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Different topographic reduction techniques for GOCE gravity data

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- Motivation

- Introduction to Bouguer Anomalies
- Overview about algorithms

- Tritop – Polyhedral representation
- Adaptive mass correction

- Conclusion
- Outlook

Motivation & Introduction

Motivation

Gravity data is used to gain information about the subsurface:
In general you have:

- Absolute gravity
- Free air anomalies
- Bouguer anomalies
- Isostatic residuals

- Freeair anomalies show all masses…

…even from topography.
➔ anomalies in the subsurface might be concealed my topograhic mass!

➔ Bouguer anomalies feature subsurface anomalies, but can be govenered by isostatic effects,

➔ Bouguer anomalies are used for isostatic residual gravity maps

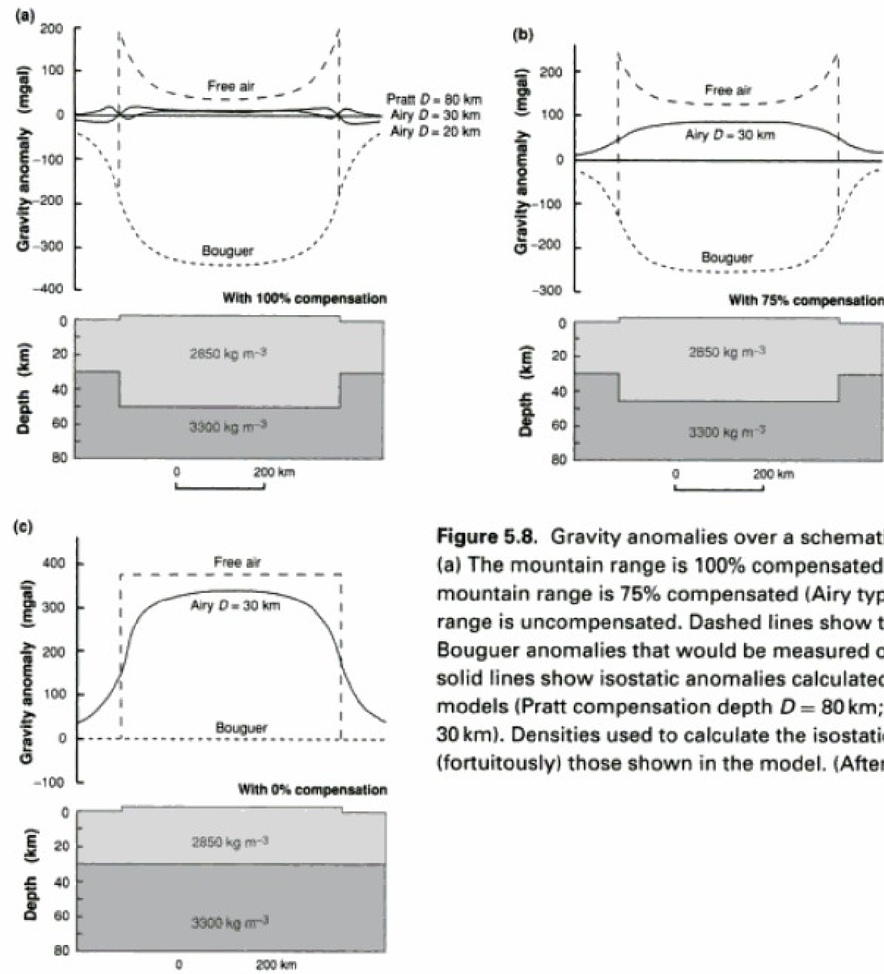

Figure 5.8. Gravity anomalies over a schematic mountain range. (a) The mountain range is 100% compensated (Airy type). (b) The mountain range is 75% compensated (Airy type). (c) The mountain range is uncompensated. Dashed lines show the free-air and Bouguer anomalies that would be measured over the mountain; solid lines show isostatic anomalies calculated for the density models (Pratt compensation depth $D = 80$ km; Airy $D = 20$ km and 30 km). Densities used to calculate the isostatic anomalies are (fortuitously) those shown in the model. (After Bott (1982).)

Theory of gravity reduction

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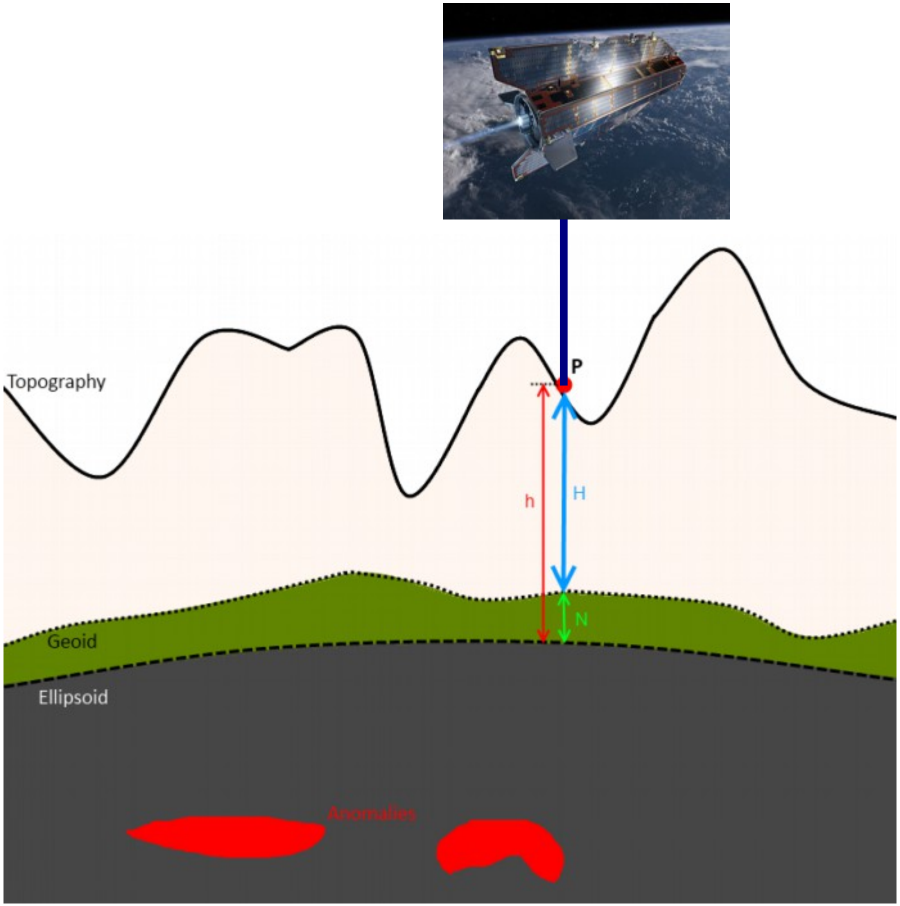
- Bouguer anomaly: widely used for modelling
- Features anomalies compared to the reference density.
- Instead of subtracting a „bouguer slab“ do a full mass correction



Theory of gravity reduction

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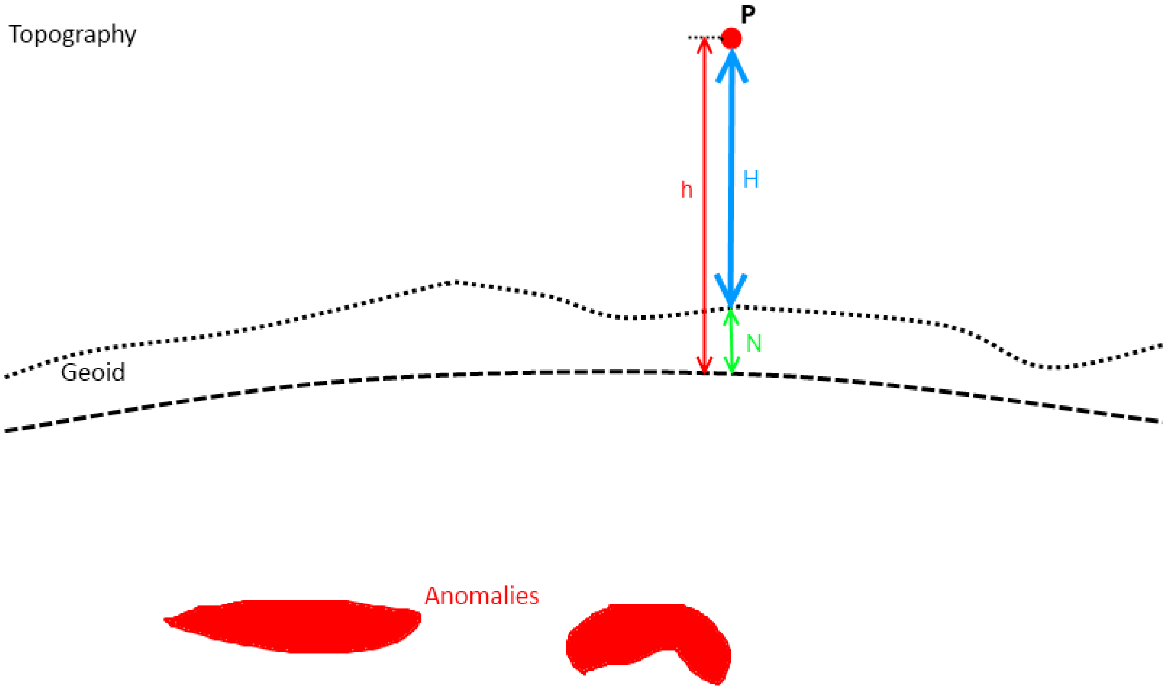
Result:

- Bouguer anomaly emphasizing only anomalies from the reference density.



Algortihms for mass correction

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- Algorithms reduce the mass effect for a given area should be:

quick and accurate!

Algortihms for mass correction

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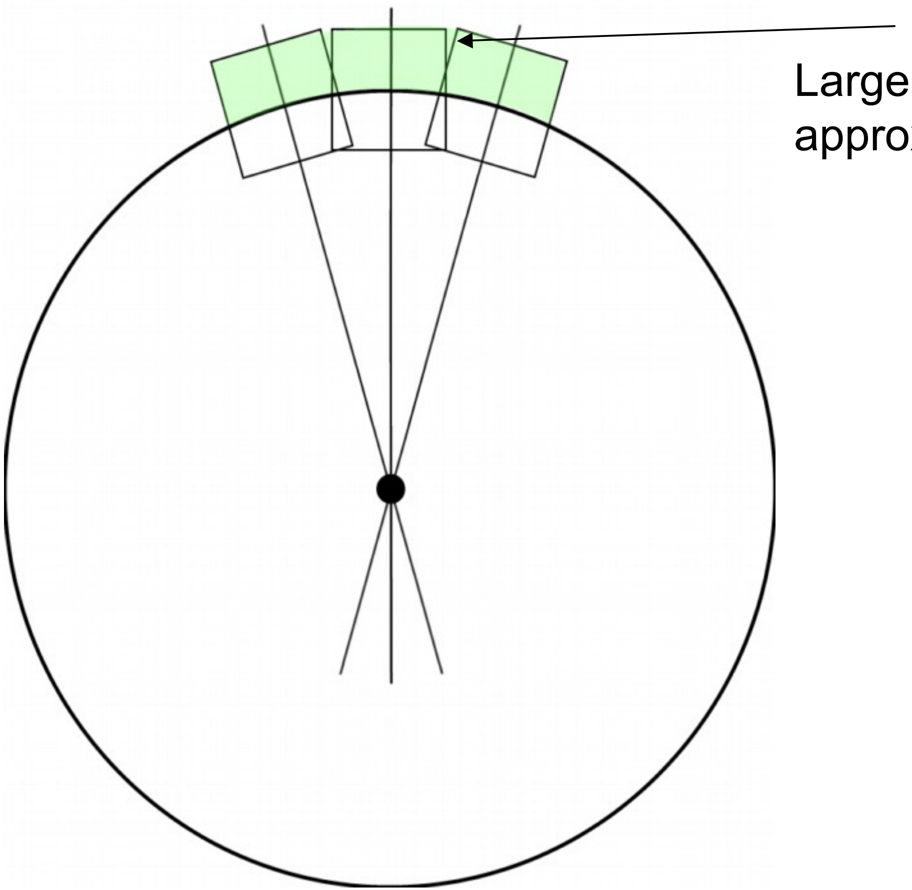

Large error due to approximation/simplification?

e.g. Ehrismann & Lettau (1971)

Questions

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- What is the error of using approximations?
  - What is better: cubes, prims, tesseroids…?

- Which resolution of topography should be used?
  - Where switch coarser grids?
  - Maximum area to correct for?
  - World wide correction?

  → How to deal with large scale areas??

Algortihms for mass correction

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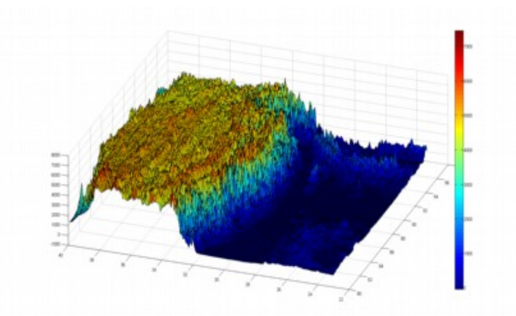
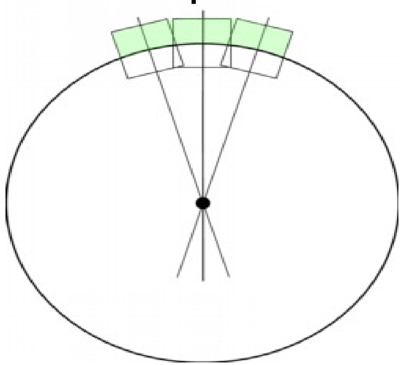
Focus on a few algorithms:

Polyeder representation



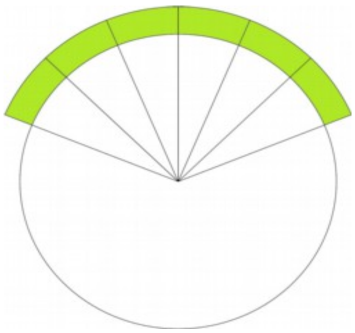
Koether & Szwillus, in prep.

Cubes representation



e.g. Ehrismann & Lettau (1971)

Tesseroid representation



e.g Braitenberg / Grombein (2011)
Adaptive approach:
Koether & Szwillus (in prep.)

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Polyeder mass correction: TRITOP

Workflow

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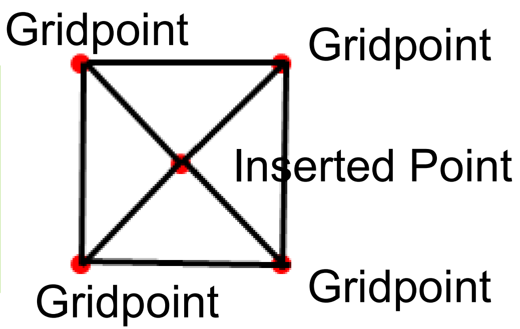
Input Output

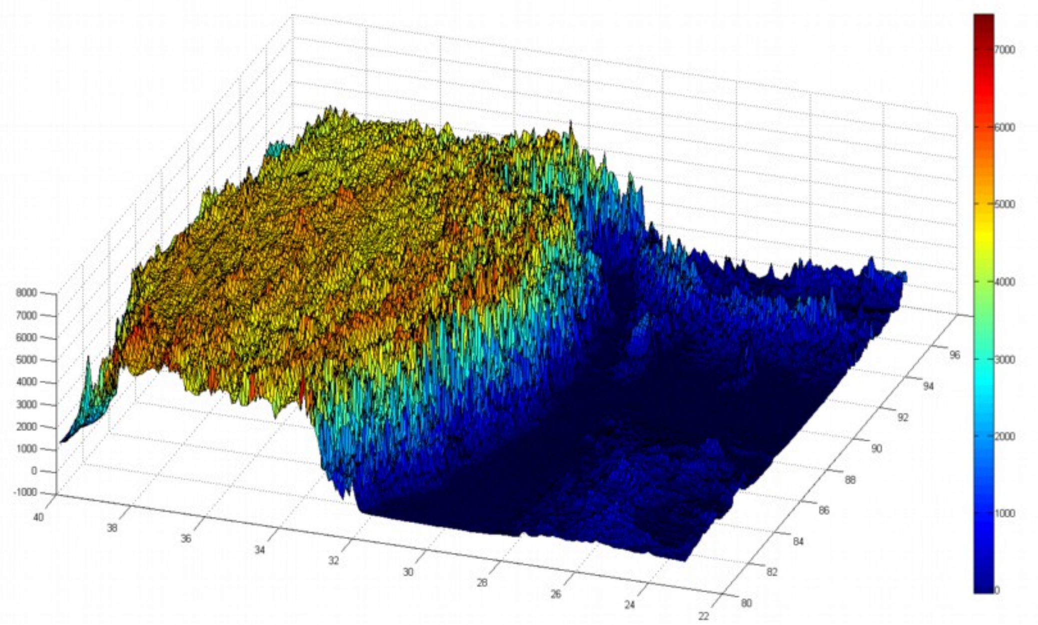
Get SRTM data
for the area
(CGIAR Server)

Fill offshore areas
with SRTM Plus
(Topex Server, San Diego)

Add additional height data
(from stations,
self made DTM, etc…)

Triangulation of the data





Workflow

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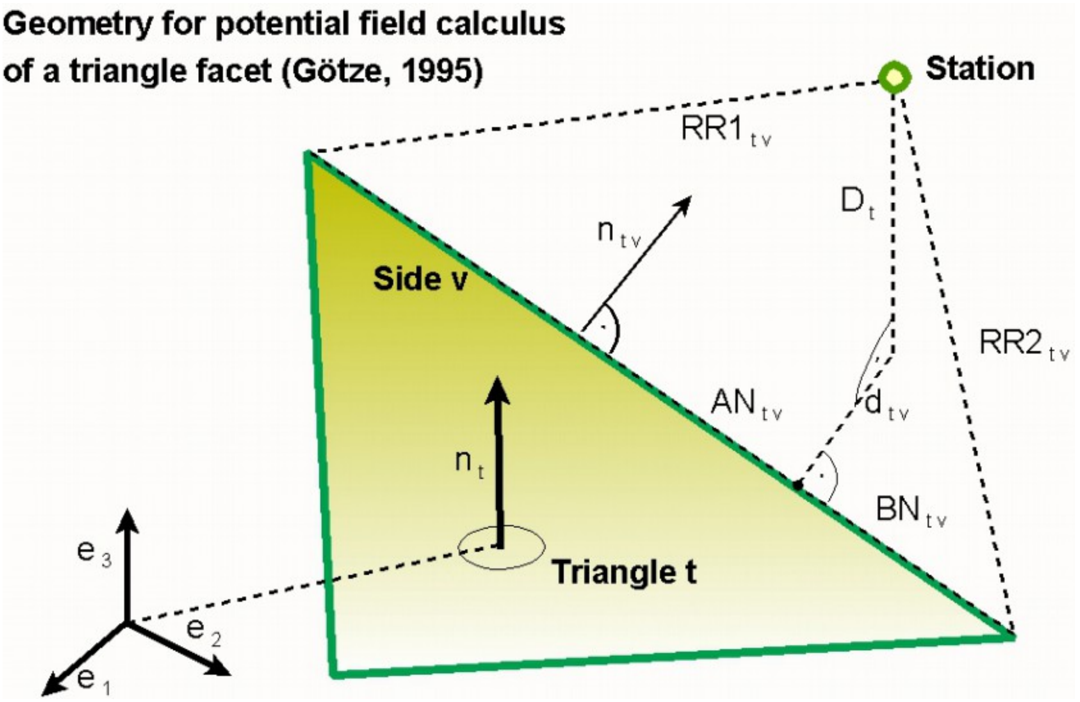
Calculation of gravity effect
Of polyhedron
for each station



Probably the best representation of topography in terms of geometry and mass!

Algortihms for mass correction

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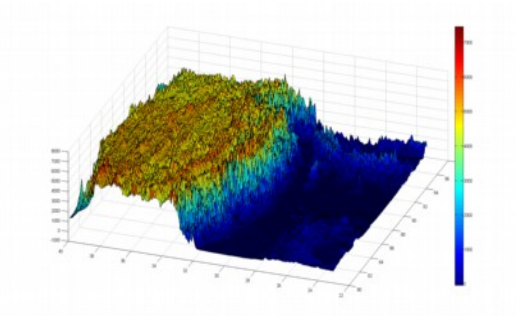
Benchmark over Himalaya

Took Polyeder mass correction with 90 m DTM as „true“

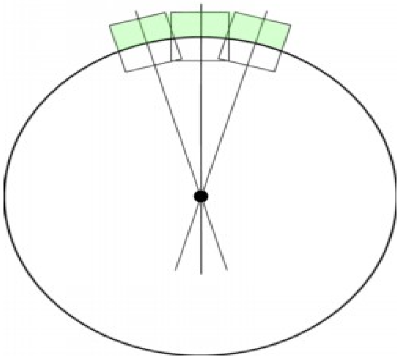
Compared with different algorithms and different resolutions

Polyeder representation



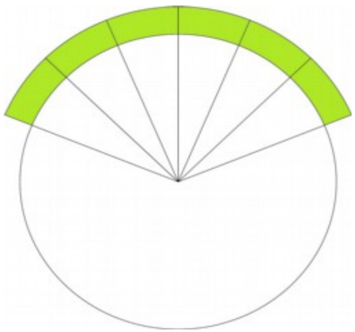
Koether & Szwillus, in prep.

Cubes representation



e.g. Ehrismann & Lettau (1971)

Tesseroid representation



e.g Braitenberg / Grombein (2011)
Adaptive approach:
Koether & Szwillus (in prep.)

Test - Benchmark

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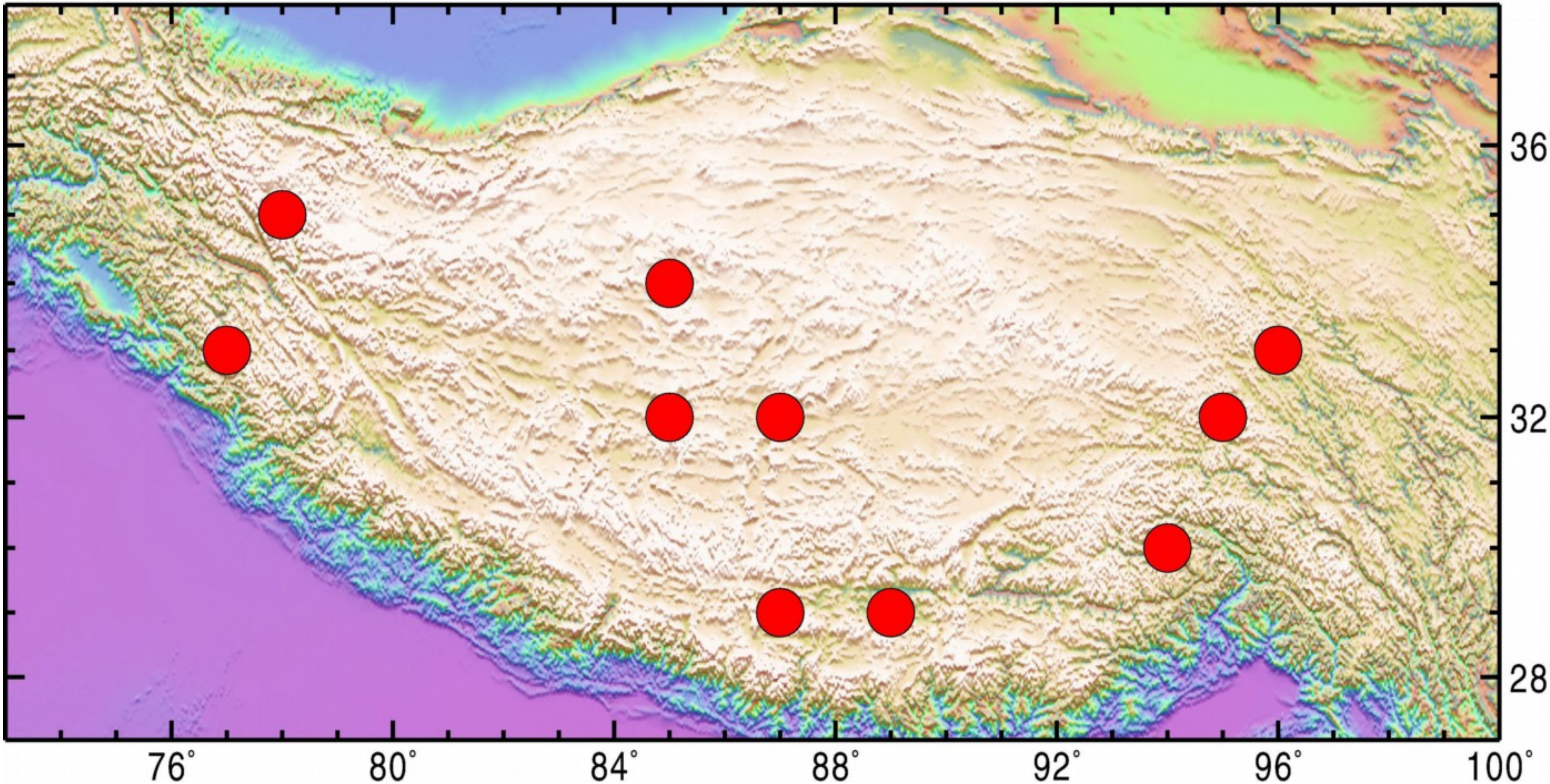
Constant density = 2.67 t/m³



Results

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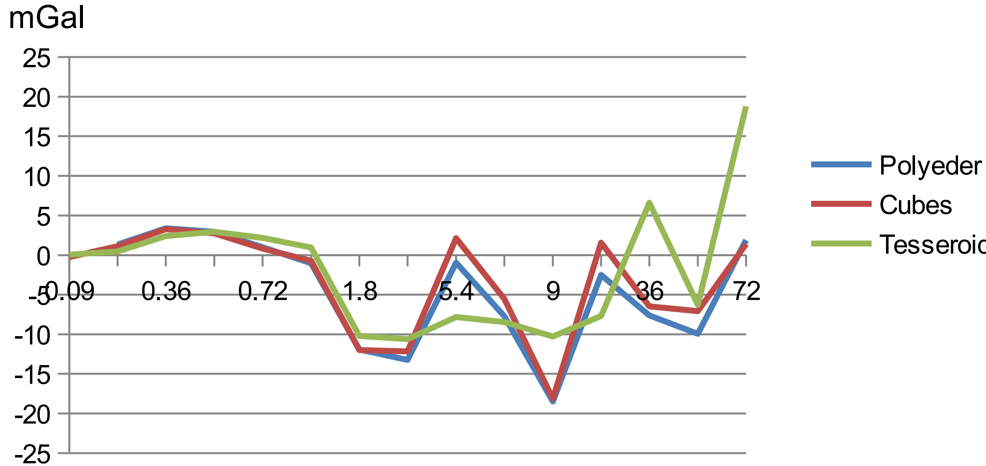
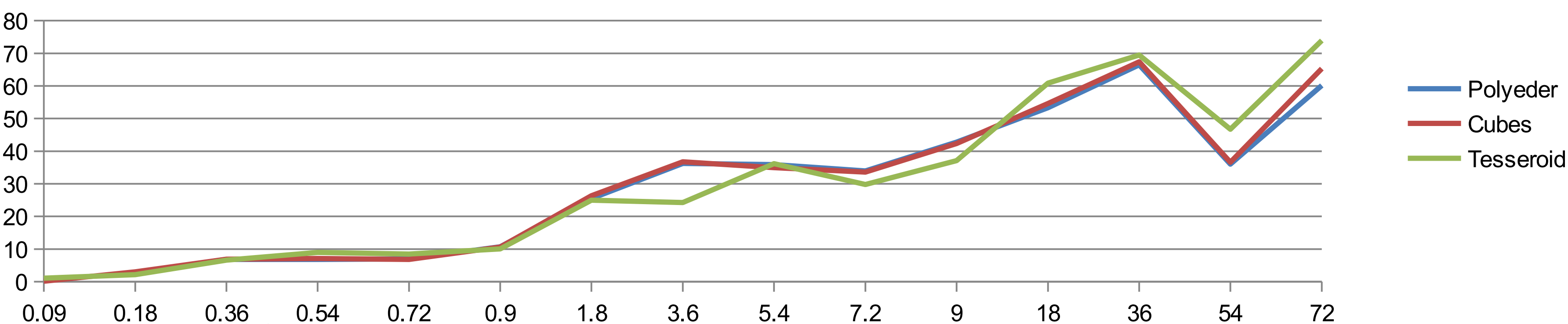
Resol. [km]	0.09	0.9	9	72
Polyeder				
Mean	0.0	-1.0	-18.5	1.9
Std deviation	0.0	10.7	42.8	60.1
Min	0.0	-25.3	-72.2	-91.6
Max	0.0	14.9	45.1	63.9
Cubes				
Mean	-0.2	-0.7	-18.1	1.4
Std deviation	0.1	10.6	42.4	65.3
Min	-0.5	-24.3	-74.0	-98.4
Max	-0.1	13.3	47.9	70.9
Tesseroid				
Mean	-0.1	-0.2	-0.6	9.2
Std deviation	0.2	16.3	52.5	70.1
Min	-0.5	-25.3	-74.0	-98.4
Max	0.1	14.9	47.9	70.9

Mean differenceof all stations



Standard deviation



Results

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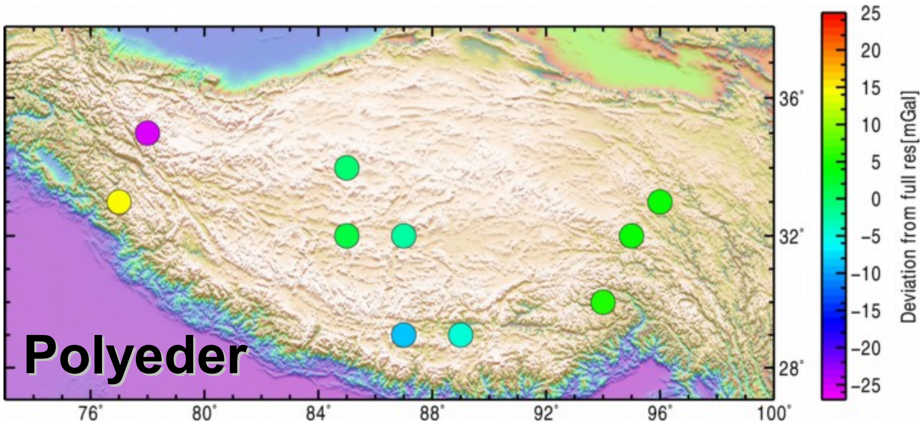
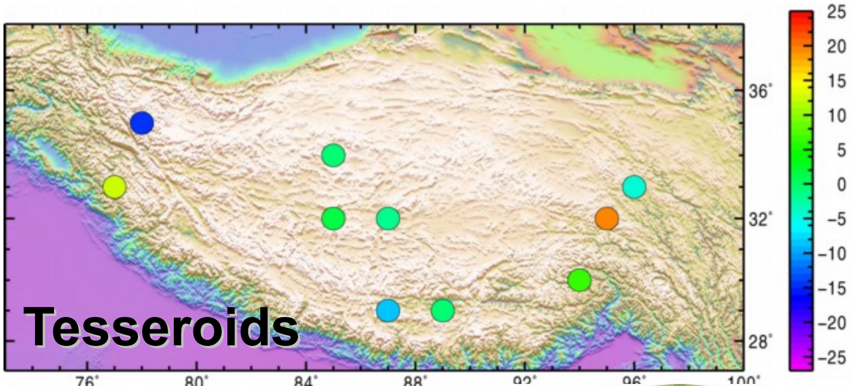
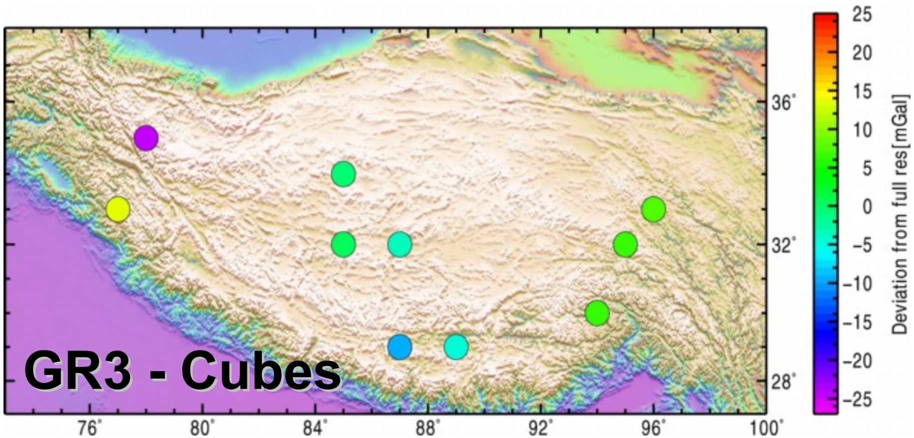
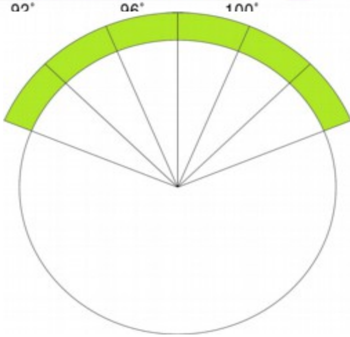
Difference 90m DTM (Polyeder) and 1 km DTM









Results

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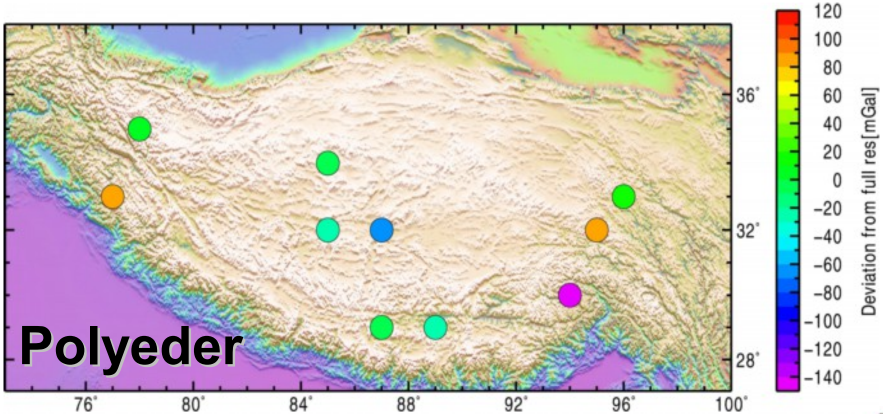
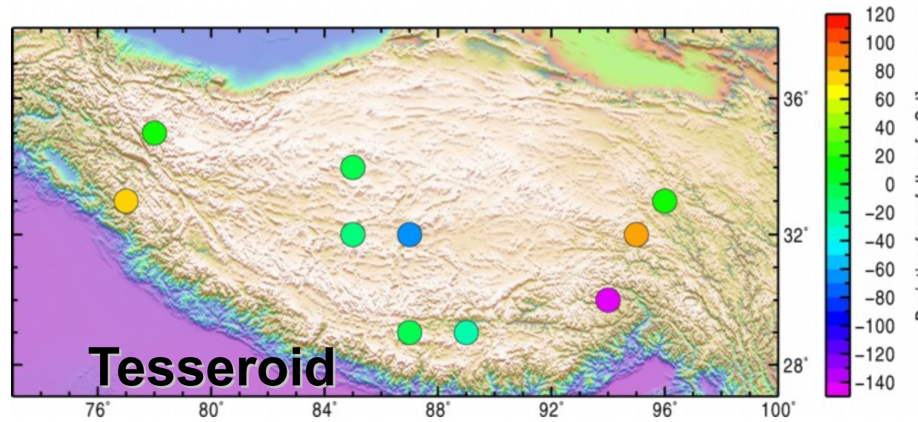
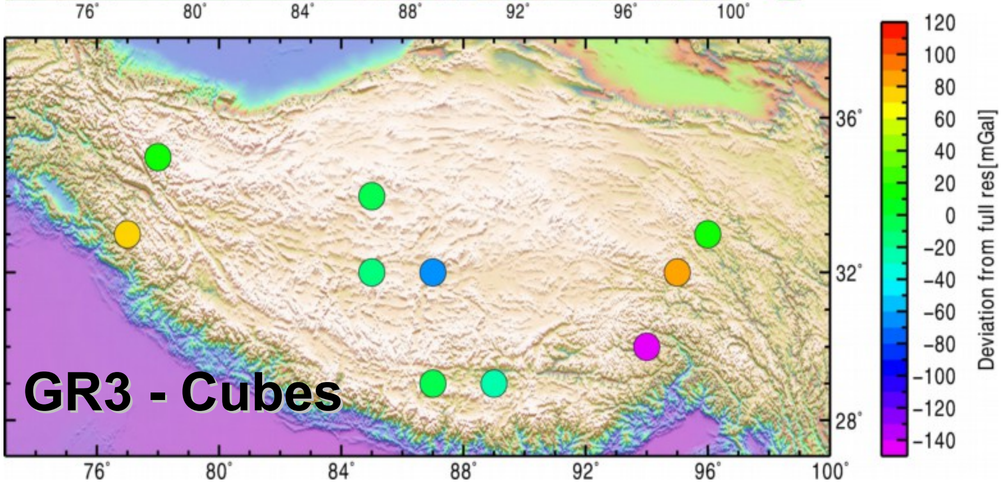
Difference 90m DTM and 36 km DTM







Results

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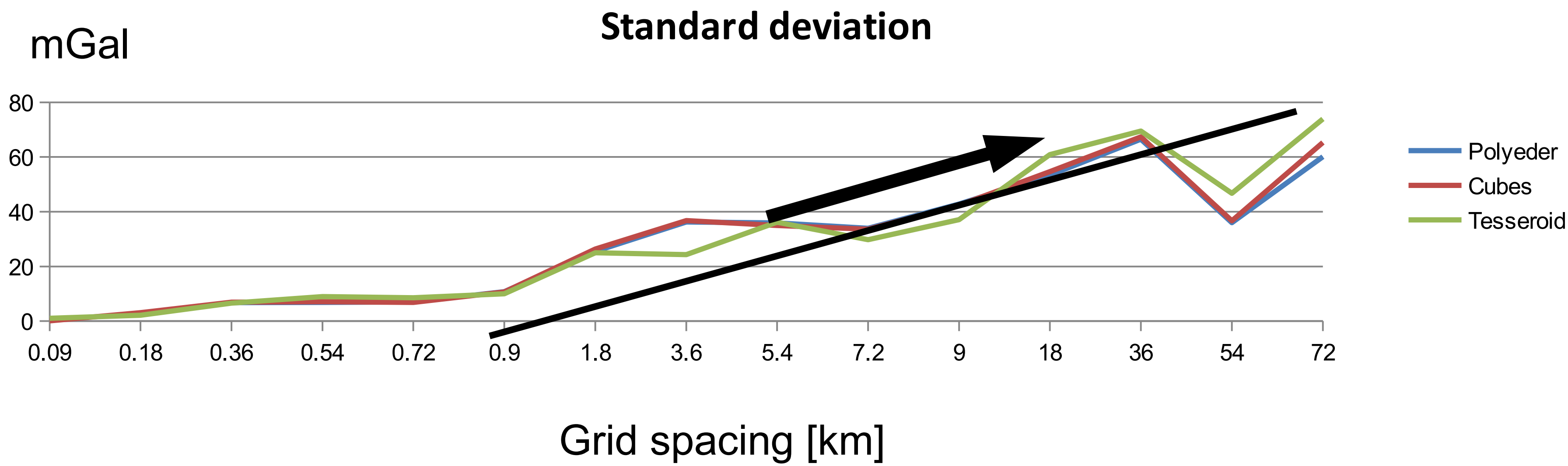

- Distance between station to topography changes,
- High “peaks” close to the station disappear,

- Loss of total mass is only 15 % due to mean heights

Results

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- Prism approximation is very close to Polyeder representation,
- Tesseroids perform also with the same accuracy

- Standard deviation increases with coarser grids
  - Due to geometry & mass change of coarse grid

  Conclusion: The tested algortihms perform similar

  Open question: Do I always have to use a full resolution DTM?

- Calculation of large areas with high resolution can end up in millions of calculations!
  - e.g. Andes area ° 12 x 20° area ~ 365 grid million points (for 90 m resolution)!
  - Full earth: ~98 billion points..

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Adaptive change of topography resolution with Tesseroids

Nils Koether, GOCE Workshop, Enschede, 17.10.2012

Grid sizes

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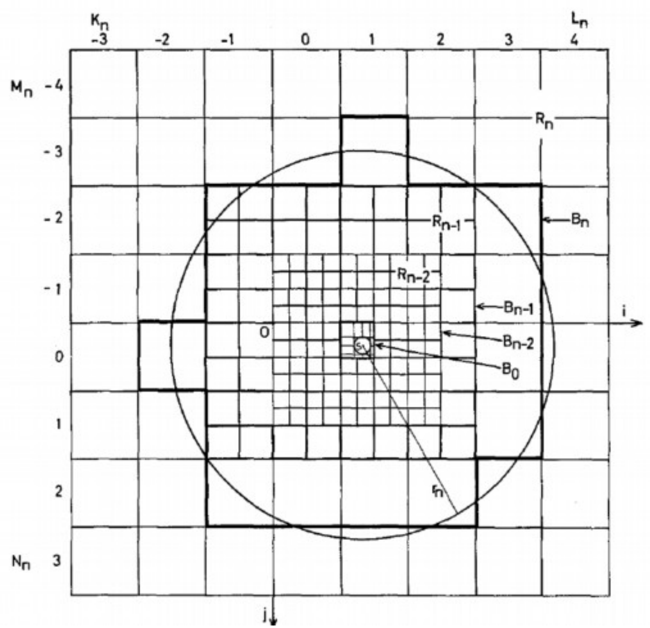
- Most algorithms use a fixed area to reduce (typically 1.5 °),
- and a fixed increase of grid size.



Ok, but:

- can use high resolution in flat areas (when close to station),
- and coarse resolution in rugged topography.

➔ Spacing not linked with input data

Comparison of adaptive calculation

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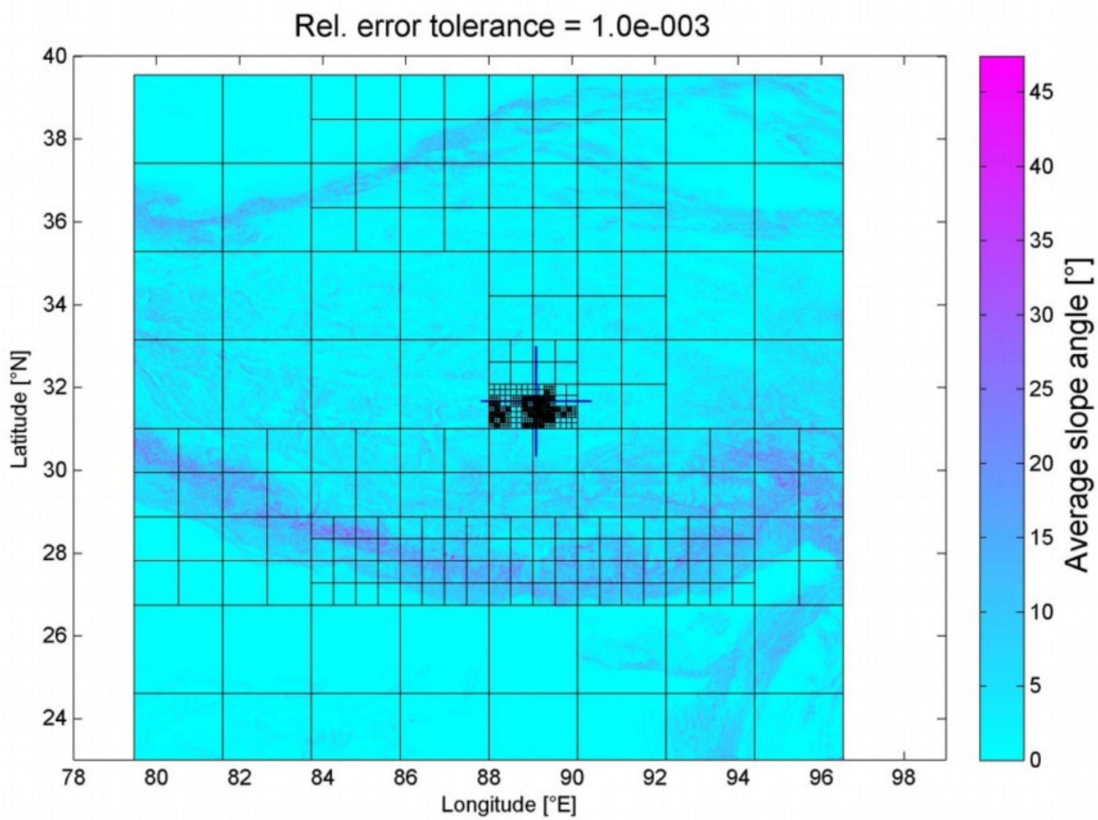
- New Idea: Resolution is dependent on topography and influence on the station.



Adaptive calculation of topographic correction

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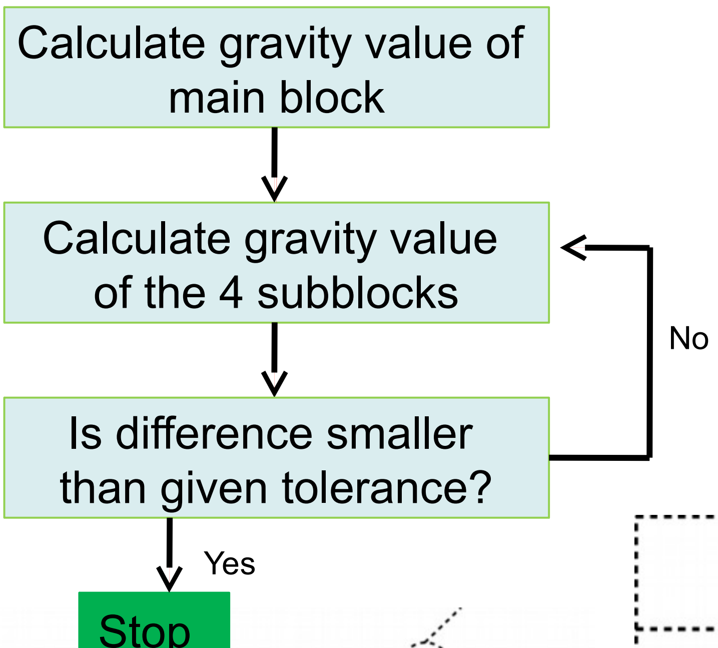
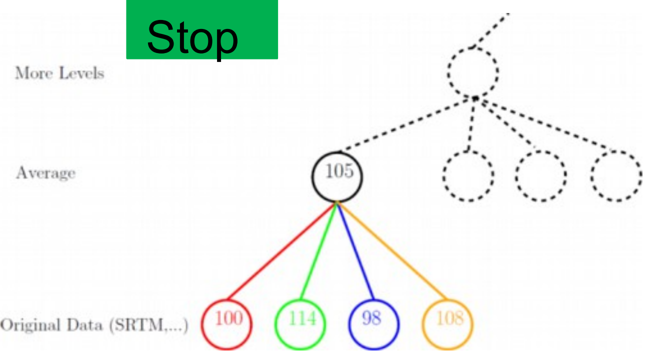
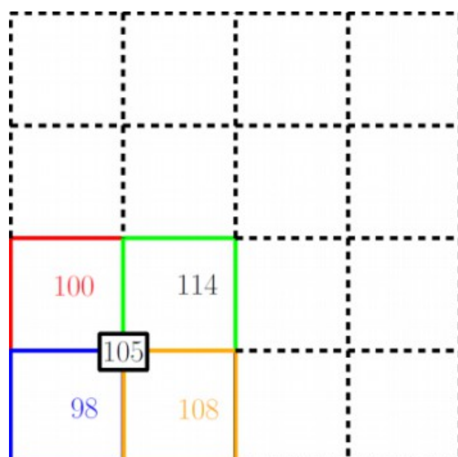
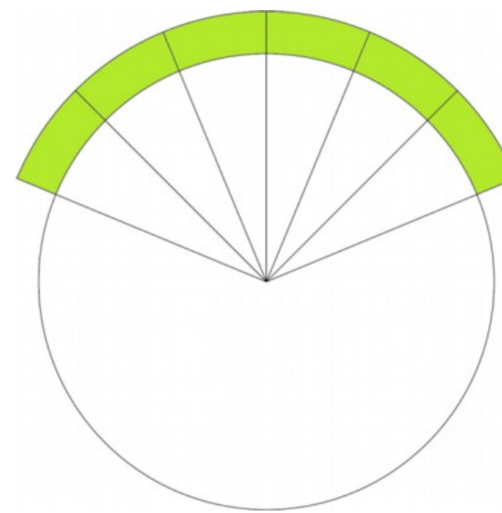


Tolerance will be scaled by gravity influence on station, too.

➔ Blocks with higher gravity values will only allow a smaller relative tolerance!







Comparison of adaptive calculation

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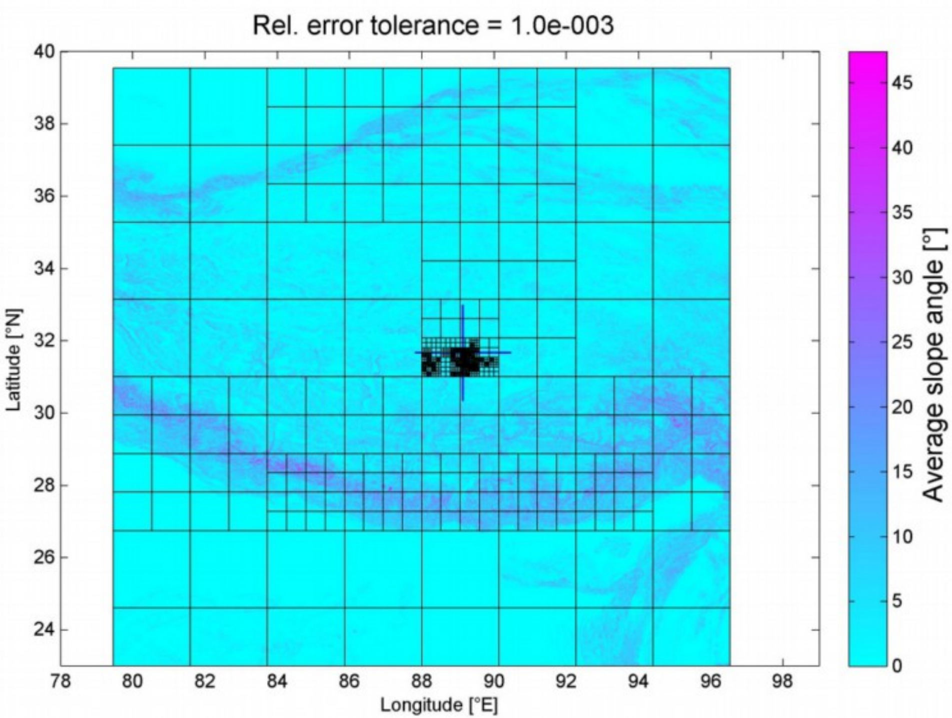
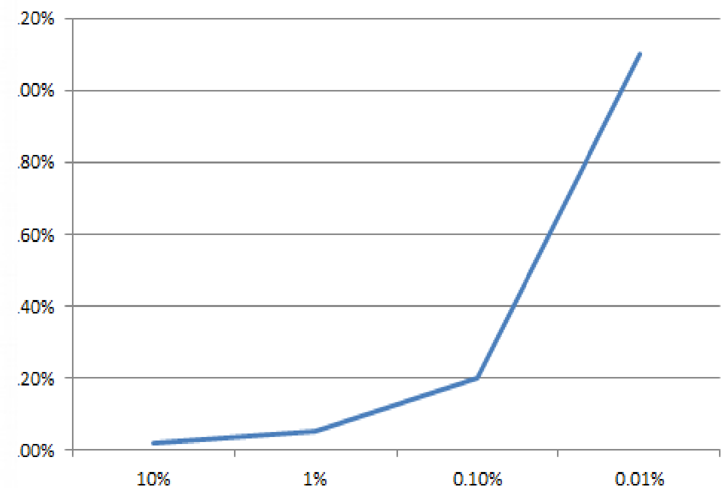
- New Idea: Resolution is dependent on topography and influence on the station.



- Topography grid contains ~450 million values,
- Only 1 million points (<1%) are used with an absolute error of 1 mGal



Comparison of adaptive calculation

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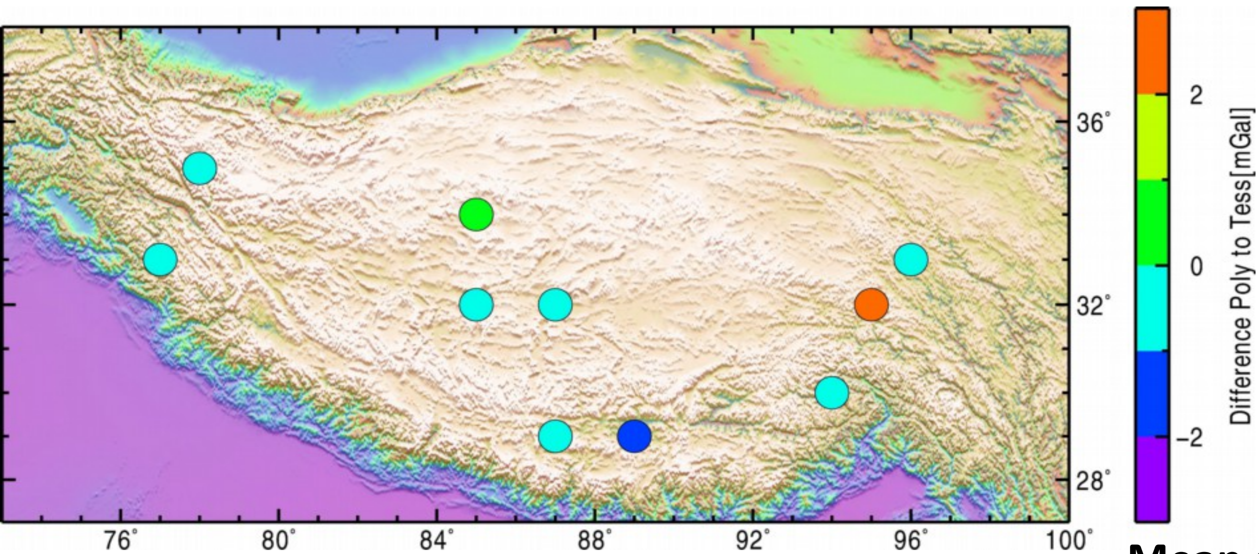
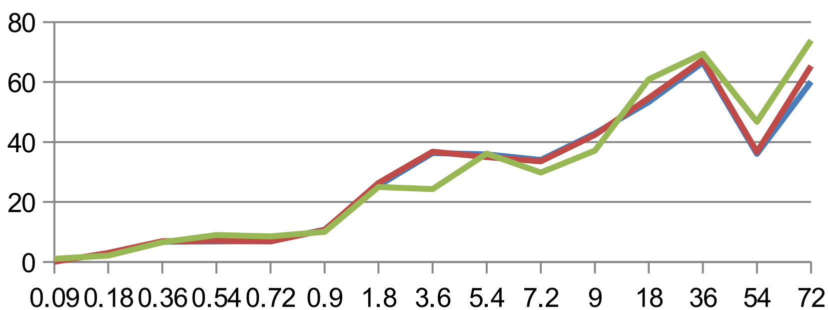


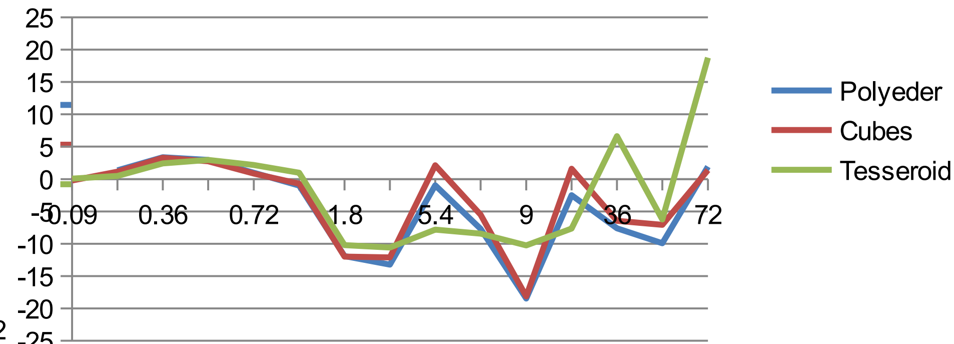
Difference between Polyeder and Tesseroids for 90 m DTM

- Almost the same calculation with less than 1 % of calculations.

Mean difference

Standard deviation





Grid spacing [km]

Conclusion & Outlook

Conclusion

- Polyhedral calculation almost equals approximations, but best representation of topography.
- Seems useful close to the station and in „complicated areas“ like coastal areas or rugged topography.

- Adaptive choice of resolution leads to a reliable, fast and accurate resampling of topography with the same mass correction result than other methods.

- Very good scalable appraoch for whole world correction.
- Coarser grids increase errors in mass correction!

Outlook

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- Towards global topographic reduction:
  - SRTM data make it possible, adaptive resolution leads to good scaleable calculation.
  - Distant topography can affect your reduction area ➔ important for global scale interpretations, e.g. isostasy.
  - Gradient correction for GOCE gradients.