Gravity corrections to measured geometric slopes in Puna, Argentina, at 4000 meters Above the sea level

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1- ABSTRACT

The National Geographic Institute of Argentina (IGN) is currently completing the adjustment of the national altimetric network. In order to complete this operation, the IGN is measuring the remaining geometric slopes, and taking gravity and differential GPS measurements in the area of Puna, Argentina.
The Puna, considered the "Roof of America," is an area characterised by its unique topography, including heights from 3000 M.A.S.L and steep slopes over short distances, for example of approximately 2000 meters in 25 kilometres. Performed measurements have allowed the calculation of orthometric and normal heights along benchmarks with altitudes that oscillate between 3000 to 4000 meters. GPS observations made over the benchmarks have also permitted the calculation of the position of the Geoid in the area.
This work shows the applied measuring methods and calculations to obtain orthometric and normal heights. It is also exposes the differences between geometric, orthometric and normal heights. Finally, it makes a comparison between the geoidal heights of the benchmarks obtained from the measurements and the ones obtained from the EGM08 model.

2- INTRODUCTION

The vertical datum in Argentina was developed in 1924 with observations from the Mar del Plata tide gauge.
At this time the Argentine National Geographic Institute (IGN) began a field campaign in order to establish over 30,000 levelling benchmarks over 200,000 km.
The benchmarks that compose the vertical reference system were classified according to the precision in which the elevation was defined. Three precision orders were established as follows:

High Precision Leveling Lines
These leveling lines divide the country into closed and peripheral polygons (on the coastline or international boundaries).
Accuracy: $3 \cdot \sqrt{\text{Distance}[km]}\,[mm]$

Precision Leveling Lines
These leveling lines were developed inside the polygons generated by the high precision lines.
Accuracy: $5 \cdot \sqrt{\text{Distance}[km]}\,[mm]$

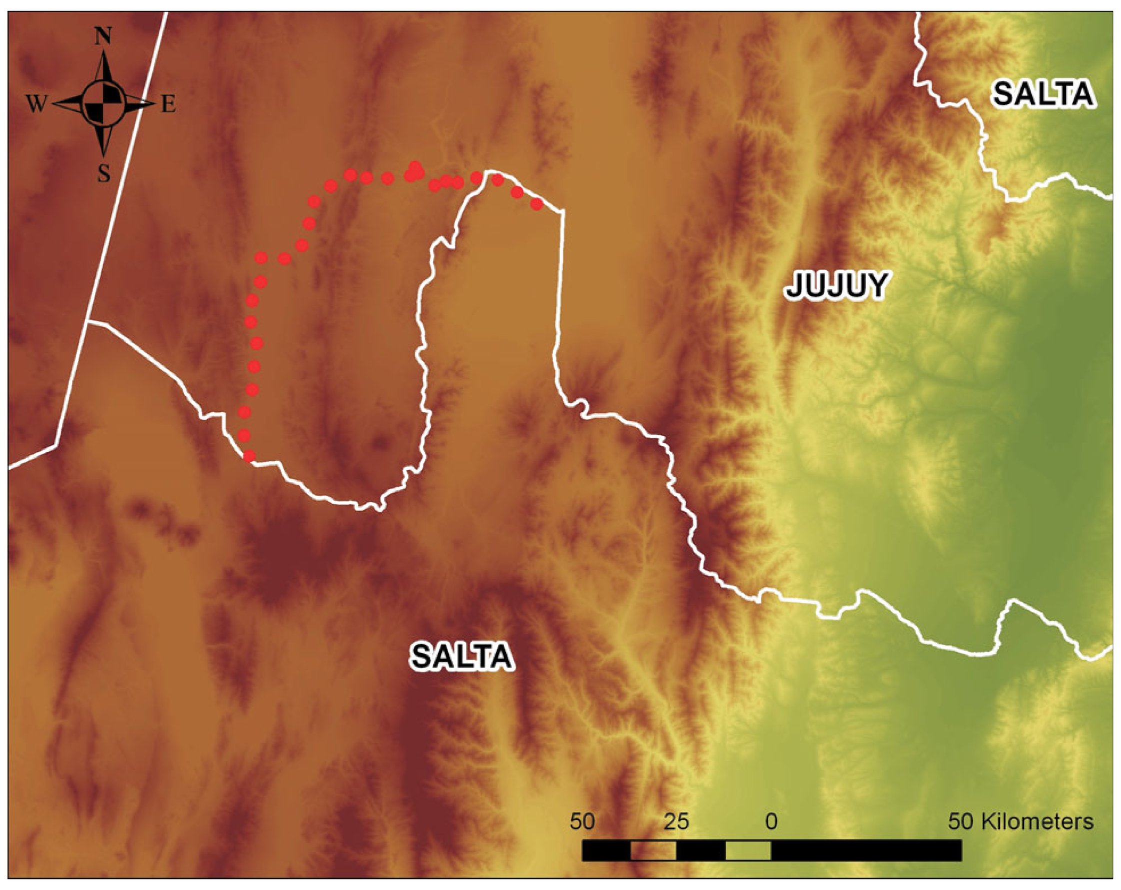
Topographic Leveling Lines
These leveling lines are used to densify some areas.
Accuracy: $7 \cdot \sqrt{\text{Distance}[km]}\,[mm]$

Gravity measurements were taken over the benchmarks that compose the High Precision Levelling Lines. The orthometric heights of the benchmarks were obtained using this data.

The IGN is currently undertaking the final adjustment of the altimetric network. In order to do this, it is imperative to measure the remaining geometric slopes in the area of the Puna.

3- MEASUREMENTS

The following physical map shows the 28 benchmarks that were recently measured in Puna.



Several measurement methods have been utilised in this area.

High Precision Geodetic Leveling:
Trimble DiNi 12 and Invar rods were used in order to ensure the precision standards established by the IGN. The equidistance between the rods was 50 meters at all times. The 28 benchmarks were measured twice and the mean value of each slope was used to determine the calculations.

Gravimetric Observations:
A LaCoste & Romberg G43 gravimeter was used. The estimated error of the gravity readings was approximately 0.5 mGal. The gravity determinations were linked to the IGSN 1971 datum.

Differential GPS:
Double-frequency GPS equipment was used to determine the precise position of each benchmark. The sessions were two hours long to ensure centimetric precision of the coordinates. GAMIT / GLOB K and GPPS / FILLNET software was used for post-processing GPS data. The coordinates of the benchmarks were obtained in the ITRF05-IGS05 reference frame.

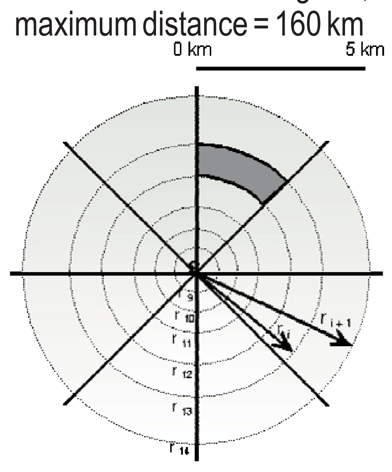
4 - CALCULATION & RESULTS

1- Gravity Reductions

A- Remove Bouger Plate: -0.1119 * H [mGal]
B- Free-Air Reduction: + 0.3086 * H [mGal]
C- Restore Bouger Plate: -0.1119 * H [mGal]
D- Topographic correction (Hammer Chart):

$$\sum \rho \frac{2\pi}{n} G\left(r_{i+1} - r_i + \sqrt{r_i^2 + \Delta h_i^2} - \sqrt{r_{i+1}^2 - \Delta h_i^2}\right)$$

The SRTM v4 model was used to implement topographic corrections. Other used parameters used were:
$\rho = 2.67$ gr/cm^3, $\alpha = 2\pi/n$ ($n = 360$ or $\alpha = 1°$),
$G = 6.67428 \cdot 10^{-11} \cdot m^3 \cdot kg^{-1} \cdot s^{-2}$, $r = 100$ m,
maximum distance = 160 km



Hammer Chart

2- Orthometric and Normal Heights Calculations

Orthometric Height

$$H^0 = \frac{C}{\bar{g}}$$

$$C = \int_0^H g \cdot dH$$

$$\bar{g} = \frac{1}{H}\int_0^H g \cdot dH$$

Normal Height

$$H^N = \frac{C}{\bar{\gamma}}$$

$$C = \int_0^{H^N} \gamma \cdot dH$$

$$\bar{\gamma} = \frac{1}{H^N}\int_0^H \gamma \cdot dH^N$$

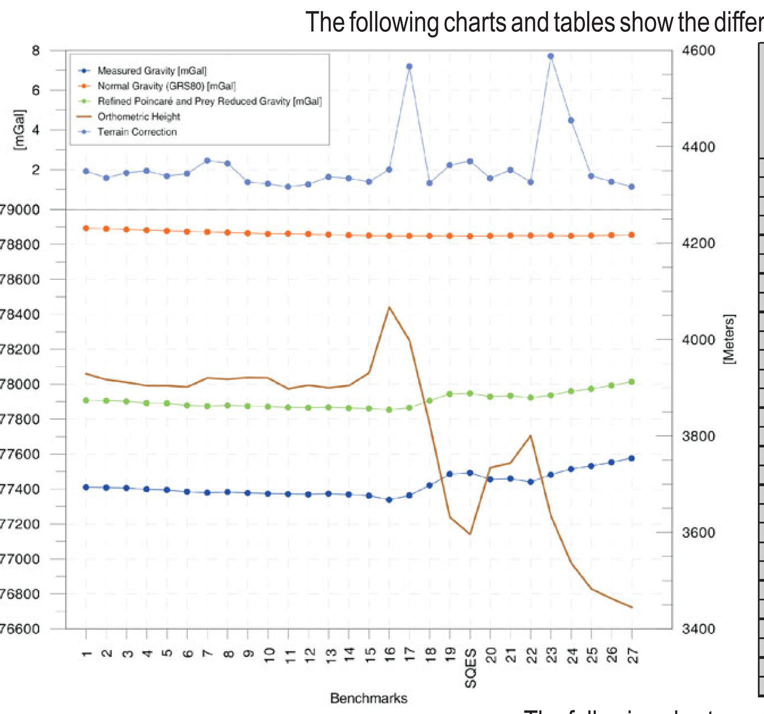
3- Ellipsoidal Heights

After calculating benchmarks positions the Geoidal Undulation (IGN N) was calculated:

$$N = h - H$$

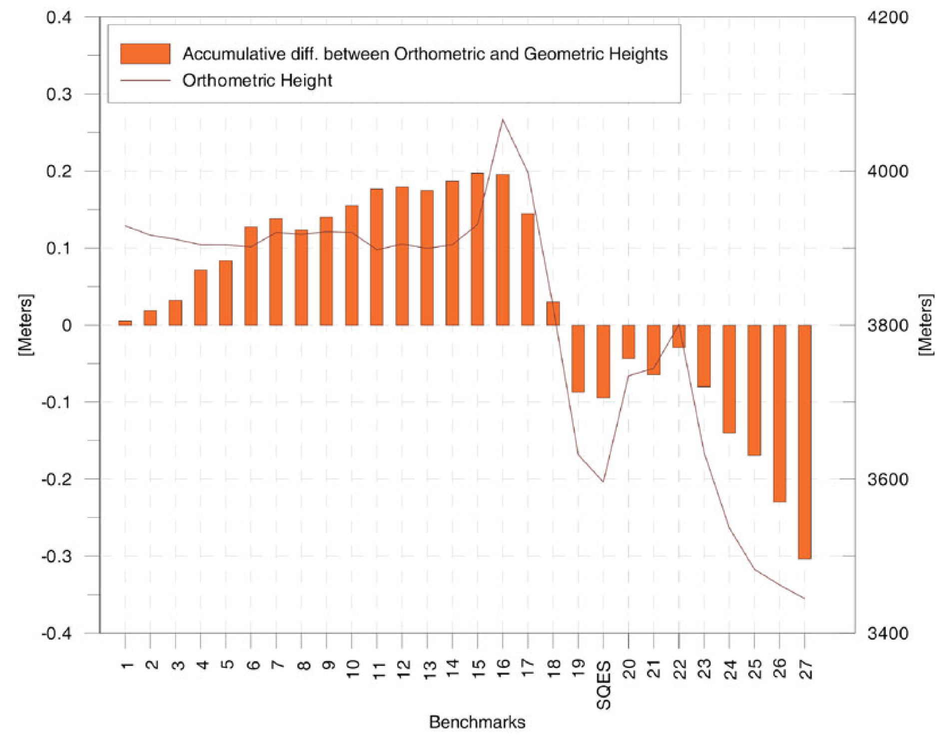
Finally these values were compared with EGM08 Geoidal Undulation Model (EGM08 N).

The following charts and tables show the different gravity results obtained:



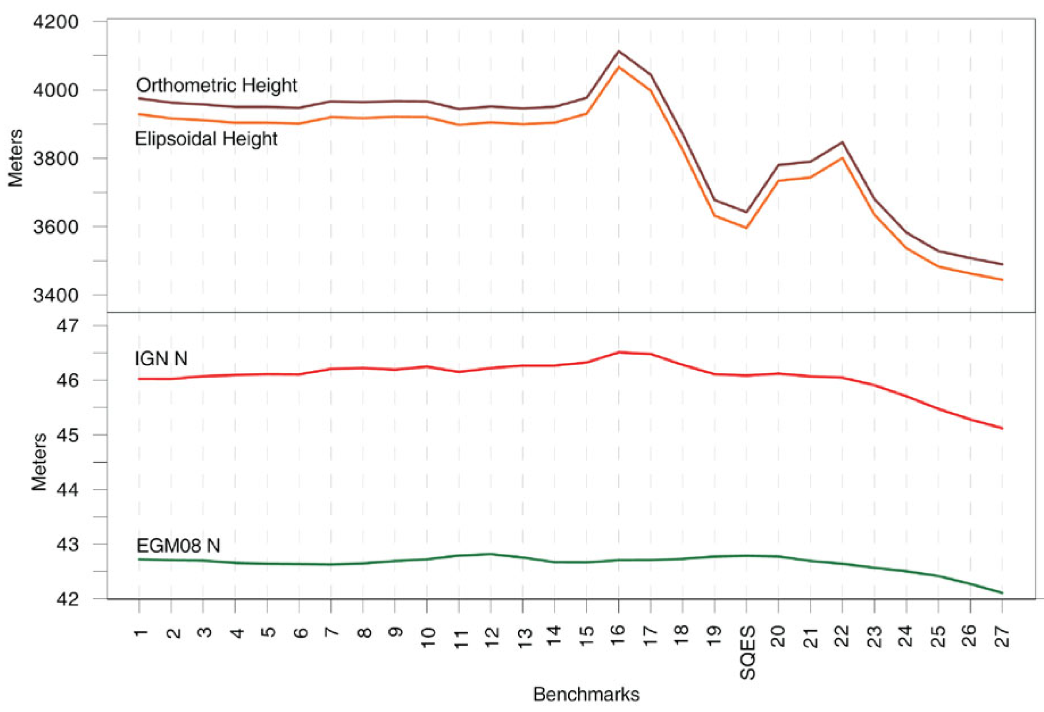
Station Name	Orthometric Height [m]	Poincaré & Prey Reduced Gravity [mGal]	Terrain Correction [mGal]	Refined Poincaré & Prey Reduced Gravity [mGal]	Normal Gravity (GRS80) [mGal]	Complete Bouger gravity Anomaly [mGal]
1	3928.900	977909.9	1.9	977908.0	978892.4	-984.5
2	3916.744	977907.0	1.6	977905.4	978889.2	-983.7
3	3911.439	977904.0	1.8	977902.2	978885.5	-983.3
4	3904.271	977894.4	1.9	977892.5	978882.0	-989.4
5	3904.205	977891.4	1.7	977889.7	978878.2	-988.5
6	3901.528	977880.5	1.8	977878.7	978874.6	-995.8
7	3920.413	977877.1	2.5	977874.6	978871.2	-996.6
8	3917.952	977880.9	2.3	977878.5	978867.7	-989.2
9	3921.251	977876.5	1.4	977875.1	978864.8	-989.7
10	3920.456	977872.8	1.3	977871.5	978861.0	-989.6
11	3897.949	977868.4	1.1	977867.2	978861.3	-994.1
12	3905.297	977867.4	1.3	977866.1	978859.3	-993.2
13	3899.782	977868.8	1.6	977867.2	978855.9	-988.7
14	3904.504	977865.6	1.6	977864.0	978852.5	-988.5
15	3930.765	977861.9	1.4	977860.5	978850.1	-989.6
16	4067.410	977856.5	2.0	977854.5	978848.5	-994.0
17	3998.440	977871.7	7.2	977864.5	978849.0	-984.5
18	3824.449	977907.7	1.3	977906.4	978849.2	-942.8
19	3631.550	977946.6	2.2	977944.4	978848.9	-904.5
SQES	3595.881	977950.1	2.4	977947.7	978847.6	-899.9
20	3734.083	977930.7	1.6	977929.1	978848.5	-919.4
21	3743.759	977935.7	2.0	977933.7	978850.5	-916.8
22	3800.633	977924.2	1.4	977922.8	978849.9	-927.1
23	3634.558	977944.6	7.7	977936.9	978850.2	-913.3
24	3536.550	977965.1	4.5	977960.7	978849.5	-888.9
25	3482.688	977975.6	1.7	977973.9	978849.9	-876.0
26	3462.279	977993.4	1.4	977992.0	978852.0	-860.0
27	3444.377	978015.0	1.1	978013.8	978854.0	-840.1

The following charts and tables show the different heights results obtained:



Station Name	Geometric Height [m]	Orthometric Height [m]	Normal Height [m]
6 N(355)	3944.337		
1	3928.895	3928.900	3928.885
2	3916.725	3916.744	3916.708
3	3911.407	3911.439	3911.386
4	3904.200	3904.271	3904.175
5	3904.122	3904.205	3904.096
6	3901.400	3901.528	3901.373
7	3920.275	3920.413	3920.259
8	3917.828	3917.952	3917.811
9	3921.111	3921.251	3921.096
10	3920.301	3920.456	3920.285
11	3897.773	3897.949	3897.743
12	3905.118	3905.297	3905.092
13	3899.608	3899.782	3899.579
14	3904.317	3904.504	3904.291
15	3930.568	3930.765	3930.558
16	4067.215	4067.410	4067.292
17	3998.295	3998.440	3998.328
18	3824.419	3824.449	3824.345
19	3631.637	3631.550	3631.457
SQES	3595.976	3595.881	3595.777
20	3734.126	3734.083	3734.001
21	3743.824	3743.759	3743.704
22	3800.662	3800.633	3800.575
23	3634.638	3634.558	3634.460
24	3536.690	3536.550	3536.462
25	3482.857	3482.688	3482.603
26	3462.508	3462.279	3462.245
27	3444.680	3444.377	3444.410
ΔH	-499.657	-499.541	-499.927

The following charts and tables show the differences between Orthometric and Ellipsoidal Heights and the difference between IGN N and EGM08 N:

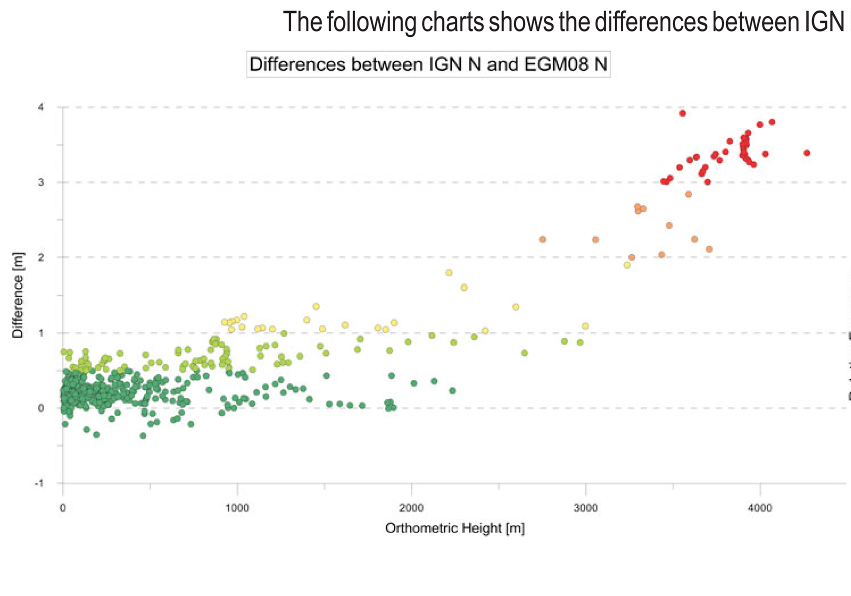


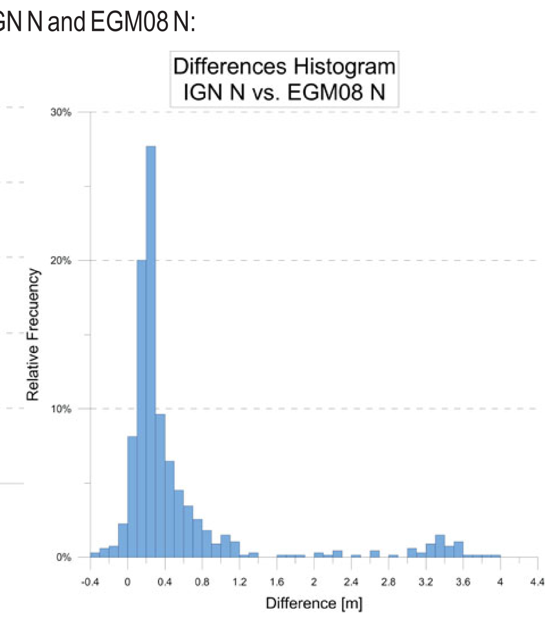
Station Name	Ellipsoidal Height [m]	Orthometric Height [m]	IGN N [m]	EGM08 N [m]
1	3974.925	3928.900	46.025	42.724
2	3962.757	3916.744	46.013	42.707
3	3957.487	3911.439	46.048	42.701
4	3950.303	3904.271	46.032	42.658
5	3950.242	3904.205	46.037	42.643
6	3947.516	3901.528	45.988	42.637
7	3966.488	3920.413	46.075	42.629
8	3964.057	3917.952	46.105	42.649
9	3967.310	3921.251	46.059	42.693
10	3966.553	3920.456	46.097	42.724
11	3943.936	3897.949	45.987	42.793
12	3951.348	3905.297	46.051	42.819
13	3945.885	3899.782	46.103	42.757
14	3950.593	3904.504	46.089	42.671
15	3976.896	3930.765	46.131	42.668
16	4113.695	4067.410	46.285	42.707
17	4044.762	3998.440	46.322	42.710
18	3870.726	3824.449	46.277	42.732
19	3677.819	3631.550	46.269	42.775
SQES	3642.141	3595.881	46.260	42.788
20	3780.296	3734.083	46.213	42.776
21	3789.940	3743.759	46.181	42.694
22	3846.743	3800.633	46.110	42.642
23	3680.618	3634.558	46.060	42.570
24	3582.491	3536.550	45.941	42.505
25	3528.439	3482.688	45.751	42.419
26	3507.902	3462.279	45.623	42.274
27	3489.919	3444.377	45.542	42.110

5- BEHAVIOR OF EGM08 IN ARGENTINA

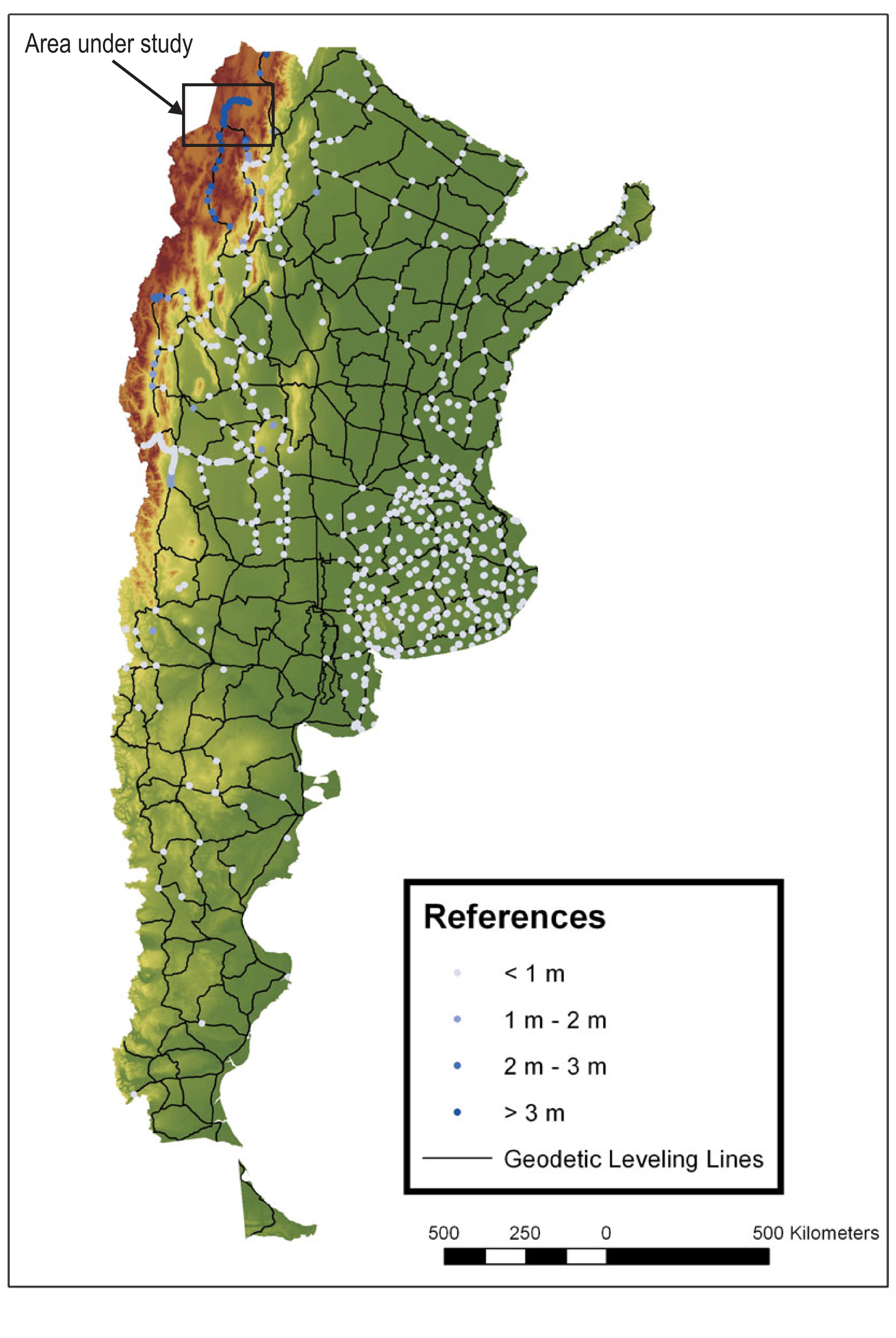
Data sets composed of 664 leveling and GPS benchmarks arranged along the Argentine territory was used to calculate the differences between IGN and EGM08 geoidal undulations.

The following charts shows the differences between IGN N and EGM08 N:





The following physycal map shows the differences between IGN N and EGM08 N:



6- FINAL COMMENTS

The results obtained from the evaluation study reveal that the EGM08 model is coherent with on-site measurements in some areas of Argentina. Nevertheless, the geoidal undulation differences in the Puna area show that there is not enought field information gathered for this area to establish a more aproximately N value of the EGM08 model.

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