VERTICAL GRAVITY GRADIENT MEASUREMENTS IN THE YELLOWSTONE NATIONAL PARK IN AUGUST 2014

Report

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Foreword

This report contains the results of relative gravity measurements carried out in the Yellowstone National Park (YNP) in August 2014. These data are used to determine the vertical gravity gradient at the sites where absolute gravity measurements have been performed for a decade between 2009 and 2021. The absolute gravity stations are spatially well spread in the center of YNP (Figure 1). The sites (Grant Village, Lake, Norris, and Old Faithful) were chosen within walking distance of permanent GNSS stations.

Modifications of the FG5 absolute gravity meter forced us to perform precise measurements of the vertical gravity gradient. The new model FG5X used for the last campaigns has a higher drop starting height than the FG5: about 1.38 m for the FG5X instead of about 1.30 m for the FG5. For our research project, we calculate the final gravity g-values at a reference height of 1.30 m. It was chosen close to the starting height of the FG5 drop to minimize the error in the vertical gravity transfer. This transfer height is only a few centimeters for the FG5 but close to 10 cm for the FG5X. To reach an error less than 1 microgal for the gravity transfer, one needs to know the vertical gravity gradient with an uncertainty less than 1%.

All the relative gravity measurements were made with the spring gravimeter Scintrex CG5-010 from the University of Luxembourg. In this report, we provide a short description of the sites and of the measurements protocol. Finally, the values of the linear and quadratic vertical gravity gradients are presented in tables.

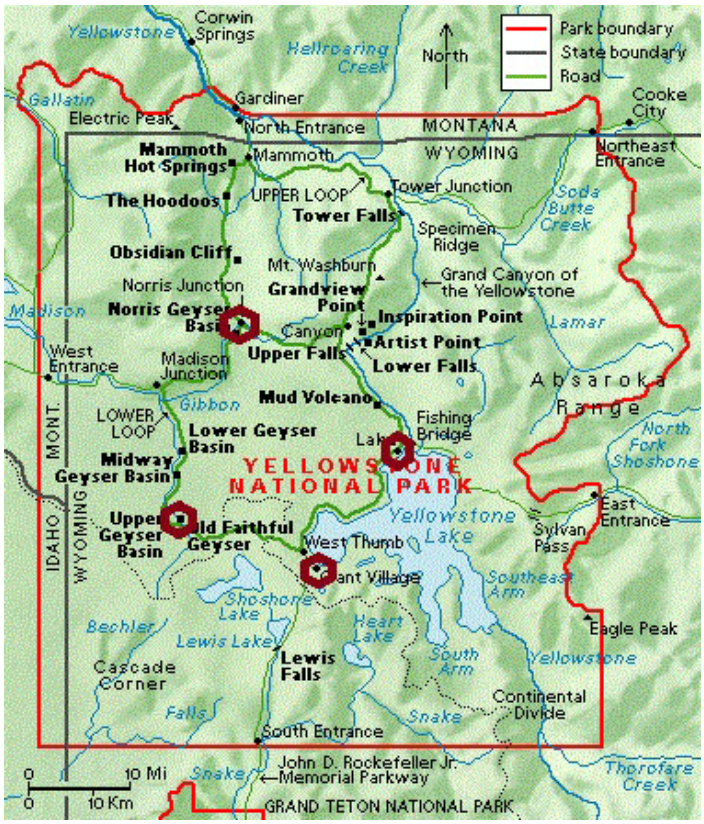


Figure 1. Location (red circles) of the absolute gravity sites the Yellowstone National Park: Norris, Lake, Grant Village and Old Faithful.

1. The absolute gravity sites

The vertical gravity gradient was measured at the four absolute gravity sites: Lake, Grant, Old Faithful and Norris. The coordinates are given in Table 1. All the stations are indoor except in Lake where the measurements are performed under a tent on a parking lot.

Table 1. Coordinates of the absolute gravity stations in Yellowstone National Park.

Station	**Latitude /degree**	**Longitude /degree**	**Altitude /m**
Grant	44.56920	-110.56319	2389
Lake	44.56264	-110.39615	2298
Norris	44.72453	-110.69311	2293
Old Faithful	44.45643	-110.84225	2232

In **Grant Village**, the absolute gravity site is located inside the maintenance garage of the Park Service area. The benchmark is fixed to the ground level on the left side at about 1 m from the sliding garage door (Figure 2).

Figure 2. Grant Village absolute gravity site in the maintenance garage of the Park Service.

The **Lake** station is situated in the maintenance lodging area in front of the Mess Hall. The benchmark is put on the asphalt of the parking lot outside of the Mess Hall.

Figure 3. Lake absolute gravity site on the parking lot in front of the Mess Hall in the maintenance lodging area.

In **Norris**, the gravity benchmark is in the basement of the blackwater sewage treatment plant.

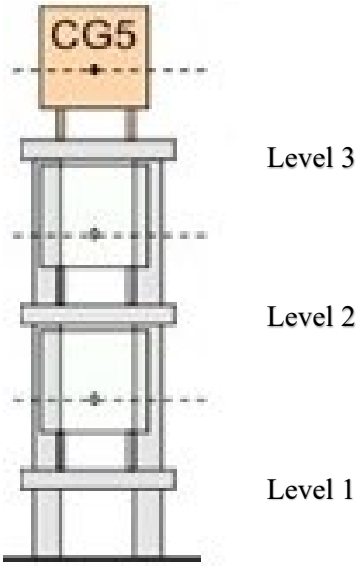
Figures 4. Building of the blackwater treatment in Norris. The benchmark is in the basement.

In **Old Faithful**, the gravity benchmark is in the basement of the disused sewage treatment plant.

Figures 5. Building of the disused Old Faithful sewage treatment plant. The gravity benchmark is in the basement.

2. Vertical Gravity Gradient Protocol

The relative gravity differences were measured between three different levels (0.259 m, 1.518 m and 1.655 m) above the benchmark at the ground level (Figures 6). The sequence of measurements is the same for each station: it consists of 10 rotations corresponding to the different levels: 1-2-3-1-2-3-1-2-3-1. One must secure enough rotations between these three different levels to acquire enough data. Otherwise, one cannot obtain a stable and precise estimate of the parameters (i.e. vertical gravity gradient and instrumental drift). At each level, three successive measurements of 1-minute length are taken, corrected for tides and then the mean g-value is calculated.



Figures 6. Vertical gravity gradient measurements with the Scintrex CG5-010 at the Old Faithful indoor absolute gravity station. Schematic of the tripod with the 3 different levels above the ground (0.259 m, 1.518 m and 1.655 m).

The data are the gravity differences between three fixed heights. The gravity change is fitted as function of the height using a polynomial of the first degree (linear model) or of the second degree (quadratic):

$$g(h) = \mathbf{a_1} + \mathbf{b_1} \times h \qquad \text{linear model}$$
$$g(h) = \mathbf{a_2} + \mathbf{b_2} \times h + \mathbf{c_2} \times h^2 \qquad \text{quadratic model}$$

The vertical gravity difference between level h_1 and h_2 is given by:

$$\Delta g(h_2 - h_1) = g(h_2) - g(h_1) = \mathbf{b_1} \times (h_2 - h_1) \qquad \text{linear model}$$
$$\Delta g(h_2 - h_1) = g(h_2) - g(h_1) = \mathbf{b_2} \times (h_2 - h_1) + \mathbf{c_2} \times (h_2^2 - h_1^2) \qquad \text{quadratic model}$$

As the gravimeter is a relative instrument, the constants a_1 and a_2 are of no use. They are arbitrary and vary with time due to the instrumental drift. The results of the estimated parameters for the linear and quadratic models are presented in Tables 2 and 3, respectively.

Table 2. Coefficient $\mathbf{b_1}$ of the vertical gravity gradient for the linear model.

Station	$\mathbf{b_1}$ /microgal m^{-1}
Grant	-299.2 ± 0.4
Lake	-306.7 ± 0.5
Norris	-251.3 ± 0.5
Old Faithful	-239.4 ± 0.3

Table 3. Coefficients $\mathbf{b_2}$ and $\mathbf{c_2}$ of the vertical gravity gradient for the quadratic model.

Station	$\mathbf{b_2}$ /microgal m^{-1}	$\mathbf{c_2}$ /microgal m^{-2}
Grant	-302.3 ± 7.4	1.6 ± 3.9
Lake	-257.2 ± 7.1	-26.6 +/-3.8
Norris	-247.0 ± 9.2	-2.4 ± 4.9
Old Faithful	-230.9 ± 7.0	-3.6 ± 3.8

The only significative non-linear vertical gravity gradient is measured at Lake. This is quite surprising as the site is in the open air although the proximity of the Mess Hall building may explain it. The low values for Norris and Old Faithfull are reasonable both sites being in building basements under the ground level.

Conclusions

We report the results of the vertical gravity gradient measured at four absolute gravity sites inside the Yellowstone National Park. The gradient is used to process the measurements of the absolute gravimeter as it must be included in the equation of motion describing the trajectory of the dropped object of the ballistic instrument. It is also needed to transfer the g-values from the observed height of the absolute gravimeter to the ground level or any other desired level.

For all the stations except Lake, the vertical gravity gradient is linear. The lowest values are found in basements as expected.