Precise Determination of the Orthometric Height of Mt. Kilimanjaro

The team KILI2008

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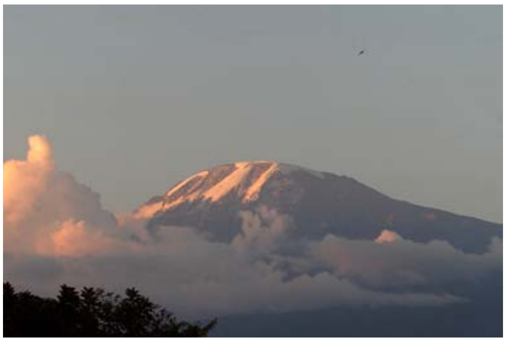
UPIMAJI SAHIHI WA UREFU WA MLIMA KILIMANJARO
MEDIÇÃO PRECISA DA ALTITUDE DO MONTE KILIMANJARO
PRECISE HEIGHT MEASUREMENT OF MOUNT KILIMANJARO

SUMMARY

- MOTIVATION AND INNOVATION
- DATA ACQUISITION
- DATA PROCESSING AND RESULTS

MOTIVATION & INNOVATION



Mount Kilimanjaro is the highest point of Africa and the highest isolated mountain which summit can be reached without the use of special climbing equipment.

Furthermore, its location close to equator, associated with the existence

of permanent glaciers and its almost perfect volcano shape has contributed to make this mountain one of the most important natural landmarks in the world.

MOTIVATION & INNOVATION

The current accepted value of 5 895 m was measured in 1952.

However, this value had a large uncertainty since it was obtained by classical trigonometric surveying using triangles having sizes with distances of 55Km and height differences up to 4 000 m.

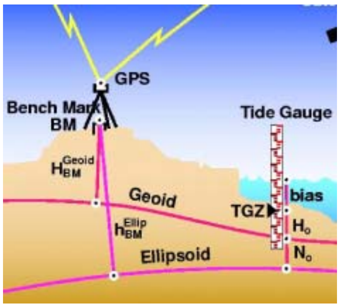
MOTIVATION & INNOVATION

In 1999, a first attempt to determine the orthometric height of Mt. Kilimanjaro using GPS was done by an international team formed by Tanzanian and German researchers (John et al., 2000).

- short period of GPS observations
- EMG96 for the geoid undulation model

The final value obtained was 5 892.55m.

MOTIVATION & INNOVATION



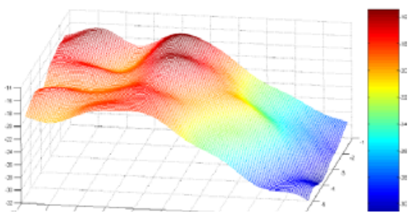
In order to use GNSS to compute heights with respect to a national datum, two steps are necessary:

Since GPS provides the height (h) with respect to a reference ellipsoid (WGS84), it is necessary to know the local geoid undulation (N) in order to estimate the orthometric height (H):

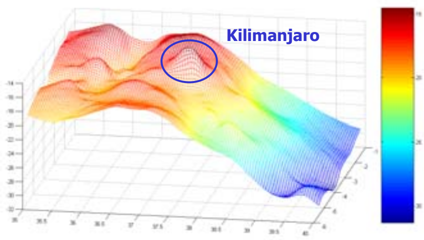
$$H \cong h + N$$

GNSS observations also need to be done at points with known coordinates in the national datum in order to convert the orthometric height between the global and the local datum.

MOTIVATION & INNOVATION



EGM96



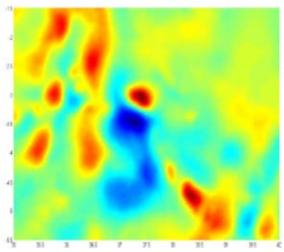
EGM2008

Uncertainties of Global Geoid Models:

EGM96 (left) and EGM2008 (right) geoid undulations (with respect to WGS84) for the Kilimanjaro region.

MOTIVATION & INNOVATION

EGM2008-EGM96
Min: -1.86m
Max: +1.76m



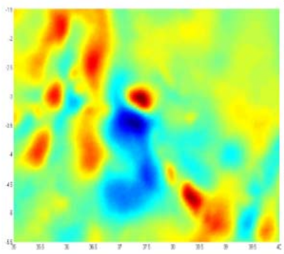
EGM2008 and EGM96 predicted geoid undulation differences between Latitudes 1.5ºS and 5.5ºS and Longitudes 35ºE and 0ºE (centered in Kilimanjaro).

They vary between -1.86m and +1.76m, with the largest gradient in the Kilimanjaro region.

EGM96 was the model used to compute the geoid undulation for the 1999 observation.

MOTIVATION & INNOVATION

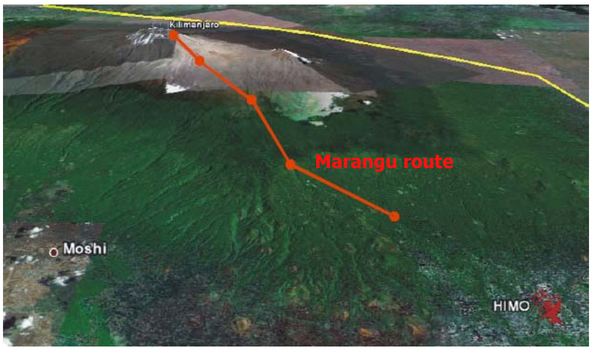
EGM2008-EGM96
Min: -1.86m
Max: +1.76m



This comparison shows that previous global models were not accurate enough to be used in order to achieve decimeter level uncertainty in the computation of the orthometric height of Mt. Kilimanjaro. It was necessary to construct a local geoid.

Notice that EGM2008 was not yet released when the project started. But, this project also allowed us to evaluate EGM2008 for this region.

MOTIVATION & INNOVATION



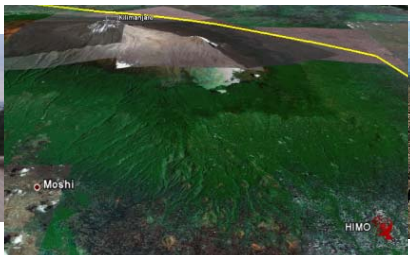
OUR PROPOSED METHODOLOGY:

To measure h: Large period of observations in the Uhuru peak using GNSS capable receivers on a physically materialized marker.

To compute N: Construction of a local geoid using a set of gravimetric (and GNSS) observations as dense as possible.

DATA ACQUISITION

Moshi



Himo

Two reference stations were installed in the framework of the KILI2008 expedition:

The first one (donated by Trimble) was installed in Moshi and it is now a CORS (Continuous Operating Reference Station) part of the AFREF project.

The second was installed in Himo, close to the departure gate during the duration of the filed works in order to ensure redundancy of reference station.

DATA ACQUISITION

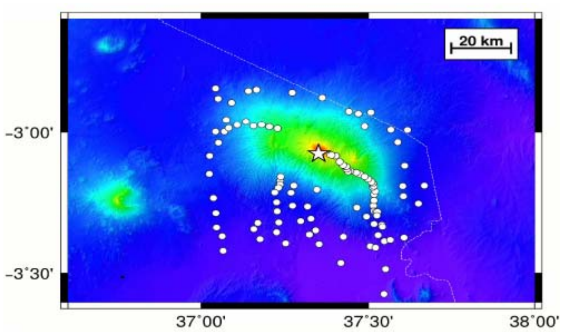
The field work took place between 1 and 9 of October. Three teams were formed:

Team A – GNSS (Trimble R8) measurements in the Uhuru peak (5 hours on the fifth day) and during the climb (for other studies)

Team B – Gravimetric observations (Scintrex G5) around and within the mountain (joined Team A the first 2 days of the climb)

Team C – Gravimetric observations (Scintrex G3) around the mountain.

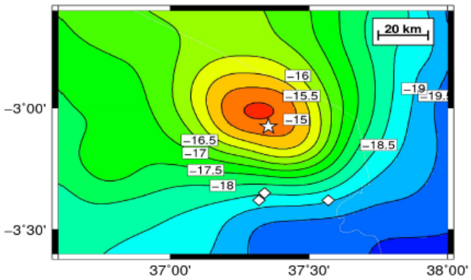
DATA ACQUISITION



Teams B and C also coordinated gravimetric points with GNSS observations (Trimble R8 receivers)

A total of 106 GNSS points and 99 gravimetric points were observed during the 9 days.

DATA ACQUISITION

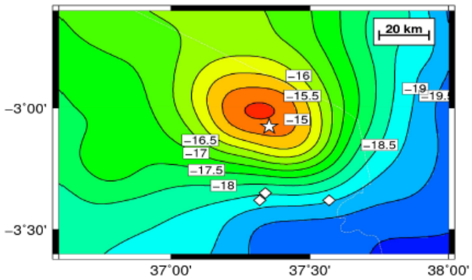


The Kili2008 undulation geoid model:

We used up to degree 360 of EGM2008 to compute the long wavelengths of the geoid.

1) **The degree 0-360 of EGM2008 were also used to compute the long wavelengths gravity field which were subtracted from the gravity observations.**
2) **We used the SRTM topography model to compute residual terrain corrections.**
3) **Finally, Least Squares Collocation (LSC) were applied to convert these gravity disturbances into geoid undulations.**

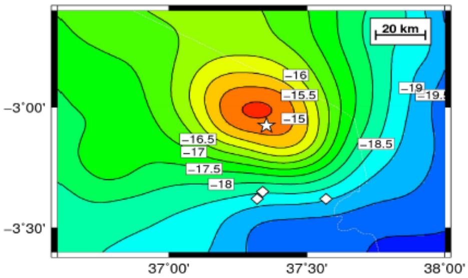
DATA ACQUISITION



The total KILI2008 geoid is the sum of

- **degree 0-360 of EGM2008**
- **the geoid due to mass of the mountain, and**
- **the geoid contribution computed with LSC.**

DATA PROCESSING & RESULTS



EGM2008 model for Kilimanjaro region

The differences between KILI2008 geoid and EGM2008

Moshi: -19 cm

Himo: -12 cm

Uhuru Peak: +24 cm

The ellipsoidal heights (h) and the Kili2008 undulations (N) are both referred to the WGS84 ellipsoid. Therefore, the orthometric height (H) is refered to the global datum used at EGM2008 that intends to minimize the differences between the Mean Sea Surface and the geoid at a global scale.

DATA PROCESSING & RESULTS

The GNSS solutions were obtained using different GNSS data processing software packages. First, we computed the precise ellipsoidal heights (and horizontal coordinates) with respect to the latest realization of the global reference frame – ITRF2005 – for the two reference stations (Moshi and Himo).

DATA PROCESSING & RESULTS

Solution	Value (m)
GIPSY	5875.43
BERNESE	5875.59
AUSPOS	5875.48
SCOUT	5875.56
TBC	5875.07

Computed value of the ellipsoidal height for the Uhuru Peak using several GNSS processing software packages.

The position of that two stations were fixed in order to compute the ellipsoidal height of Uhuru Peak.

We have computed solutions using GIPSY, BERNESE, TBC (commercial software), and, for external check, we also used online processing services: AUSPOS and SCOUT:

DATA PROCESSING & RESULTS

Solution	Value (m)
GIPSY	5875.43
BERNESE	5875.59

Differences between the solutions obtained with the academic applications reach 16 cm.

Possible causes:
a) Different procedures used to align the solution with the ITRF2005;
b) Different models for the antenna phase center;
c) Different tropospheric models;

DATA PROCESSING & RESULTS

Reference Datum	Gipsy solution	Bernese solution
Kili2008 (Global) Datum	5889.51 m	5889.67 m
Tanzanian Vertical Datum	5890.79 m	5890.95 m

In Kilimanjaro region, only one benchmark with known orthometric height referred to the official Tanzanian vertical datum was found close to Moshi. This point was observed with GNSS and the orthometric height with respect to KILI2008 datum was computed.

The difference to the global datum at Moshi was 1.28 m.

This offset was applied to the value computed for the Uhuru Peak with respect to the KILI2008 datum.

CONCLUSIONS

The final value obtained for the orthometric height of Mt. Kilimanjaro is about 4 m lower than the previous one established by trigonometric leveling in the Tanzanian vertical datum (and about 5.5 m if we consider the global vertical datum).

It is also 1.3 m lower than the estimate with GPS done in 1999.

Clearly, this difference is larger than the associated uncertainty of our computation.

CONCLUSIONS

By comparing the different computed solutions using different software and methodologies, we can say that the error in the computation of the ellipsoidal height is at decimeter level.

The error in geoid computation is also at decimeter level (±15 cm).

This give us a total uncertainty about 25 cm in the computed value of the orthometric height of Mt. Kilimanjaro.

CONCLUSIONS

The uncertainty value of 25 cm does not include the possible error on the conversion from the KILI2008 vertical datum into the Tanzanian. Since we had only one point available, there was not the possibility to verify the measured offset.

CONCLUSIONS

The improvement on the computation of the final value for the orthometric height of Mt. Kilimanjaro is now more dependent on the improvement in the models used to compute the ellipsoidal height and on the geoid computation than in the acquisition of more field observations.

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