A new geoid model for Bhutan

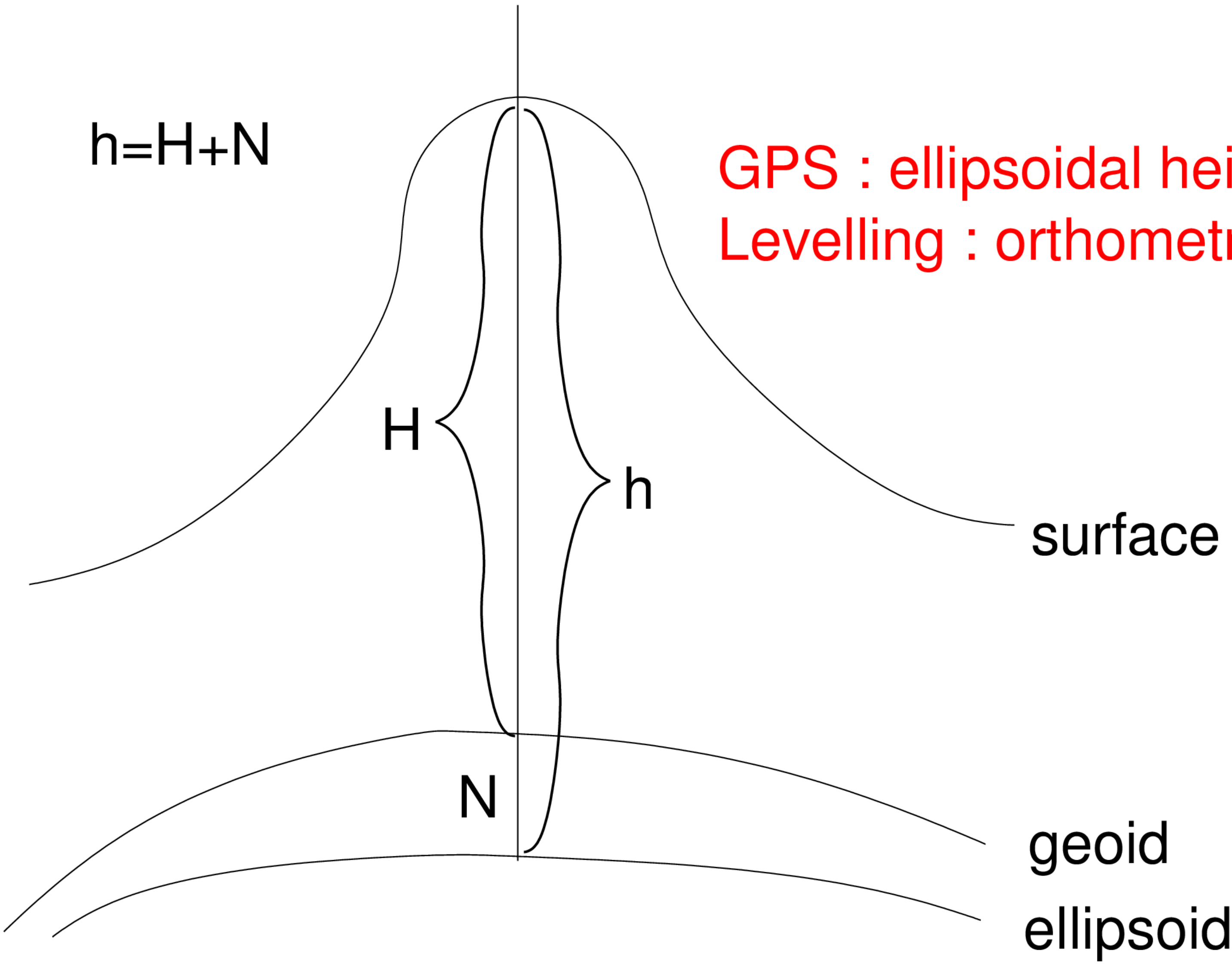
Machiel Bos (machiel@segal.ubi.pt)

Rui Fernandes (rui@segal.ubi.

Definition of heights

$h = H + N$

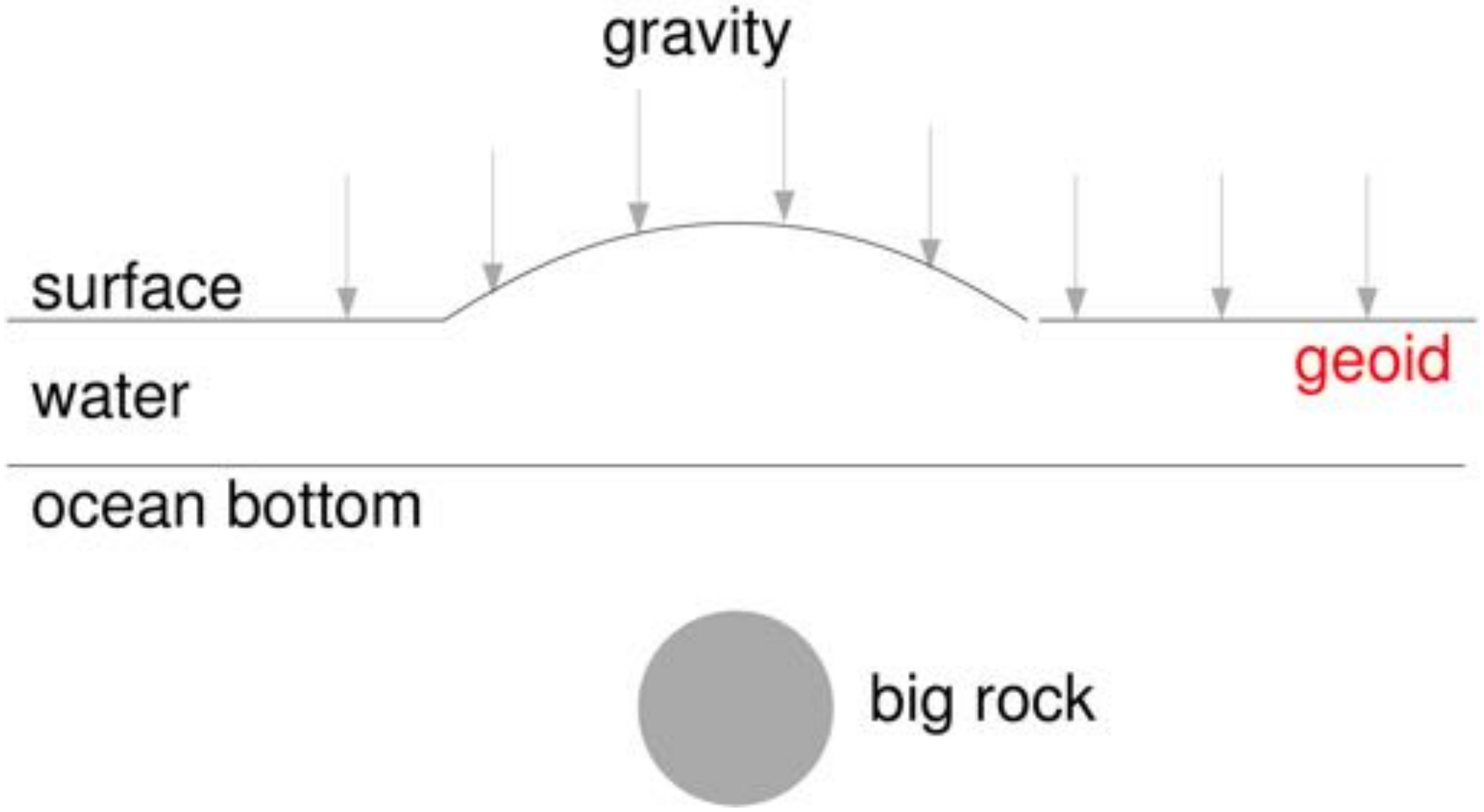
GPS : ellipsoidal heights h
Levelling : orthometric heights H



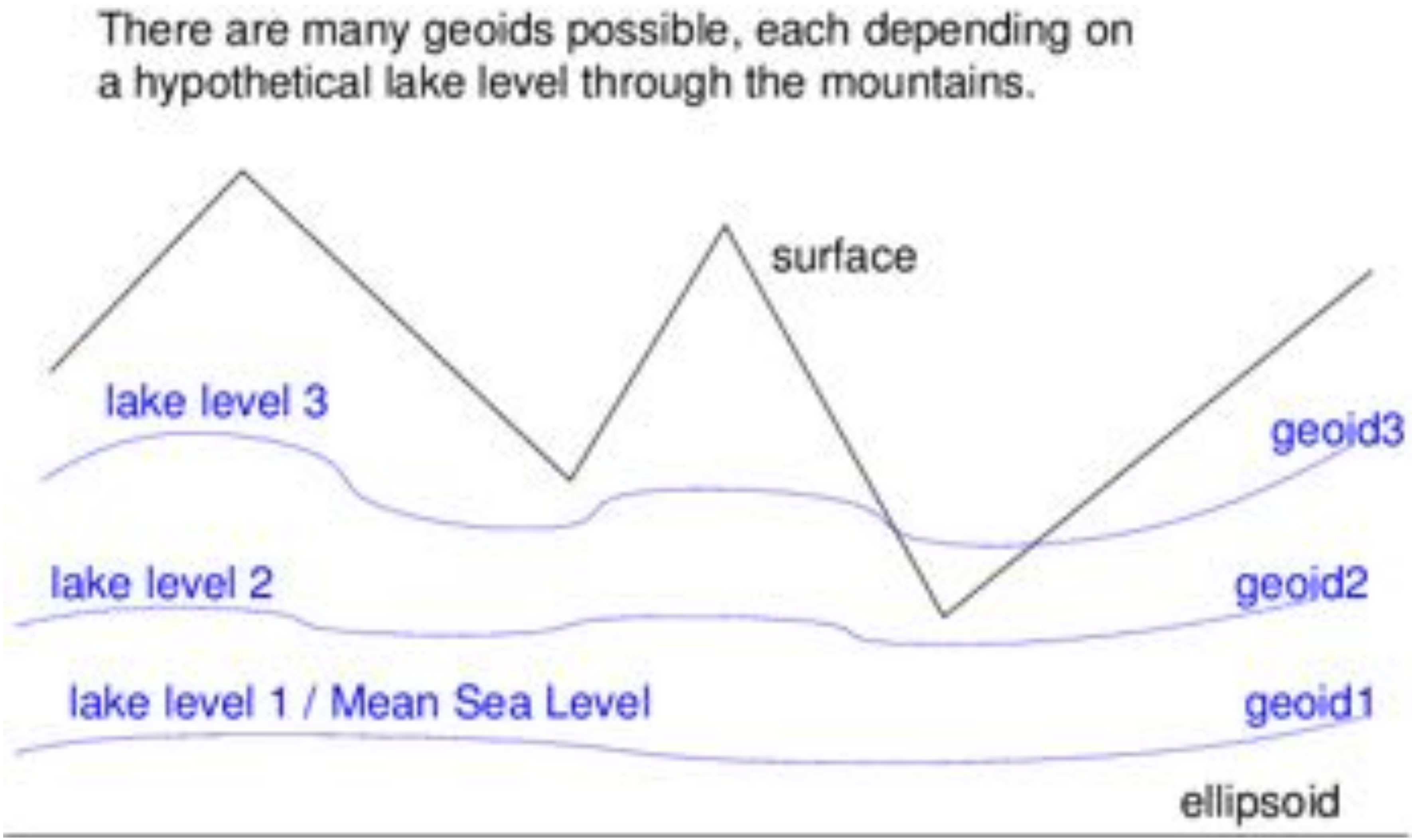
Purpose of a geoid model

- Orthometric heights are the official heights in Bhutan.
- GNSS is increasingly used to determine horizontal AND vertical position.
- Therefore, a geoid model is required to convert the GNSS ellipsoidal heights into orthometric heights.

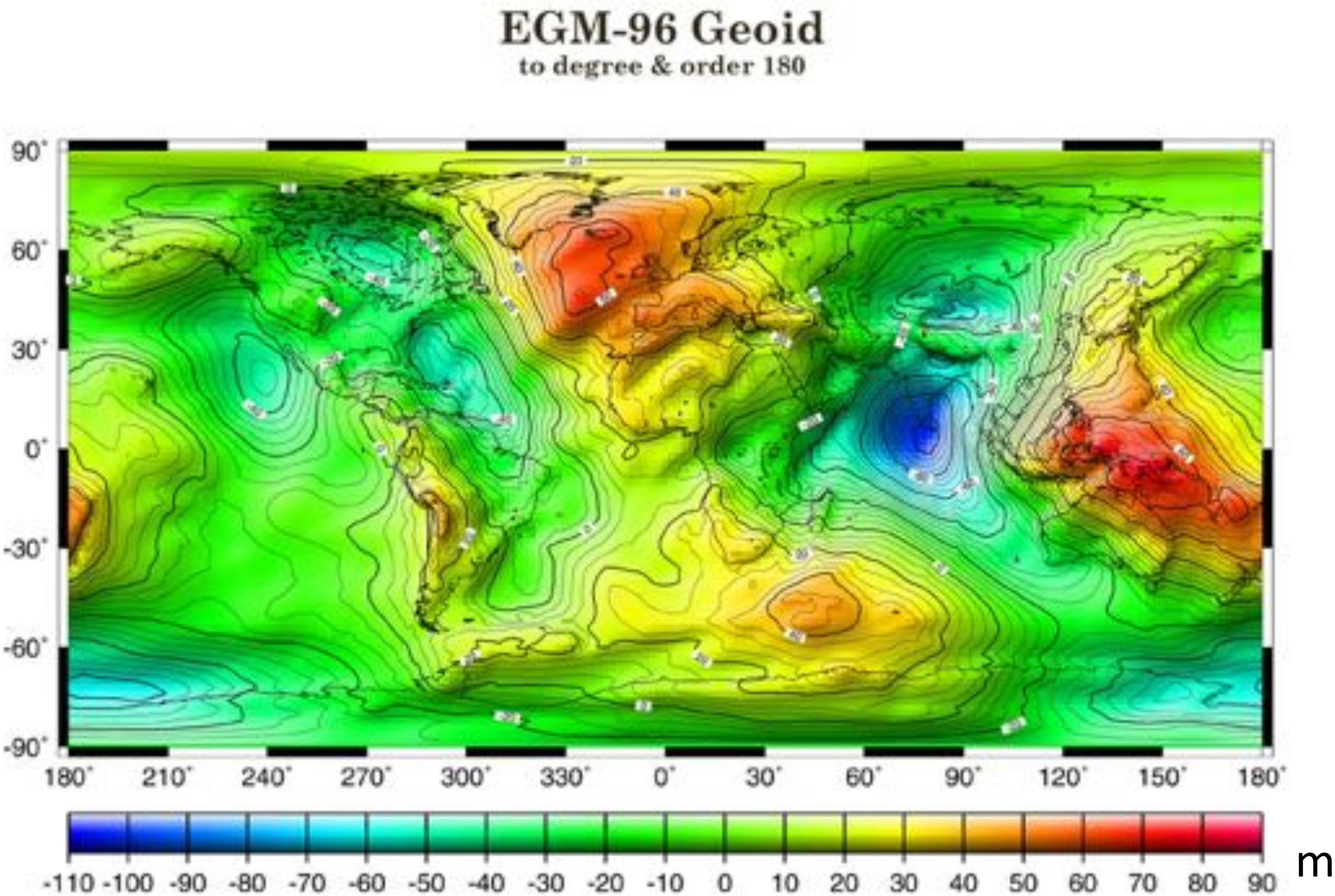
Geoid/Mean Sea Level is not flat!



Geoid over land

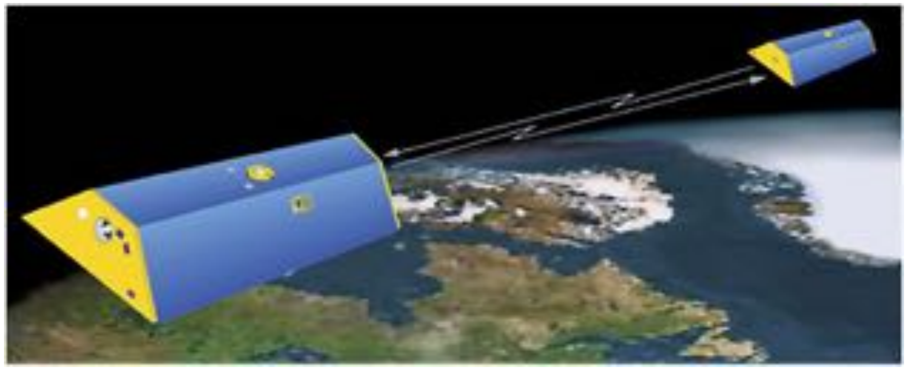


Geoid position above ellipsoid

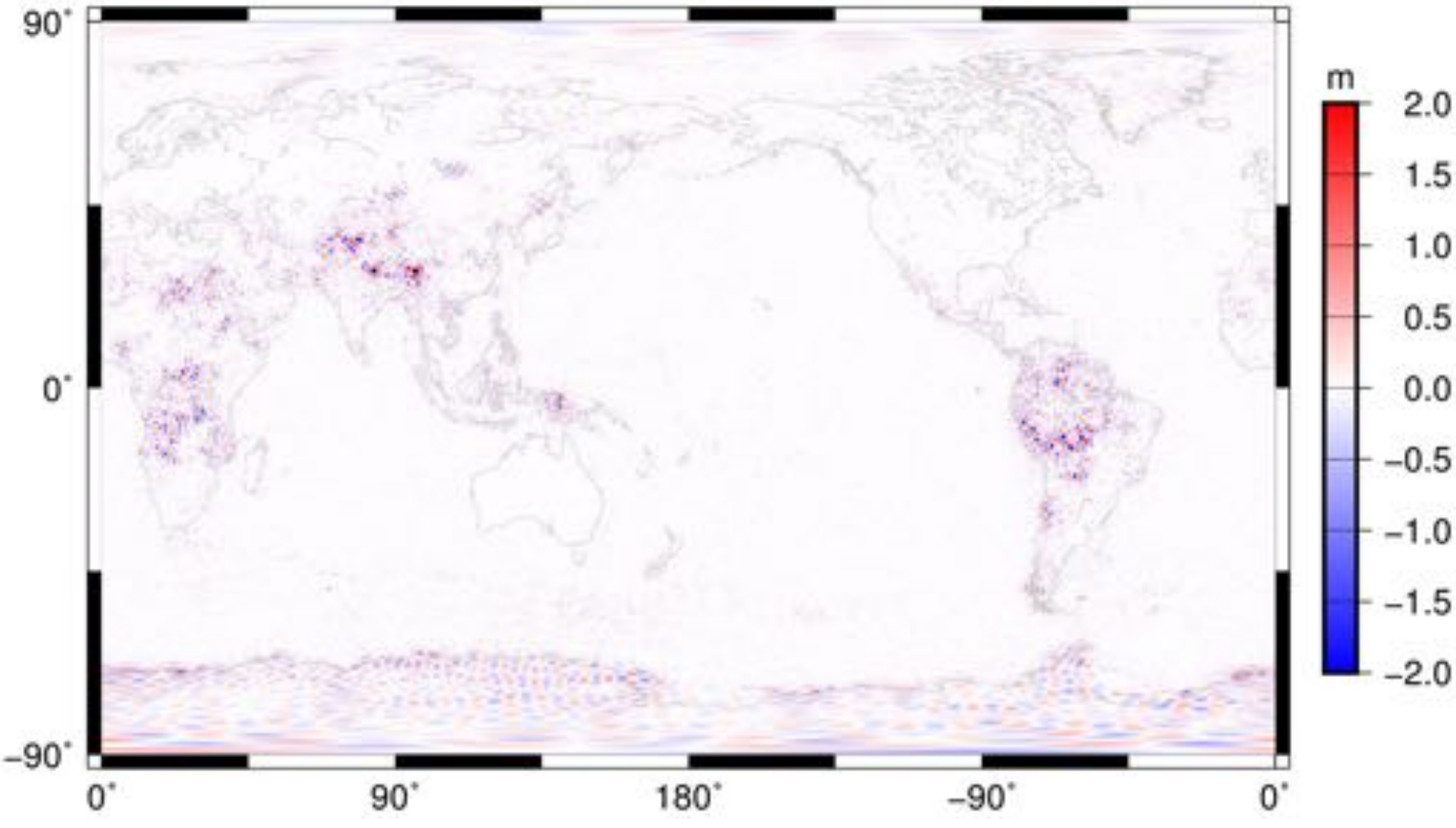


Global Geoid models

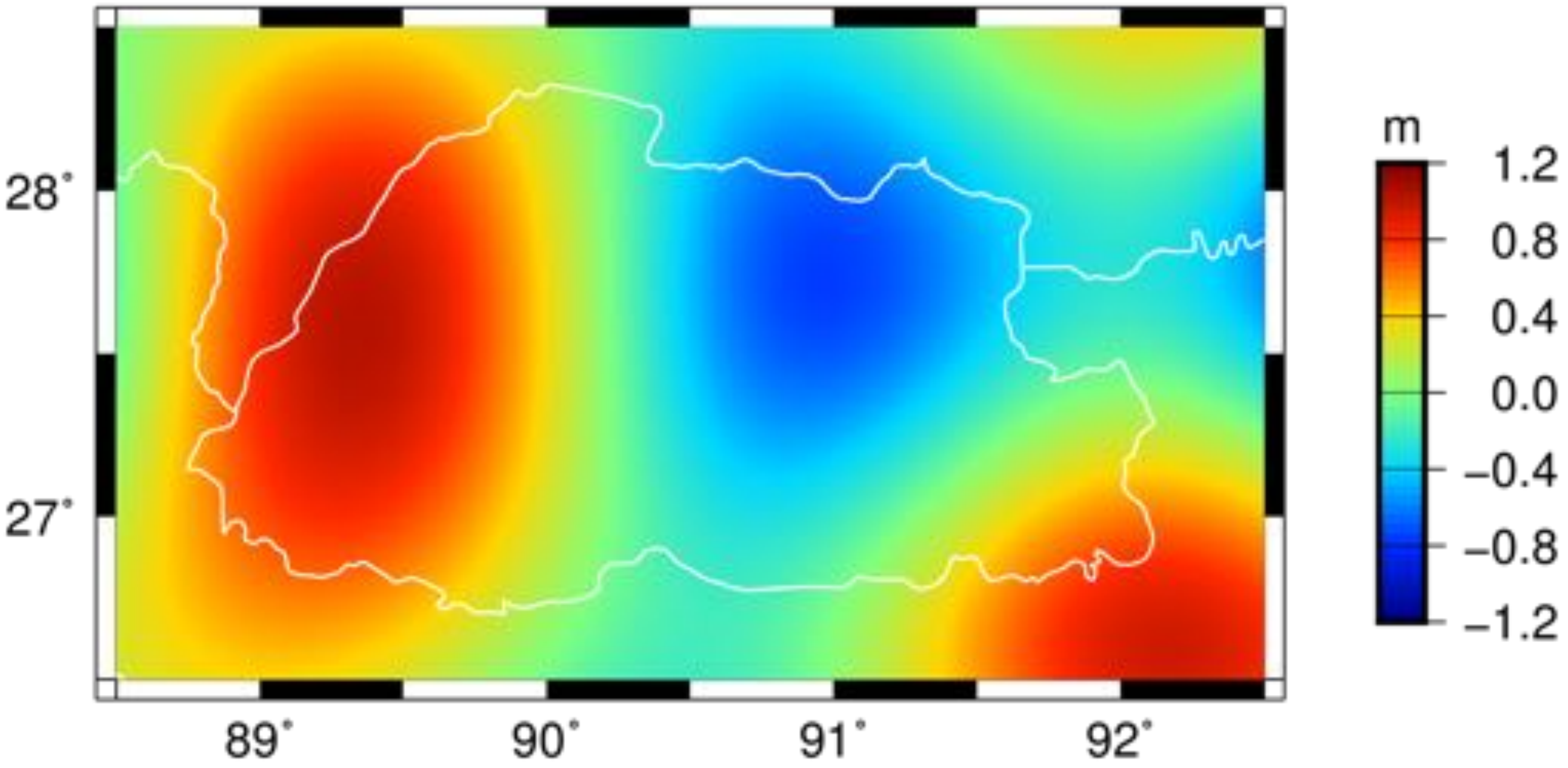
- Satellite missions GRACE and GOCE have provided much improved global geopotential models (GGM's) such as EGM2008 (Pavlis et al., 2012) and EIGEN-6C4 (Forste et al, 2011).
- Maybe these GGM's can be used to represent the geoid over Bhutan?



Geoid difference: EGM2008 - EIGEN-6C4



Geoid difference: EGM2008 - EIGEN-6C4



First Conclusion

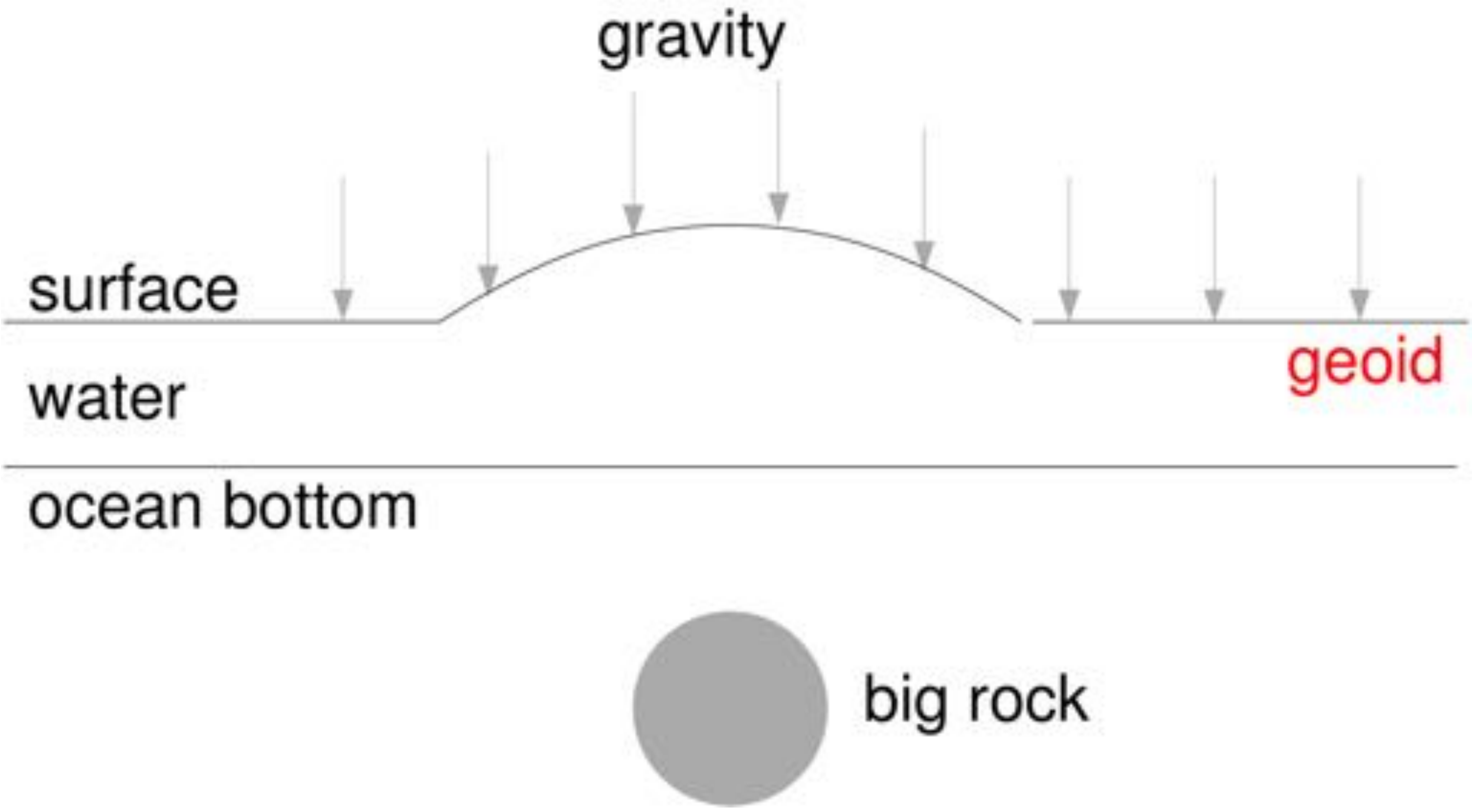
- Global geoid models still have have at least +/- 1 metre error over Bhutan.
- How to compute a better geoid for Bhutan?
- Collect gravity data!
- The results shown here are the results of a gravity campaign held from November 2014 to May 2015.

Gravity measurements

- Gravity observations were made with 2 SCINTREX CG-5 relative gravimeters.
- 272 points were observed between November 2014 and May 2015.
- The relative gravity observations were converted into absolute ones using the absolute point at NCL.

Big rock in ground example once more

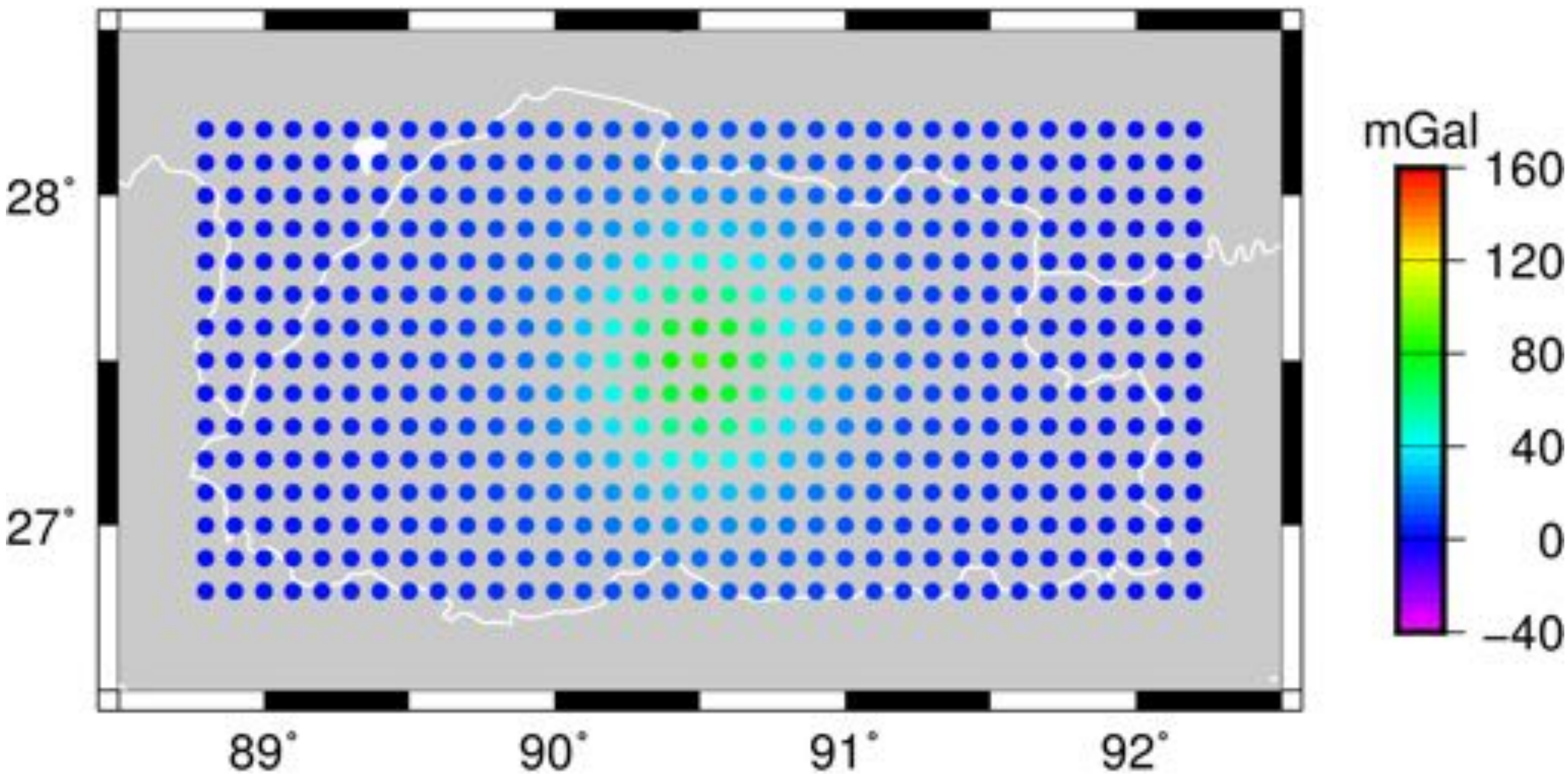
Gravity decreases with 0.3086 mGal/m with increasing height Because you move further away from the Earth.



Gravity versus Geoid

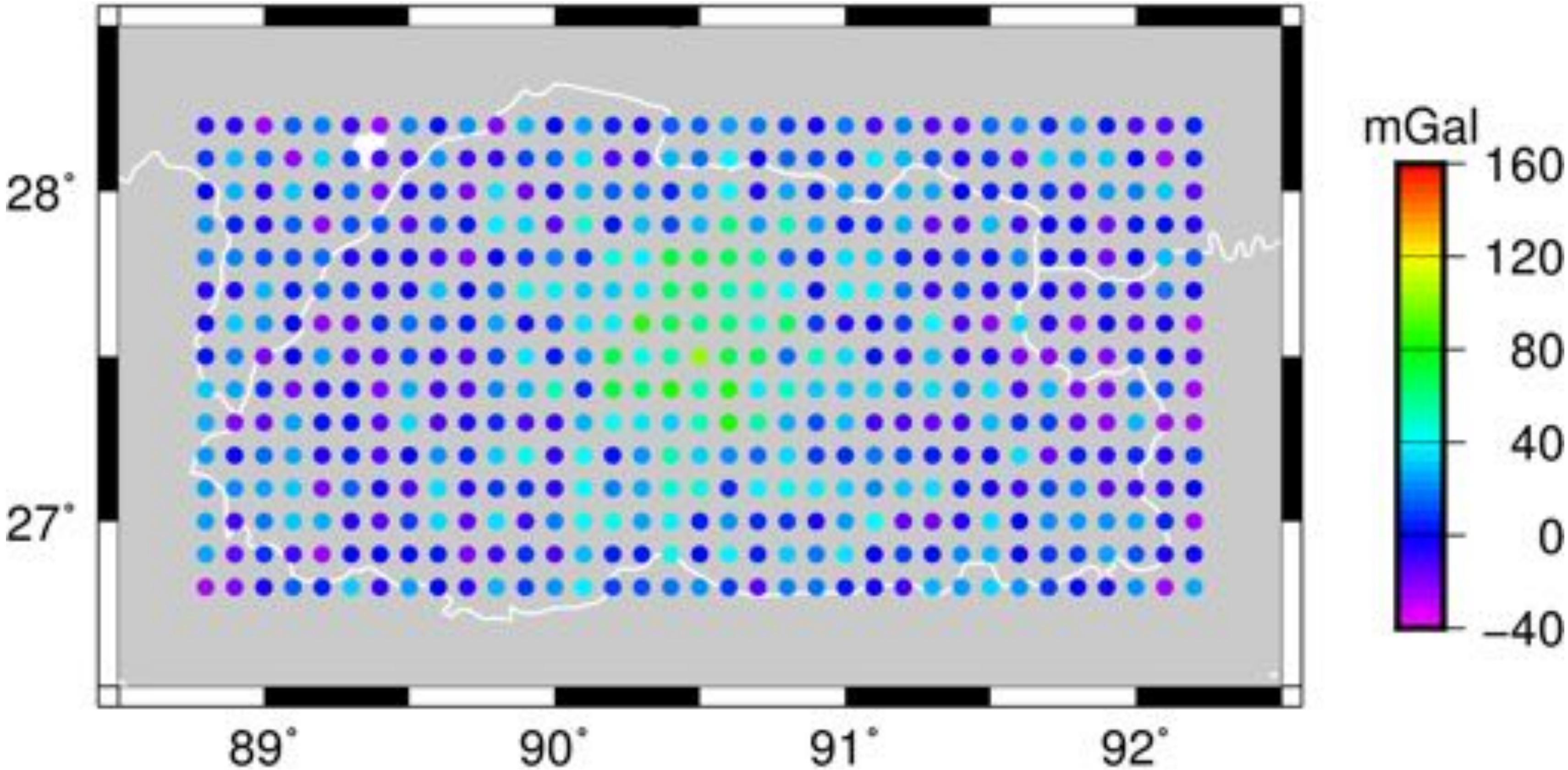
- The gravity field and the geoid show a similar pattern and one can convert the observed gravity field into a geoid.
- However, gravity only provides geoid **variations**. Therefore, a relative geoid will be produced.

Perfect height observations



Rock underneath surface is clearly visible in gravity data

Imperfect height observations



Rock underneath surface is not clearly visible in gravity data

GNSS heights were measured at all gravity points

A mean observation period of 1 hour was acquired at all points.

The vertical offsets of the GNSS antenna and gravimeter was measured in order to use the ground as reference surface.

GNSS observations

- Where possible, Differential GNSS solutions were computed using the Trimble Business Center software and the GNSS data from the Permanent Reference Stations (PRS's).
- The PRS were used as known points that were fixed into the international reference frame (ITRF2008).

Automatic Precise Positioning Service

- When no PRS was available within 50 km, alternative online systems using the Precise Point Positioning technique were employed.
- Online PPP services:
  - http://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php
  - http://apps.gdGNSS.net

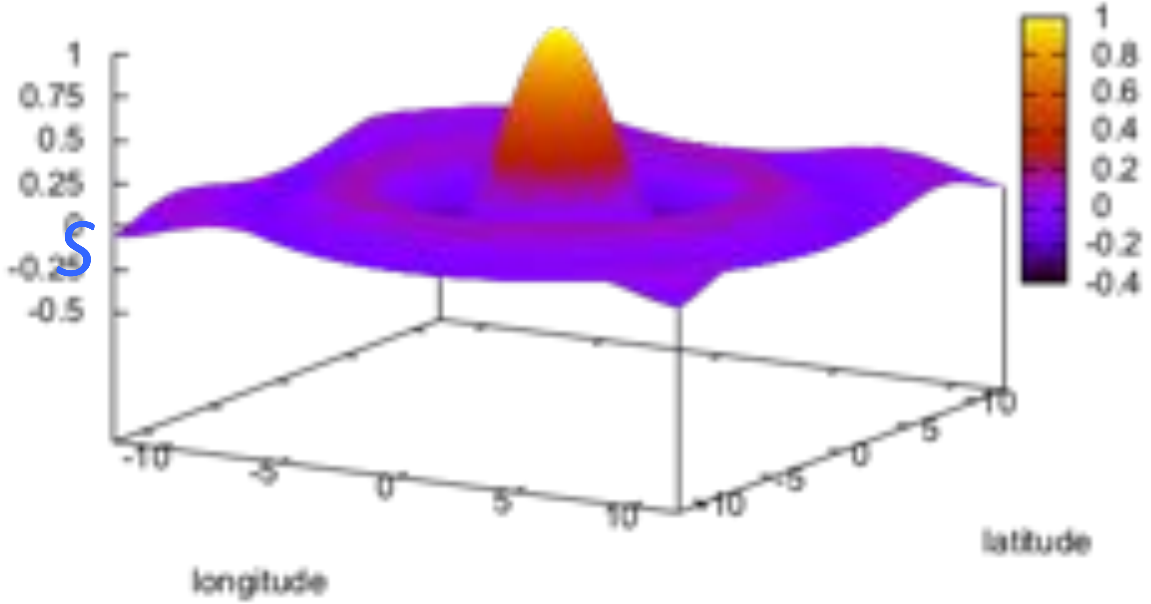
Final GNSS solutions

- Various points were reobserved.
- Some points could be analysed with TBC, others with APPS/CSRS, some by both.
- The final GNSS solutions were computed by taking a weighted mean of all solutions.

Relation between gravity and geoid

Geoid *N* is computed by averaging gravity **field** *g* with a weighting function *S* over the whole Earth Surface.

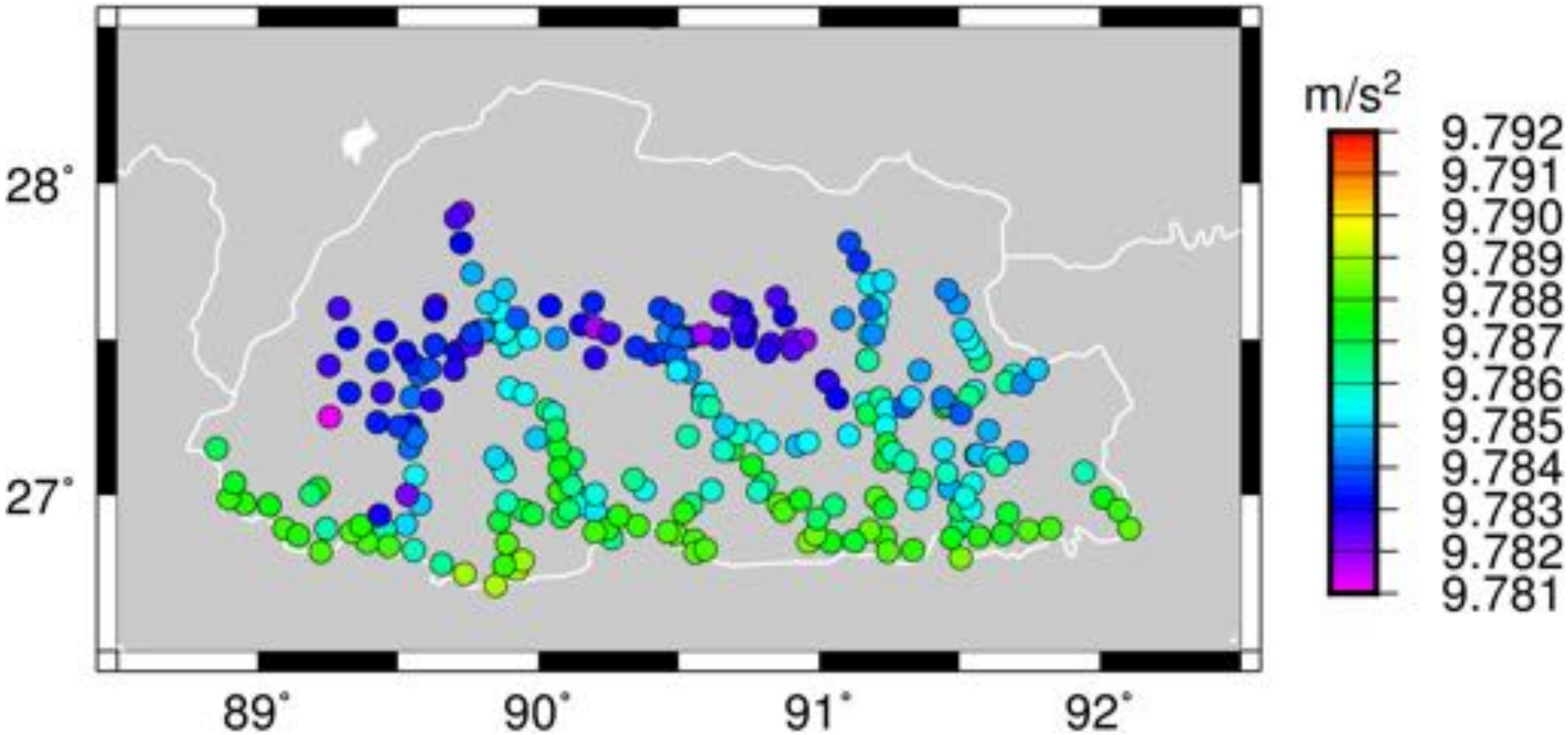
Sketch of weighting function



Relation between gravity and geoid

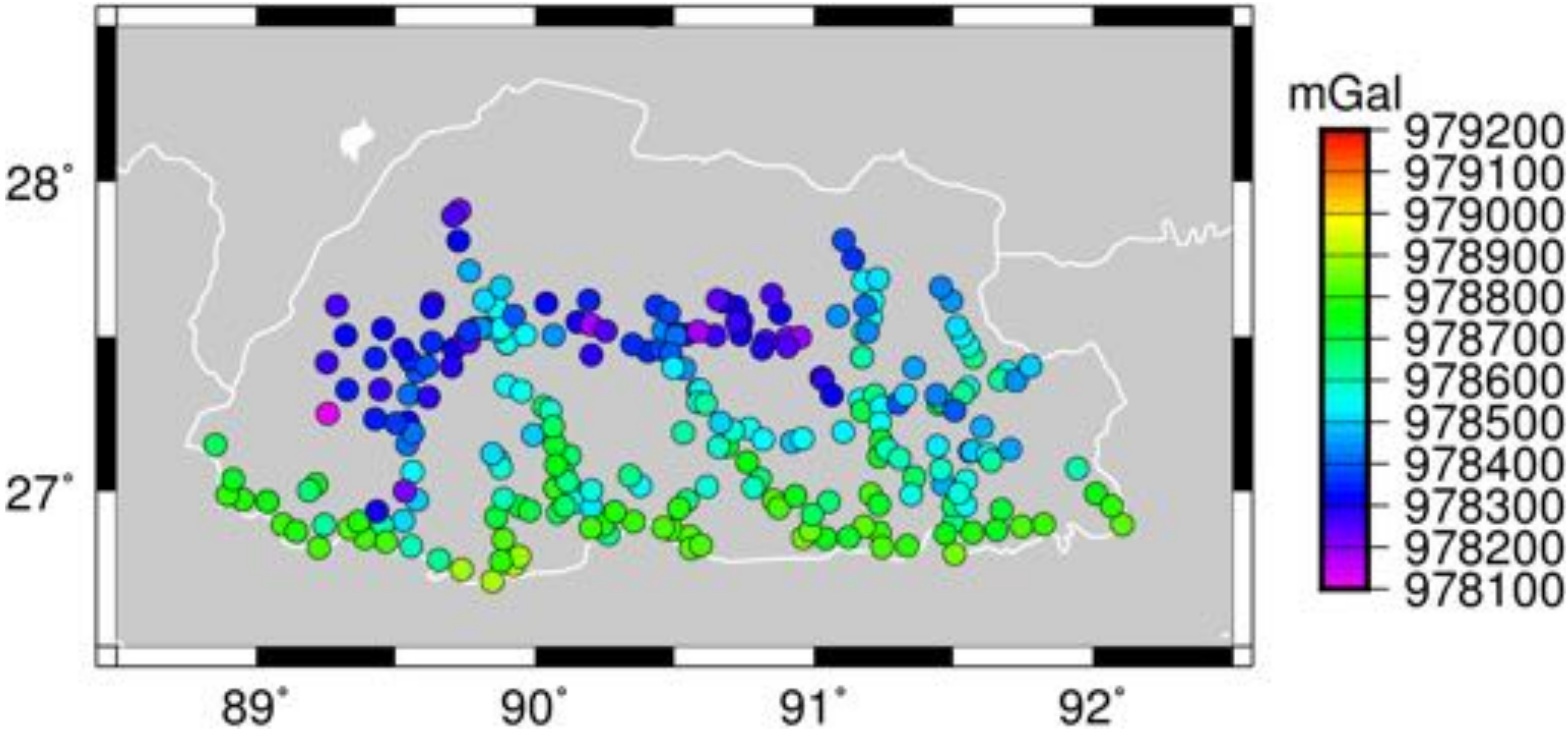
- Gravity field is spatially averaged, using a special weighting, to compute the geoid undulation.
- A single gravity value **cannot** directly be converted in a geoid value. One needs a gravity field.
- Gravity is only observed at points. Interpolation is needed to fill the whole area before averaging can be applied.

Raw observed values



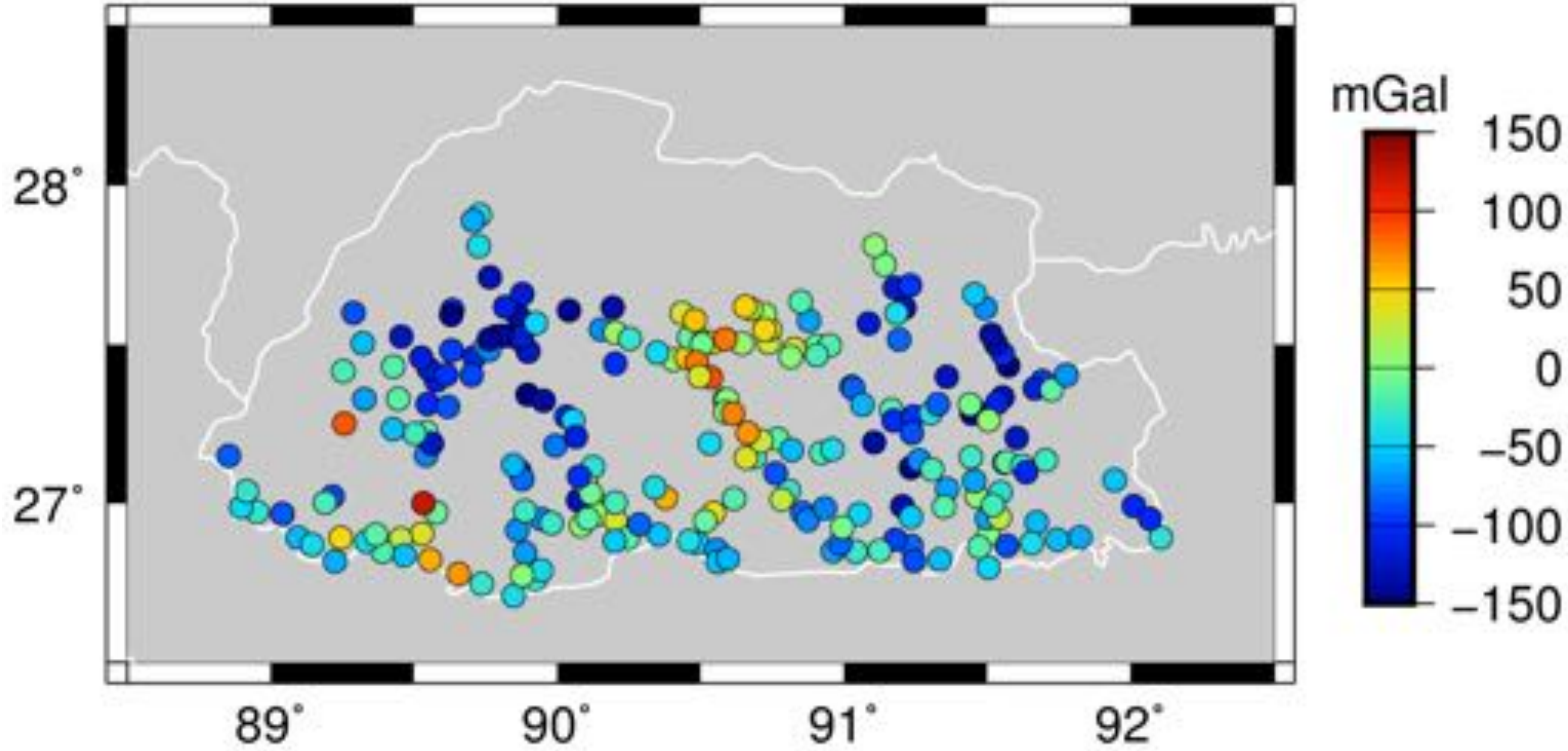
Gravity lower in the mountains because gravity decreases with increasing height

Raw observed values

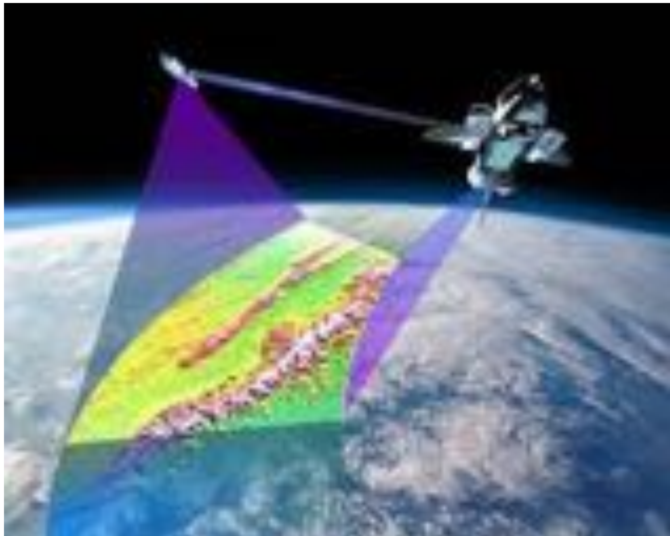


1 m/s^2 = 100,000 mGal

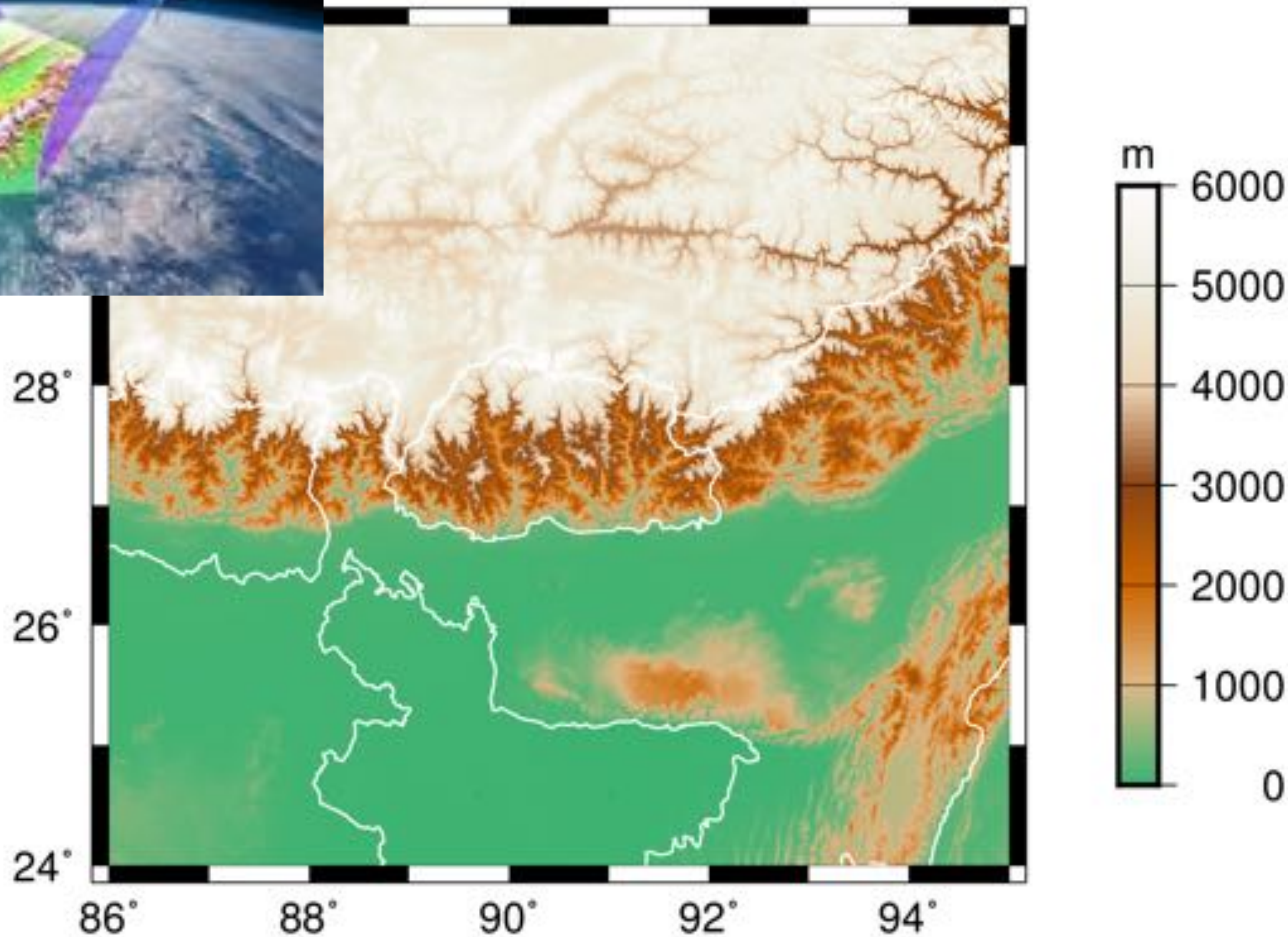
Raw – EIGEN-6C4



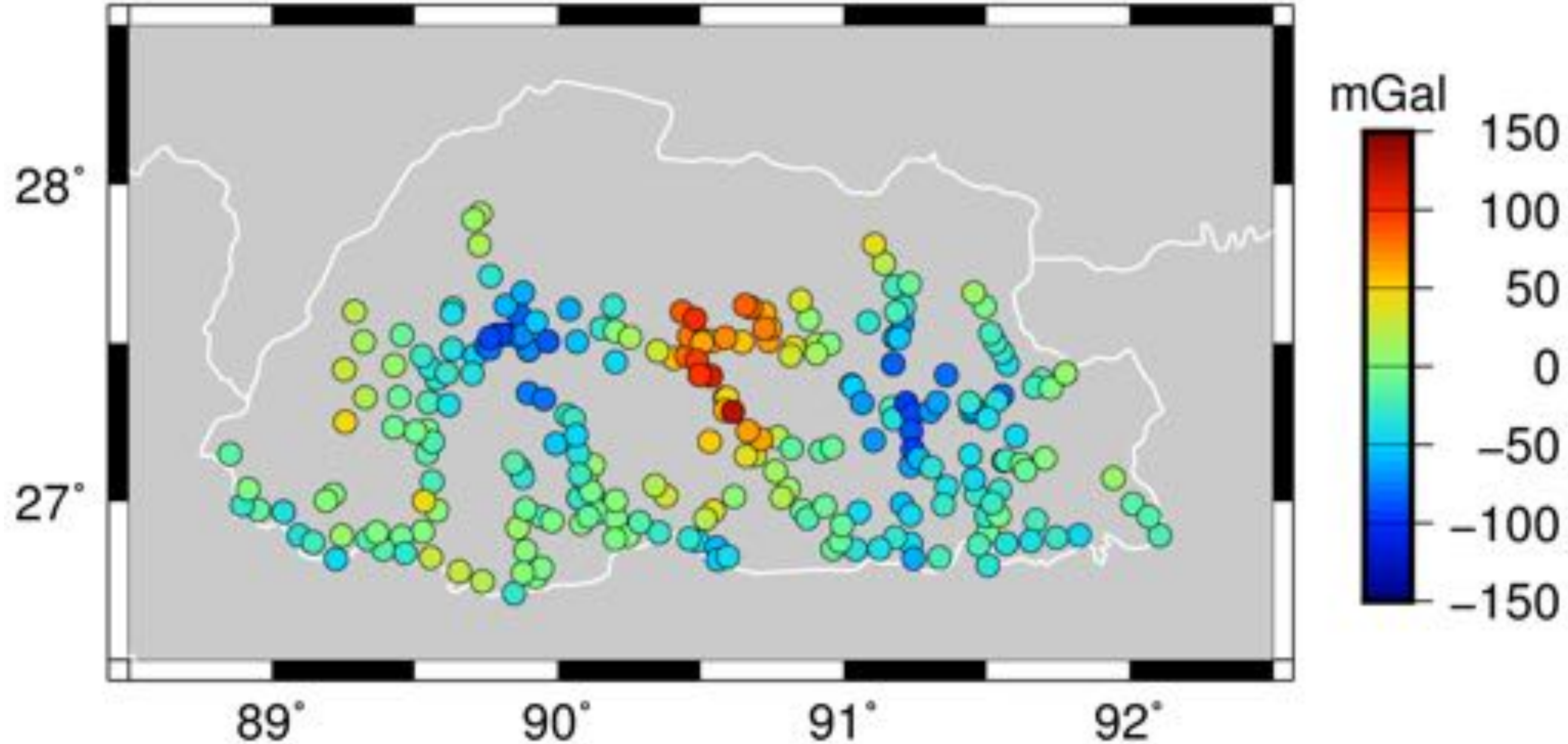
Topography



Shuttle Radar Topography Mission



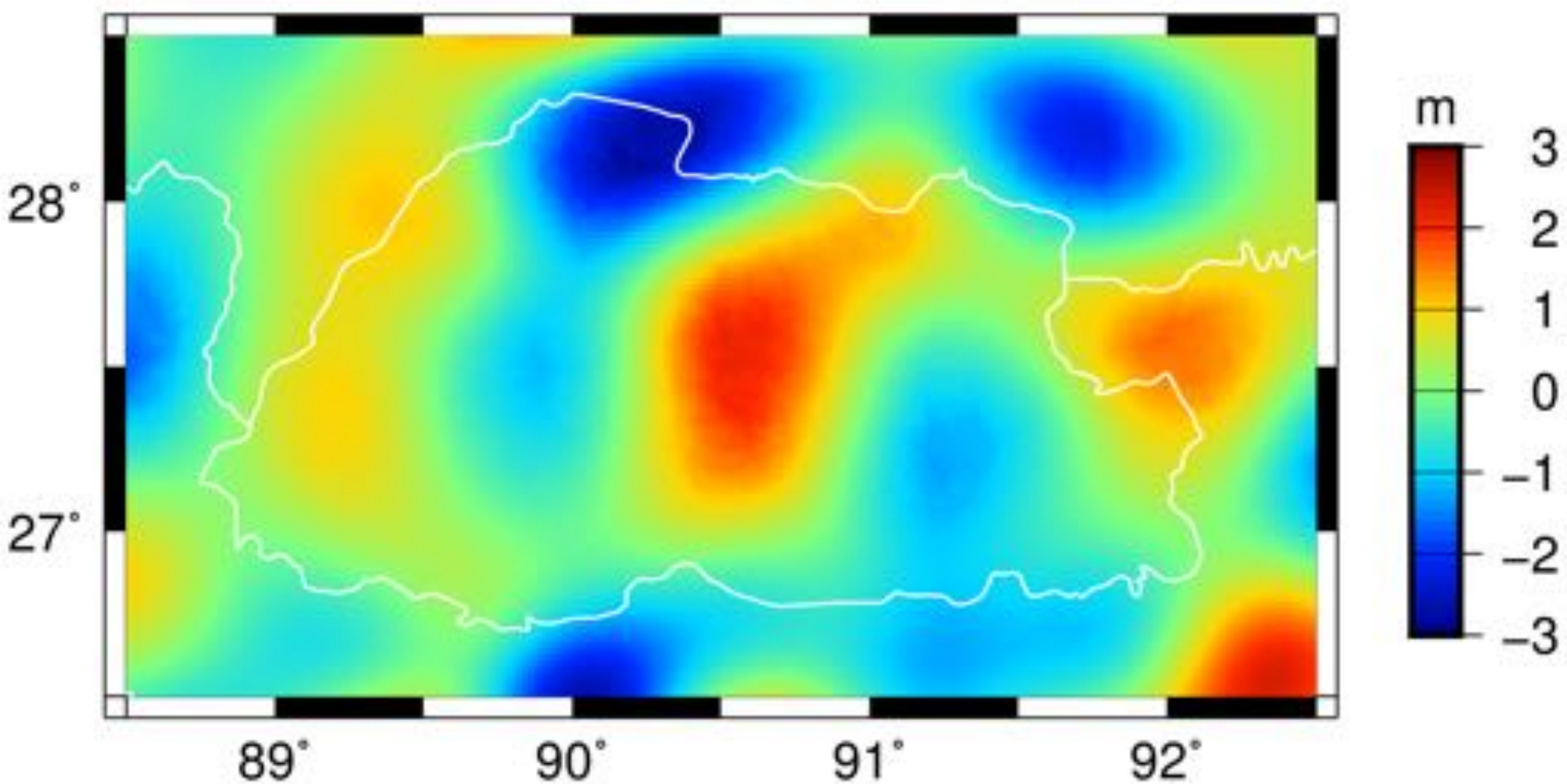
Raw – EIGEN-6C4 - Topo



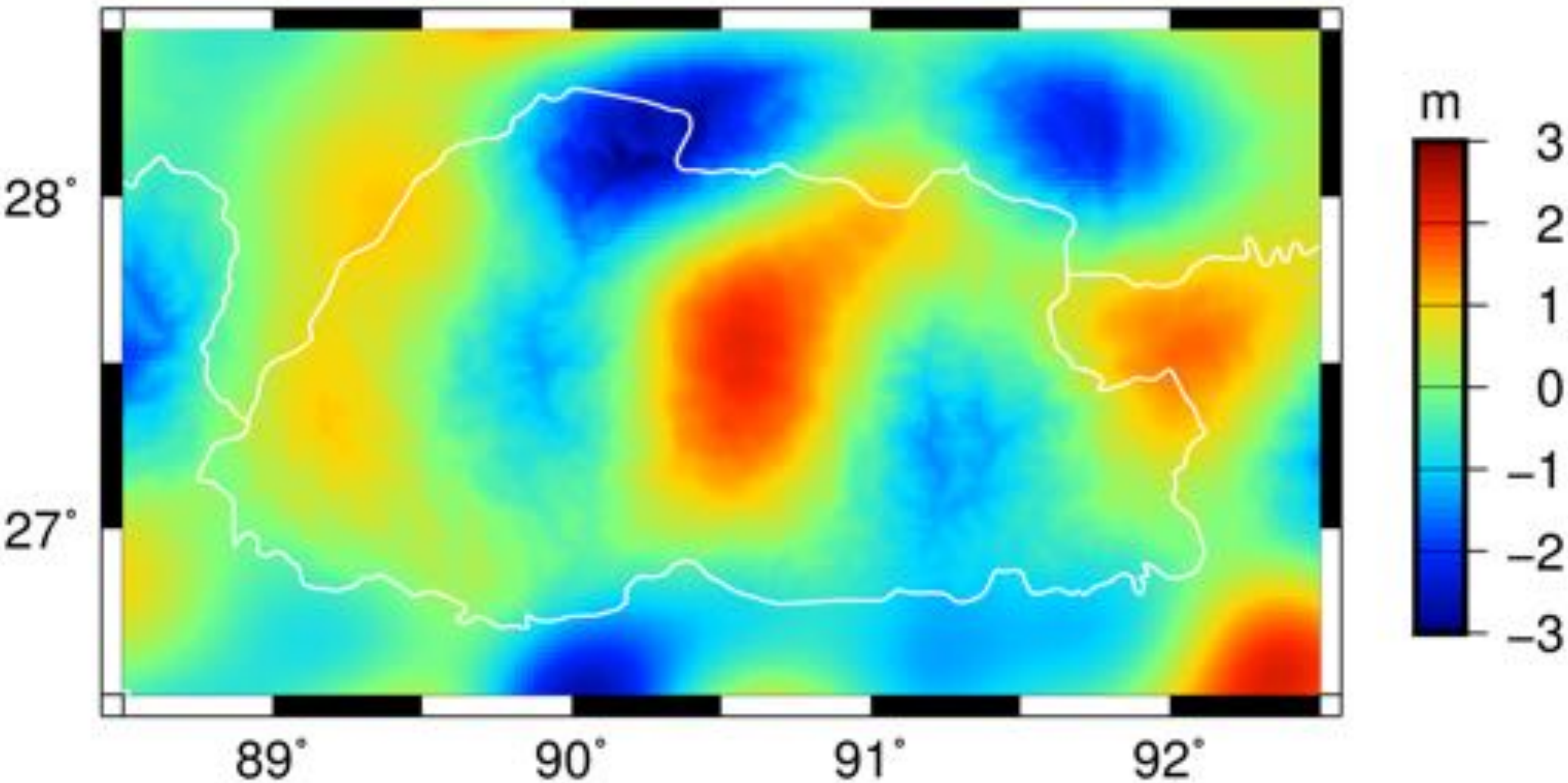
What have we obtained so far?

- After subtracting the global EIGEN-6C4 model and the effect of the topography from the observations, we have now obtained a set of gravity values that vary smoothly.
- These will now be converted into geoid undulations using spatial averaging with a special weighting function. The technical term is Least-Squares Collocation.

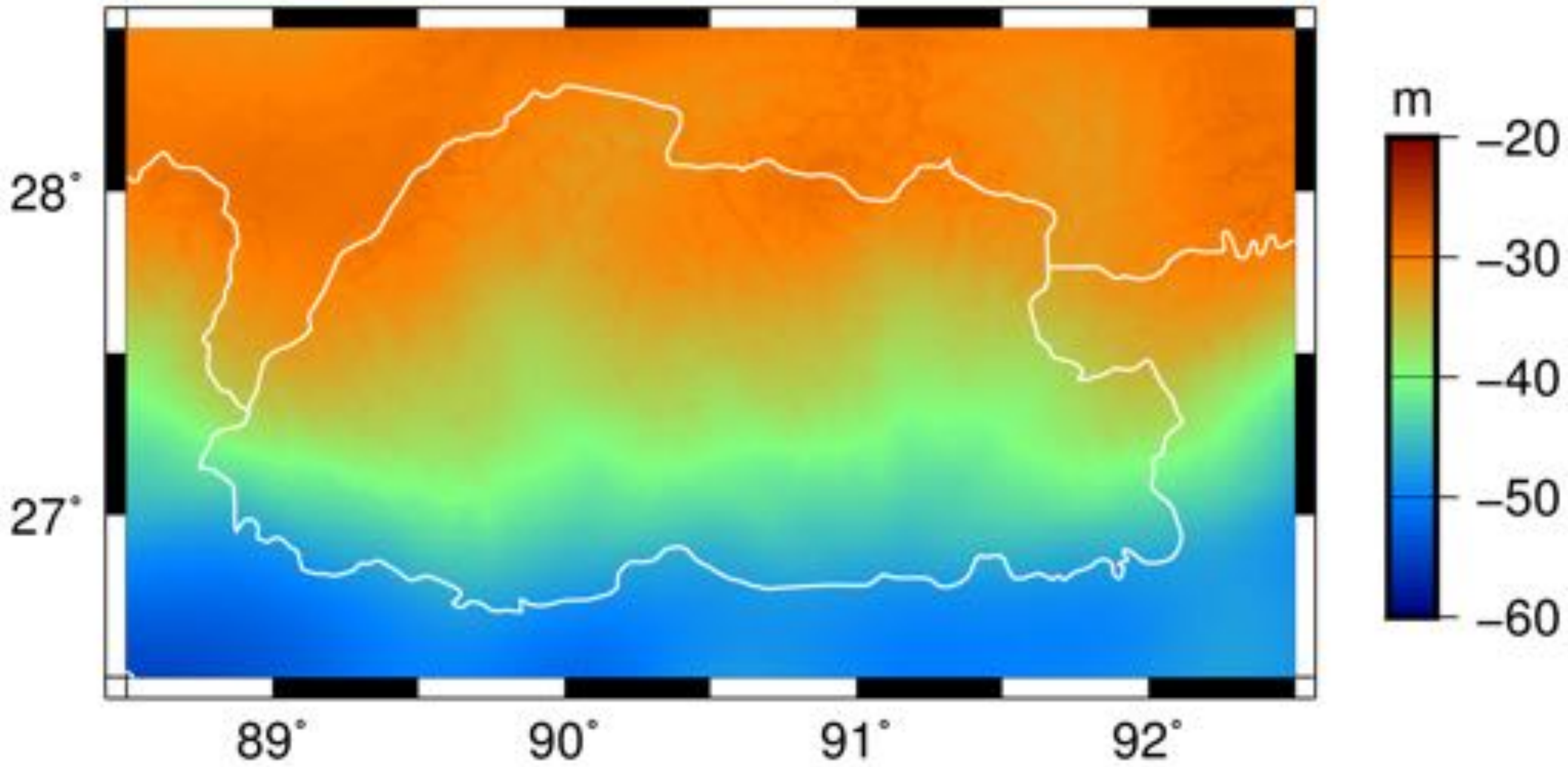
Gravity points converted into geoid undulations



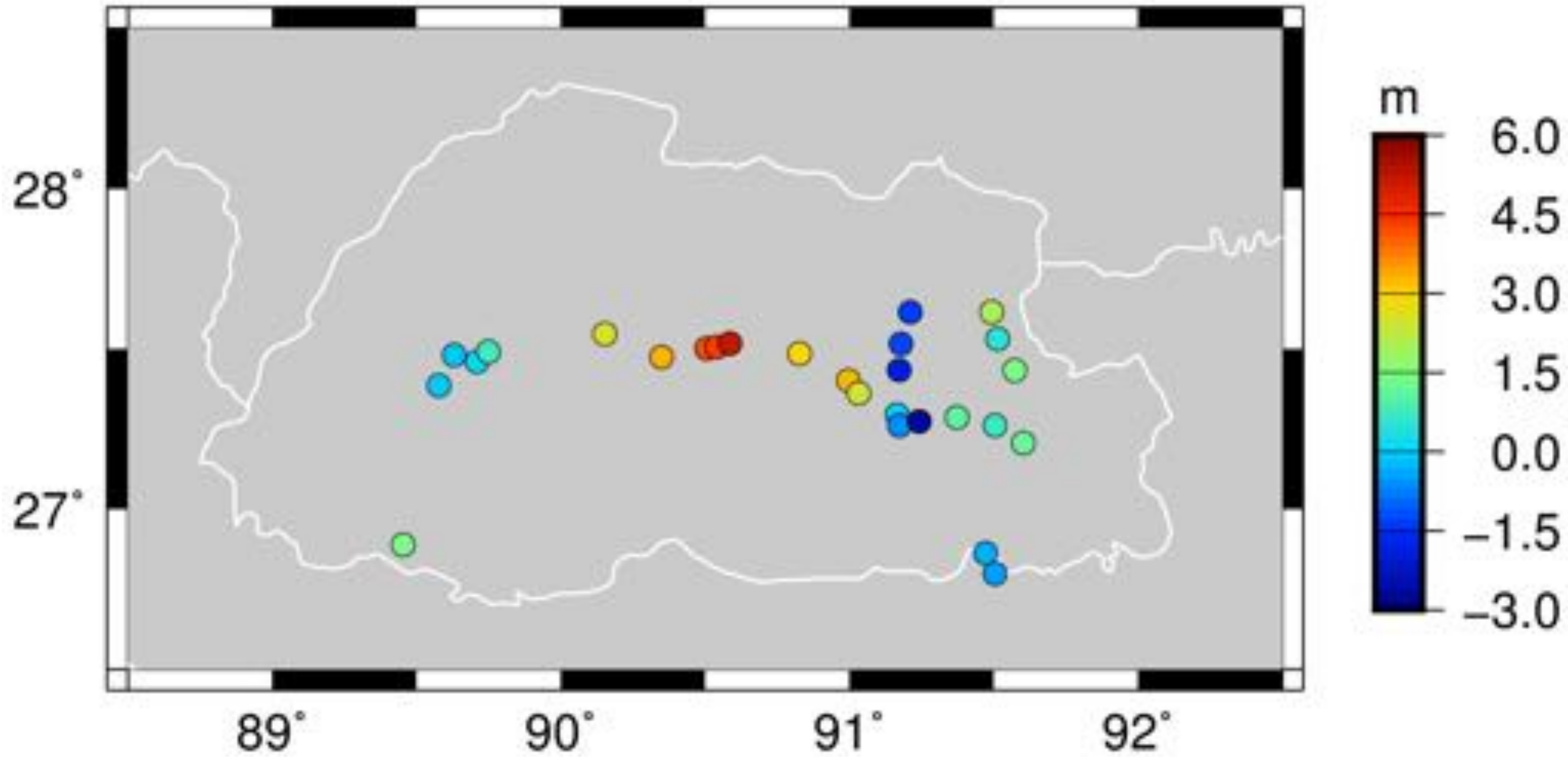
Restore effect Topography



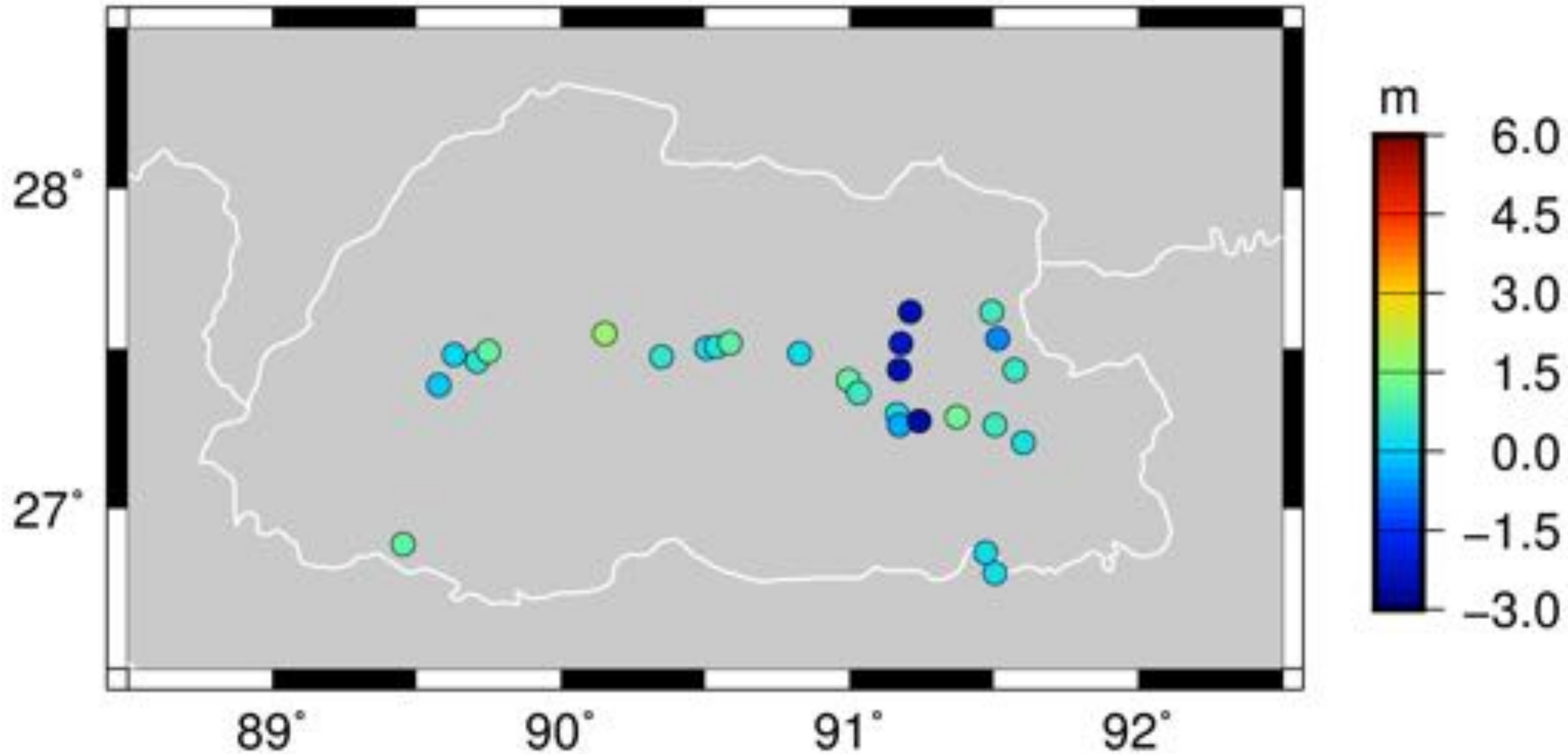
Restore EIGEN-6C4: This is new Geoid



Comparison of EGM2008 with 27 GNSS/Levelling points



Comparison of EGM2008 with 27 GNSS/Levelling points



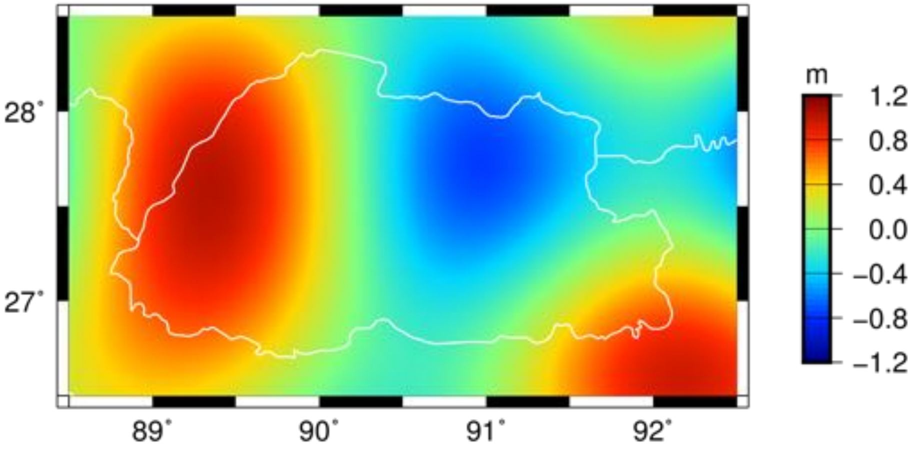
Results of comparison

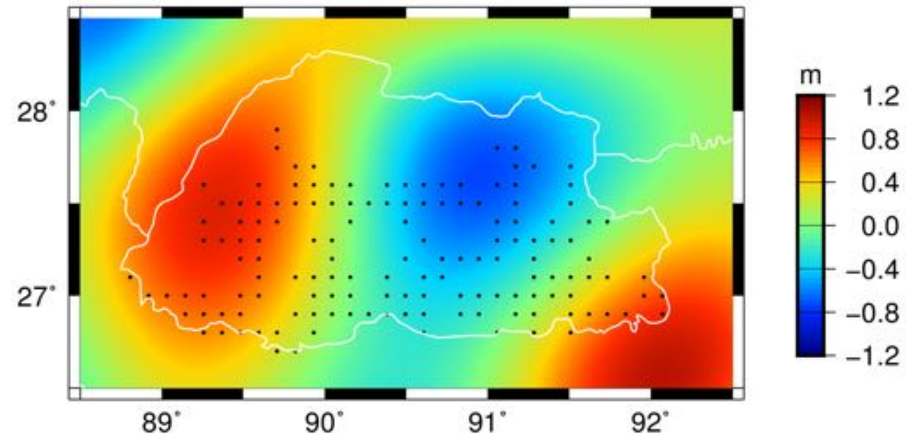
	MEAN(m)	STD(m)	MIN(m)	MAX(m)
DRUKGEOID15	0.46	0.55	-0.71	1.71
EGM2008	1.90	1.70	-0.03	5.40

At some benchmarks the height difference between GNSS antenna and benchmark could not be determined accurately.

Note that the levelling benchmarks have errors!

Accuracy of computed geoid





Using the given set of locations where gravity observations were made, we verified that this allows us to compute a geoid with an accuracy of 10-20 cm.

Height datum

- Gravity observations can be used to compute geoid **variations.**
- The new geoid still needs to be fixed to the existing height system in Bhutan.
- We recommend to fix it to the fundamental benchmark at NLC, called TH01.

Fundamental point at NLS: TH01

The datum of the new geoid is chosen in such a way that at TH01:

N_geoid + H_benchmark = h_GNSS

EXACTLY!

Conclusions (1/2)

- Using two recent global models (EGM2008 and EIGEN-6C4) we found that these still produce +/- 1 meter geoid errors over Bhutan.
- 272 Gravity & GNSS observations were made between November 2014 and May 2015.
- The new geoid has an internal accuracy of around 10-20 cm.

Conclusions (2/2)

- The new geoid has been fixed to benchmark TH01 which serves as the vertical height datum of Bhutan.
- Software to process raw gravity data was installed on computers at NLC.
- The new geoid has been provided various digital formats for the following software:
  - Trimble Total Control
  - Leica Geo Office
  - Stand alone geoid converter

Recommendations

- In the future GNSS observations can be made on the other levelling benchmarks. With accurate height measurement between GNSS antenna and benchmark.
- Gravity measurements in the North of Bhutan are still sparse and additional measurements in this region would be beneficial.

Thank you for your attention

Rui Fernandes[1)], Machiel Bos[1)], Kinzang Thinley[2)], Jamphel Gyeltshen[2)]

1) SEGAL (UBI/IDL), Covilhã, Portugal (rui@segal.ubi.pt).
2) National Land Commission, Thimphu, Bhutan.