Determination of the Highest Point in the Kingdom of Saudi Arabia

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Abstract. On August 17 and 18, 2018, we used a Trimble Geo 7x GPS unit to measure the elevations of Jabal Sawda and Jabal Ferwa to determine which is the highest peak in the Kingdom of Saudi Arabia. After post-processing the measurements using the nearest available base station correction data, we found the elevation of Jabal Ferwa to be 3,001.8m with a standard deviation of 0.7m, and Jabal Sawda to be 2,998.7m with standard deviation of 0.6m. These results indicate that the probability that Jabal Ferwa is the highest point in Saudi Arabia is approximately 98.1%.

1 Introduction

The two leading candidates for the highest point in the Kingdom of Saudi Arabia are Jabal Sawda and Jabal Ferwa, both of which are located near the city of Abha in southern Saudi Arabia. The approximate locations of the two peaks are shown in Fig. 1.

According to SRTM data (satellite-based elevation measurements), Jabal Sawda, commonly considered the highest peak in the Kingdom of Saudi Arabia, lies between the 2980m and 3000m height contours. However, there is one (and only one) other peak in Saudi Arabia, Jabal Ferwa, commonly considered the second highest mountain, that also lies between the 2980m and 3000m contours on SRTM data. SRTM elevations have errors up to 16m, thus SRTM data alone is not accurate enough to determine which of these two peaks is the highest.

2 Prior Elevation Surveys

We discovered that several land-based topographic surveys have been conducted in Saudi Arabia over the past few decades, and the results are publicly available on mapstor.com. The Soviets conducted a survey in 1978 and measured Jabal Sawda to have an elevation of 3032m and Jabal Ferwa to have an elevation of 3091m.

The US military also conducted a survey, the j06-c, and measured Jabal Sawda to be 3015m tall and Jabal Ferwa to be 3020m tall. These were the only publicly-available surveys that measured both peaks.

The UK military joint operations graphic from 1986 measured Jabal Sawda to have an elevation of 3015m, but did not measure Jabal Ferwa. The US Military NE38 measured Jabal Sawda at 2910m, but also did not measure Jabal Ferwa.

Fig. 1. The approximate locations of Jabal Sawda and Jabal Ferwa, likely the two highest peaks in Saudi Arabia.

It appeared, from all the data we could find, that no source definitively measured Jabal Sawda as taller, while several sources measured Jabal Ferwa as taller, and one source (SRTM) measured them as equal height within the margin of error of the measurement.

A summary of the measured elevations (in meters) of Jabal Sawda and Jabal Ferwa is presented in Table 1. This summary also includes the measurements determined by our survey, labeled 'Gilbertson.'

Survey		**Mountain**	
Name	**Year**	**Sawda**	**Ferwa**
SRTM data	2000	2980-3000	2980-3000
Soviet 1978 Survey	1978	3032	3091
US Military j06-c	?	3015	3020
US Military NE38	?	2910	n/a
UK Military	1986	3015	n/a
Gilbertson	2018	2998.7	3001.8

Table 1. Summary of the measured elevations in meters for Jabal Sawda and Jabal Ferwa. Note: 'SRTM' = 'Shuttle Radar Topography Mission.'

The prior survey data call into question whether Jabal Sawda is indeed the true highest point in Saudi Arabia. We learned that there now exist survey-grade GPS units which can theoretically measure elevation to 10cm accuracy, if brought to the summit of the mountain and if the data are carefully post-processed with data from a nearby base station.

3 Elevation Measurement and Post-Processing

We rented a Trimble Geo 7x GPS unit from Waypoint Technology Group (Albany, NY, USA) and brought the unit to the summit of Jabal Sawda on August 17 and Jabal Ferwa on August 18, 2018. On each summit, we placed the unit on the highest piece of permanent rock and recorded data for a minimum of ten minutes, totaling more than 500 data points for each of the two peaks. Photos of the GPS unit collecting data on each peak are shown in Fig. 2.

After consulting with Waypoint Technology Group, we processed our GPS data using measurements from base stations in Kuwait and Addis Ababa, Ethiopia. A GPS base station is a device that is placed at a known (and fixed) location that tracks the positions of GPS satellites with high accuracy. Usually, base station units are large, expensive devices that are run by organizations like universities or airports. Base station data can be used to improve the accuracy of GPS measurements taken with devices like the Trimble Geo 7X.

One of the main factors that contributes to degradation of the accuracy of GPS measurements is distortion of the satellite signals caused by the local ionospheric conditions; i.e., the flow of charged particles high in the atmosphere,

Fig. 2. Photos of the Trimble Geo 7X recording data on Jabal Sawda (N 18.266717°, E 42.368264°) [left] and Jabal Ferwa (N 17.928547°, E 43.265528°) [right].

in between the GPS satellite and earth. The base station is able to calculate the ionospheric-induced distortion at its location, which can be used to correct GPS measurements taken nearby. The goal is to have base station data that were recorded during the same period of time that the GPS measurements were taken, and from approximately the same location (ideally less than 100 km away), so that the ionospheric conditions were the same and ionospheric distortion can be corrected for.

Although there are several thousand base stations in the world for which we have data access (via Trimble's Pathfinder Office software), unfortunately we could find no base stations on the entire Arabian Peninsula. The closest base stations we could find were a UNAVCO station in Kuwait ('kuwt') —1200km away —and an IGS station in Addis Ababa, Ethiopia ('adis') —1300km away. While these distances are far from ideal, they are the best that we could do. Incidentally, we contacted the chair of the GIS department at a top Saudi University, and he also said he did not have access to any Saudi base stations. We hypothesize that there exist Saudi Aramco base stations positioned at some of the oil fields, but we have yet to find someone who can connect us to any data.

For each peak, Jabal Ferwa and Jabal Sawda, we took three sets of measurements, referred to as Ferwa1, Ferwa2, Ferwa3, for Jabal Ferwa; and Sawda1, Sawda2, and Sawda3 for Jabal Sawda, as referenced in Figures 3-5. Two base stations were used for post-processing: 'kuwt' (UNAVCO) and 'adis' (IGS). All data were post-processed using Trimble Pathfinder Office (PFO). For 'kuwt1,' PFO automatically retrieved base station data; for 'kuwt2' and 'adis,' base station data were downloaded separately and imported into PFO.

4 Results

Figure 3 shows the results from processing the data points. In this figure, the rectangle height equals two standard deviations (i.e., $\pm 1\sigma$, which encompasses a 68.2 percent confidence interval, assuming a normal distribution) and the vertical line height is four standard deviations (i.e., $\pm 2\sigma$, which encompasses 95.4 percent

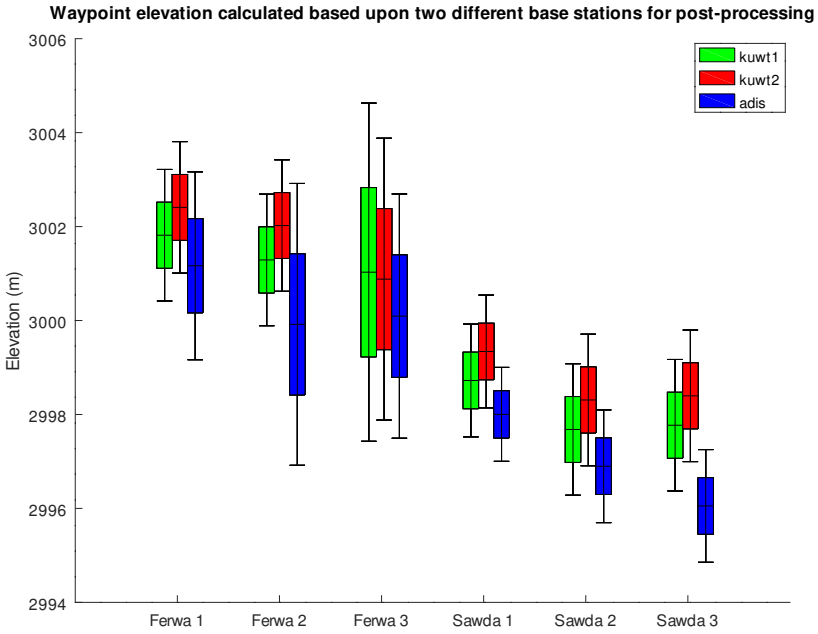

Fig. 3. Waypoint elevation for three different post-processing methods. Rectangle height equals two standard deviations (68.2 percent confidence interval, assuming a normal distribution); vertical line height is four standard deviations (95.4 percent confidence interval). Center horizontal line is the mean elevation. Rectangle color refers to post-processing method. Two base stations were used for post-processing: kuwt (UNAVCO) and adis (IGS). All data were post-processed using Trimble Pathfinder Office (PFO). For kuwt1, PFO automatically retrieved base station data; for kuwt2 and adis, base station data were downloaded separately and imported into PFO.

confidence interval). The center horizontal line is the mean elevation. Rectangle color refers to the post-processing method. The most data points were taken for Ferwa1 (581) and this is why we present data for Ferwa1. For Jabal Sawda, the most data points were taken for Sawda1 (835) and thus we present data for Sawda1.

Figure 3 shows that the measurements with the smallest errors for Ferwa1 and Sawda1 are those processed with kuwt1 base station data. Thus, we looked into these measurement in more detail. Figure 4 shows normalized histograms of the elevation measurements for Ferwa 1 and Sawda 1 data, assuming a normal distribution. These curves are based solely upon the measurement means and standard deviations from PFO post-processing.

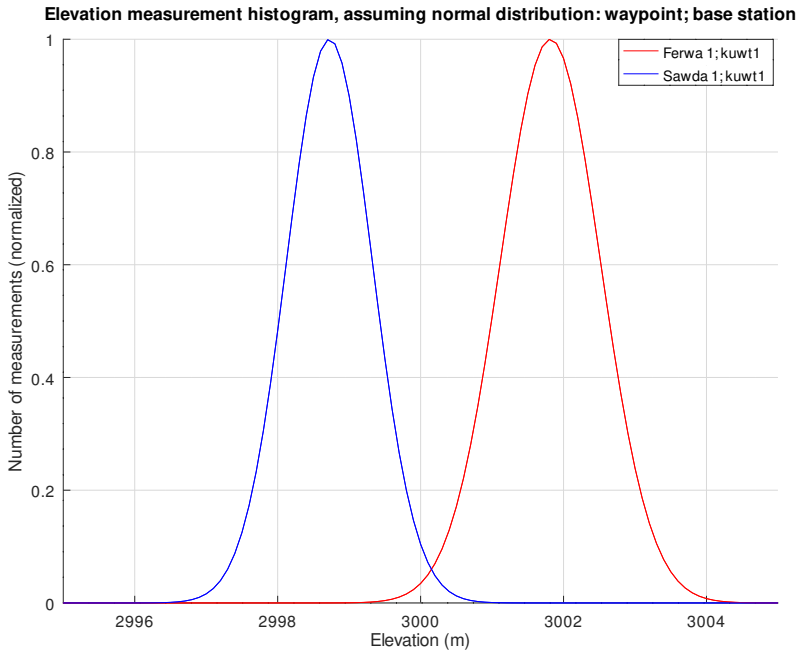

Fig. 4. Normalized histograms of the elevation measurements for Ferwa 1 and Sawda 1 waypoints, assuming a normal distribution. These curves are based solely upon the measurement means and standard deviations from PFO post-processing.

For completeness, we also present in Figure 5 normalized histograms of the elevations measurements for waypoints Ferwa 1 and Sawda 1, based upon post-processing with three different methods: kuwt1, kuwt2, and adis.

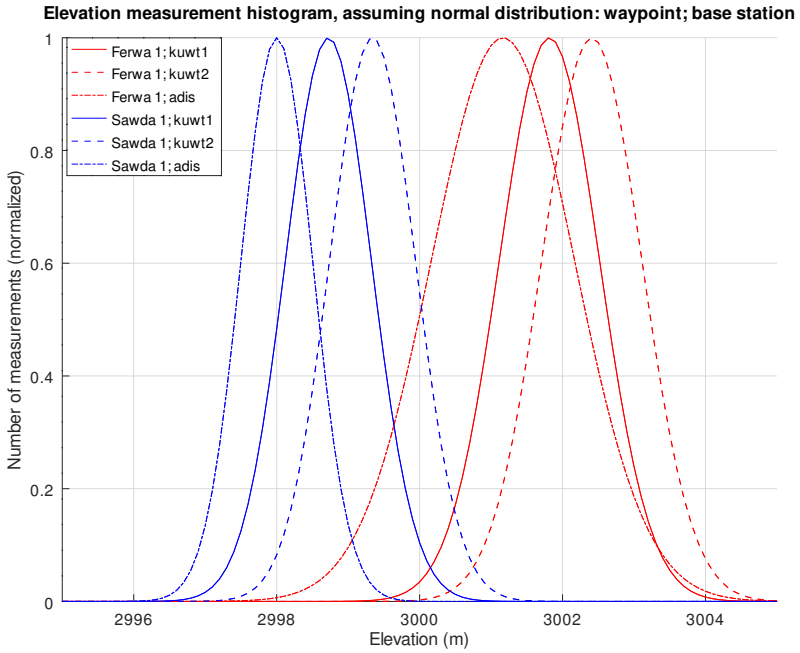

Fig. 5. Normalized histograms of the elevations measurements for waypoints Ferwa 1 and Sawda 1, based upon post-processing with three different methods: kuwt1, kuwt2, and adis; these are described in more detail in the Figure 3 caption.

5 Conclusions and Future Work

We found that, based on measurements Ferwa 1 and Sawda 1 using kuwt1 base station data, which gave the results with the smallest errors for each peak, Jabal Ferwa has an elevation of 3,001.8m with a standard deviation of 0.7m, and Jabal Sawda has an elevation of 2,998.7m with standard deviation of 0.6m.

Based on the PFO-quoted mean elevations and standard deviations and assuming a normal distribution, we calculated that the probability that Jabal Ferwa is taller than Jabal Sawda is 98.148 percent.

For reference, the positions of the two peaks that we recorded are: Jabal Sawda (N 18.266717°, E 42.368264°), Jabal Ferwa (N 17.928547°, E 43.265528°).

Future work includes taking longer measurements to further reduce the margin of error as well as post-processing the measurements with data from closer base stations. For access to the GPS data, the reader is encouraged to contact the authors.

6 Acknowledgements

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7 About the Authors

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We graduated from the Massachusetts Institute of Technology (MIT) in 2014 (Matthew) and 2015 (Eric) with our PhD degrees in Mechanical Engineering. Matthew is currently employed as an Electro-Optical Engineer at Lockheed Martin Space Systems and Eric is an Associate Teaching Professor of Mechanical Engineering at Seattle University.