements of precipitation have several important sources of uncertainty. For example, variable Z-R relationships, radar calibration, clutter, attenuation, and an inaccurate understanding of the physics behind precipitation, along with instrumentation related factors, all contribute to uncertainty. Additionally, uncertainty exists in the operation of the Radar type as well as mathematical prediction applied to the collected data under investigation.

Current research work attempts to display and quantify the uncertainty associated with the published data by use of typically normal statistical distributions fitted to the data pairs of Doppler Radar estimated precipitation (DREP) versus precipitation gauge estimated precipitation (GEP). The analysis shows that the uncertainty in such data is significant, meaning such uncertainty indicates that a point estimate prediction is not appropriate, but this uncertainty can be well visualized using currently available data visualization computational software tools such as Microsoft Excel's basic scatterplot tool. Further analysis using statistical packages in R Studio or Python accomplish the next task: visualizing standard deviations of differences between the estimated DREP and GEP values.

The next step in research will be to better describe such uncertainty trends in order to cascade the resulting distributions into application models such as rainfall-runoff models. Other computational models that incorporate precipitation data that can utilize these results include groundwater, water conservation, environmental, contamination, agricultural, soil-strength analysis (e.g., levees, earthen dams, slope stability, highway embankments, etc.), among other applications. By cascading the input Doppler Radar data into the provided distribution of uncertainty trends developed in the current work, developing a distribution of outcomes for precipitation for subsequent use in other models (e.g. a stochastic “random walk” approach) that operate off the precipitation estimates is possible. Further, it is necessary for the continuing assembly of comparative data in order to provide an exhaustive representation, if possible, of all data comparisons. With such diligence, one can update the uncertainty estimates as data are collected and synthesized to better develop the uncertainty distributions displayed in this work.

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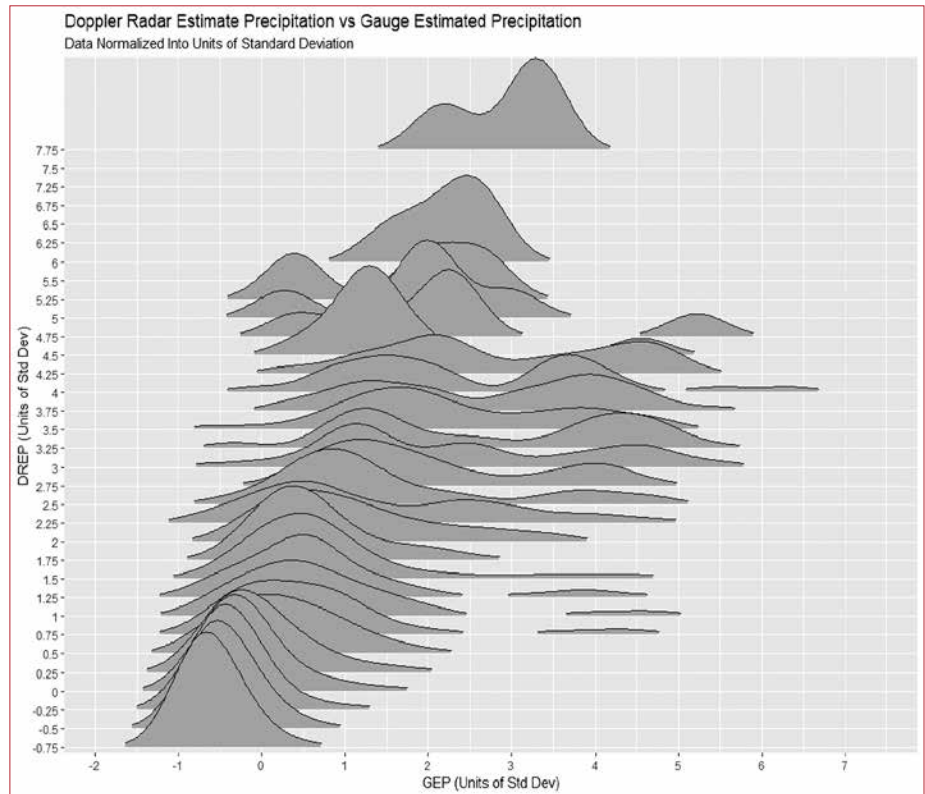


Figure 6 - DREP bands in increments of 0.25 (from -1 to 8) with kernel density estimates applied to each individual band.

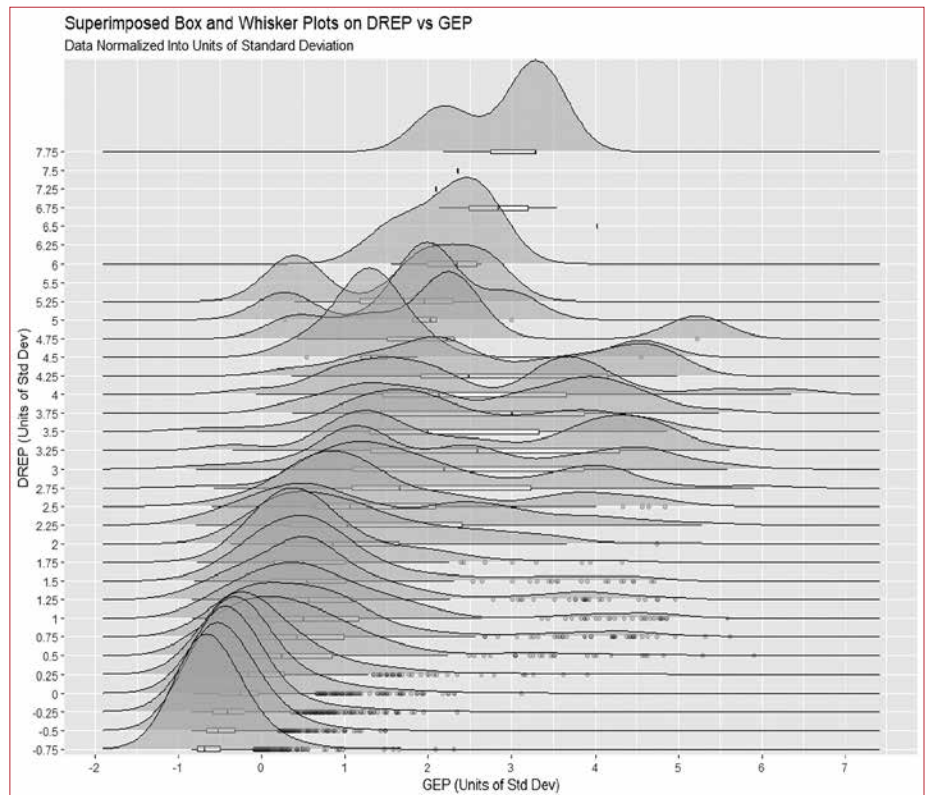


Figure 7 - DREP bands in increments of 0.25 (from -1 to 8) with kernel density estimates applied to each individual band and Box and Whisker Plots overlaid for additional fidelity.

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## Slickenside on the Corona Heights Fault



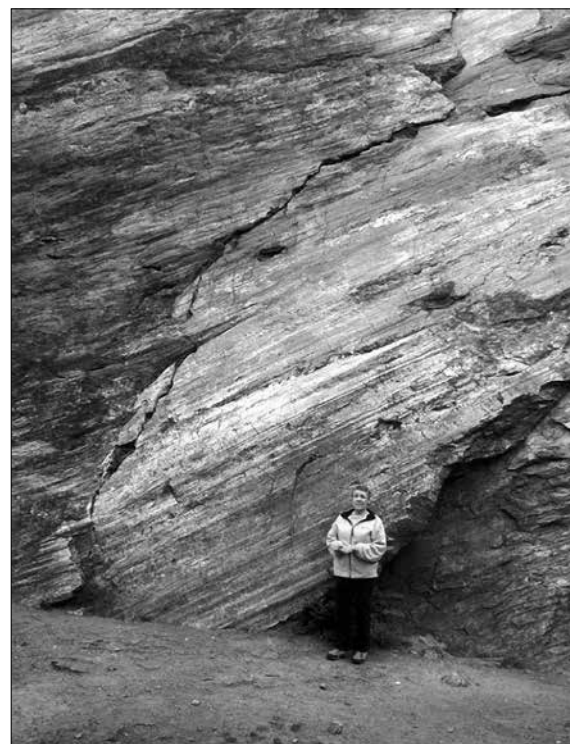
Albert L. Lamarre, CPG-06798

Given that San Francisco is a popular place for travelers, I suspect that over time many geology students pass through this fine city. I suggest that the

next time any geology student is here, he or she must take the opportunity and time to see what is perhaps the best example of fault slickenlines anywhere in the world!

Although not one of the famously known faults of the San Francisco Bay Area, the Corona Heights fault has a slickenside that exhibits one of the best exposures of slickenlines you may ever see! The beautifully exposed fault surface is about 70 meters long by 15 meters high, and it forms a cliff face that was once the wall of a quarry. This exposure of world-class slickenlines is developed in Franciscan chert of the Marin Headlands Terrane where the Corona Heights fault, an oblique-dextral fault, cuts through the Castro District south of downtown San Francisco. The fault consists of a thin breccia zone (< 1 meter thick) with an anastomosing network of highly polished grooved slickenlines within the breccia that are profoundly well developed, well exposed, and well preserved. Since the fault cuts radiolarian chert of the Franciscan Complex, the fault surface is all silica, which accounts for the high degree of polishing and mirror-like finish. You can almost see yourself in the reflection.

The fault is at 15th and Beaver streets adjacent to the Peixotto Playground and a nursery school on the west side



Corona Heights Fault

of the Castro District in southern San Francisco. It's easy to miss since buildings are so closely packed together there and you probably wouldn't find it if you did not know it is there.



Close-up view of the Corona Heights Fault.