
DTU

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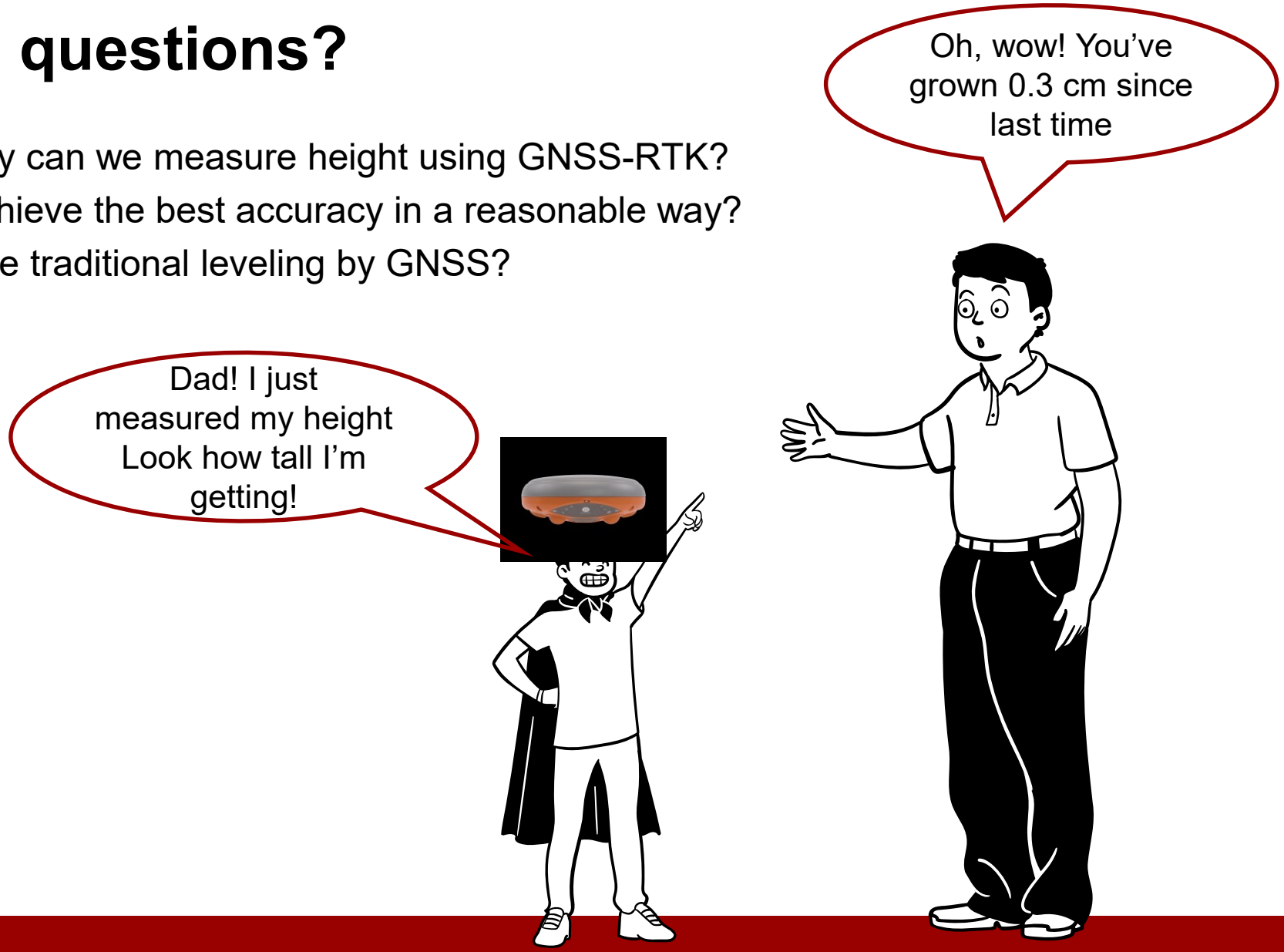
Søren Skaarup Larsen, sorla@space.dtu.dk

GNSS based leveling with cm accuracy using TAPAS

The main questions?

- How accurately can we measure height using GNSS-RTK?
- How do we achieve the best accuracy in a reasonable way?
- Can we replace traditional leveling by GNSS?



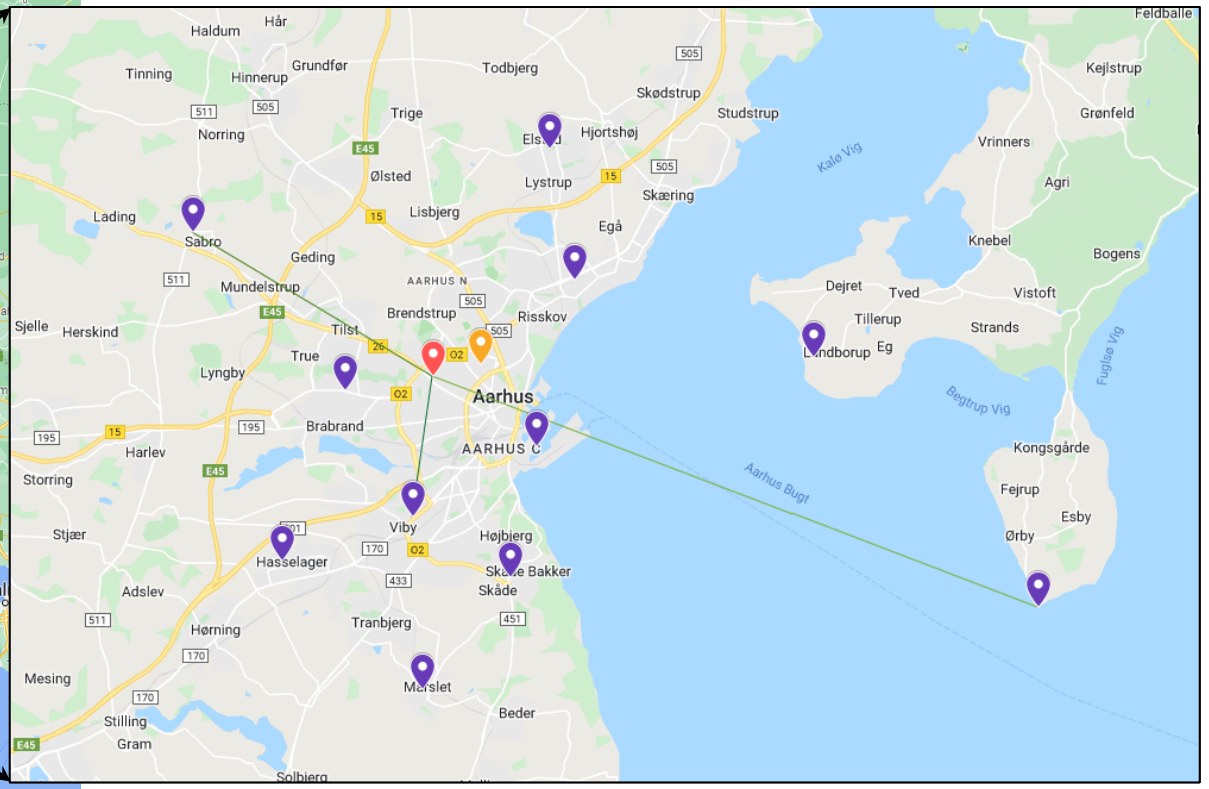
The setup

13 SDFI permanent GNSS reference stations (Green markers)

TAPAS: 11 reference stations (Purple markers)

Solutions made by a monitoring station in central Aarhus (Red marker)

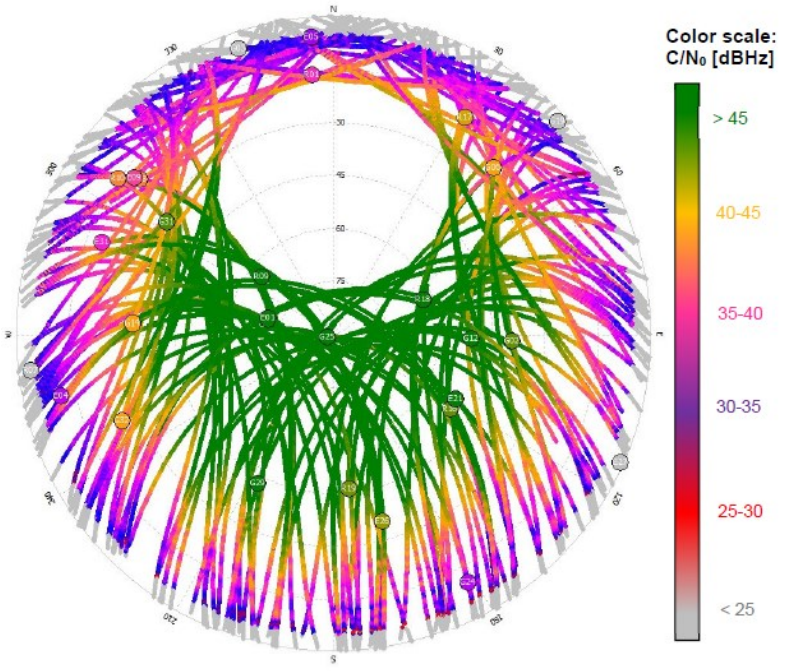
Baselines shown: 5, 10 and 23km



~30 km

The monitoring station

- A setup consisting of:
  - 8 Septentrio Mosaic Multifrequency receivers
  - A survey grade multifrequency antenna
  - Antenna mounted on top of building, in good open sky conditions
- Network solution provided by the GNSMART software developed by Geo++

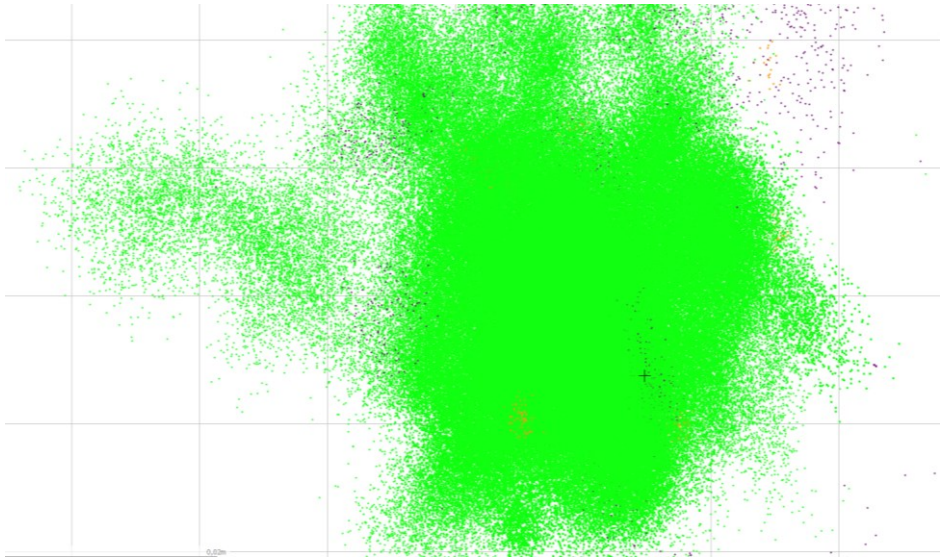


Initial investigations

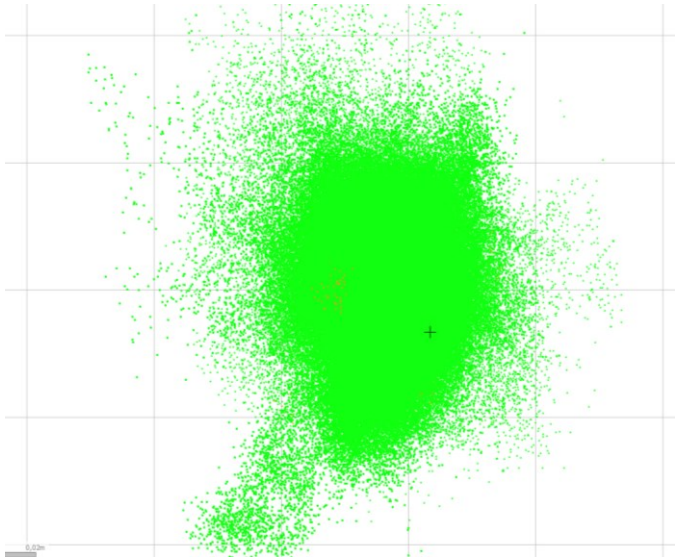
- Which provide the best accuracy?:
  - Network or single station solutions?
  - FKP, VRS or SSR network solutions?
  - What network size/density?
  - What number of satellites / signals / frequencies?
  - What elevation angle?
  - What time of day / year?

Network solutions

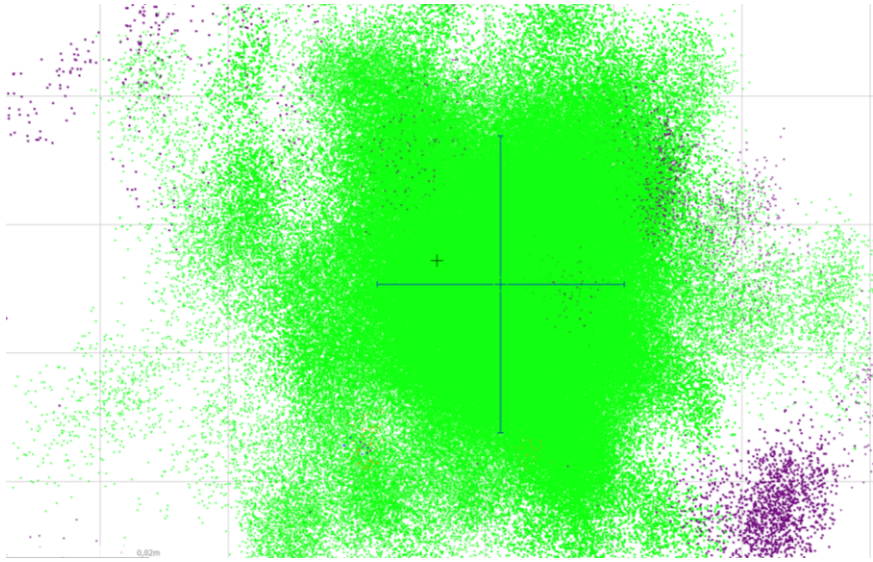
TAPAS VRS



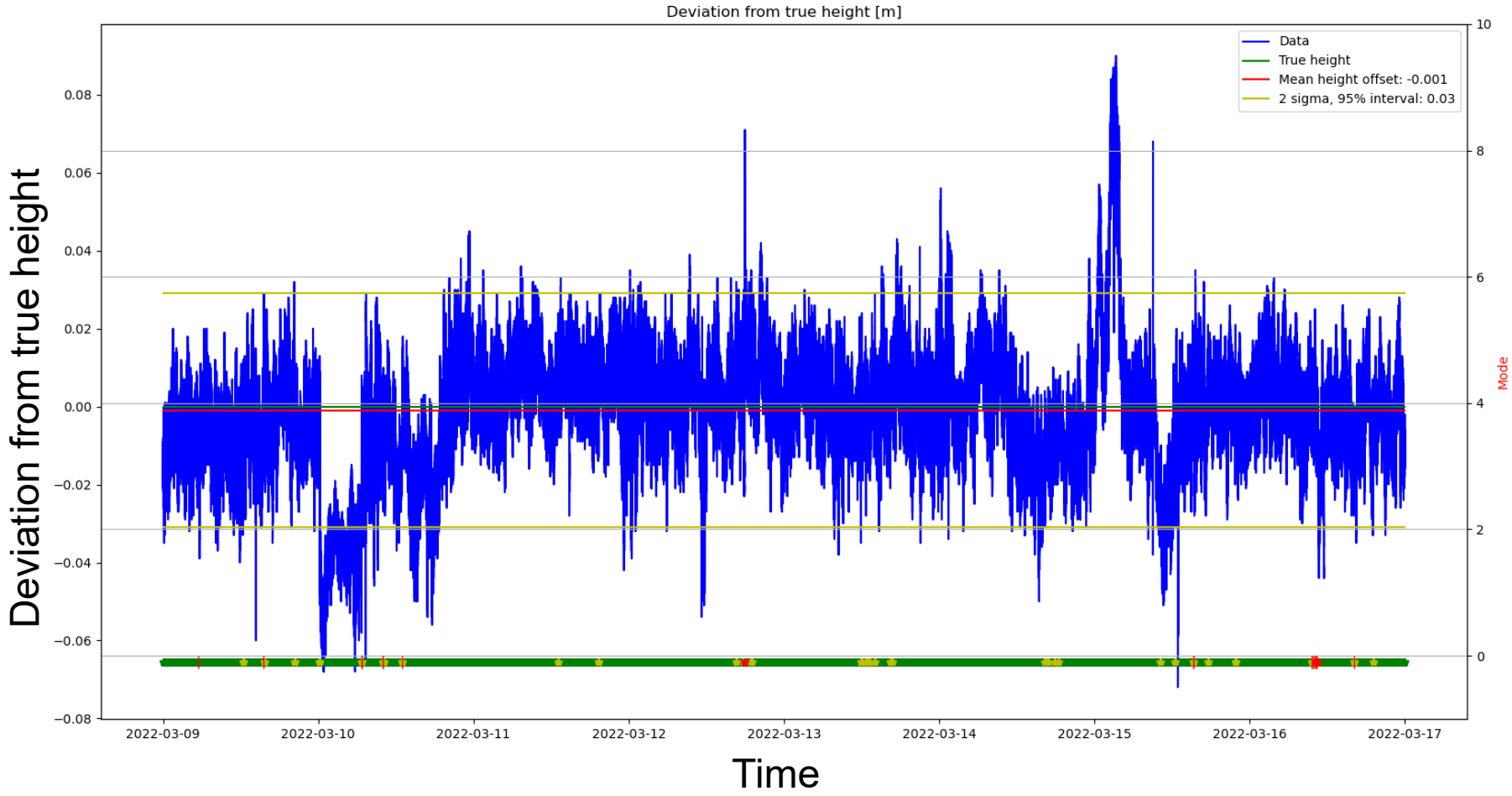
TAPAS FKP



TAPAS SSRZ



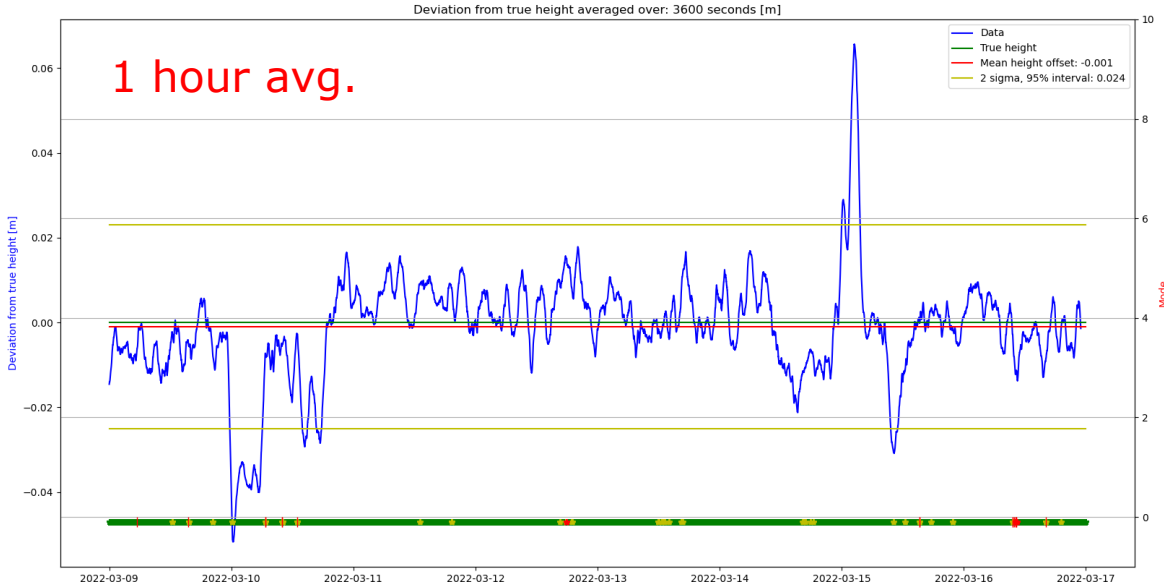
Measurements of height

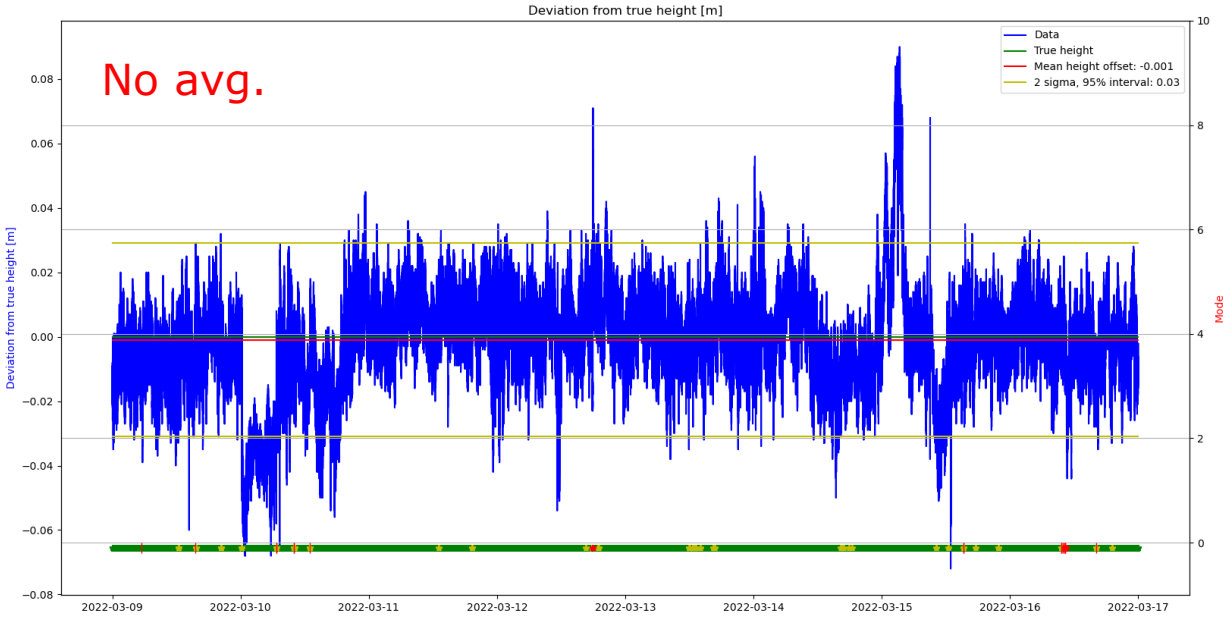


Note: We will only be taking fixed solution into account.

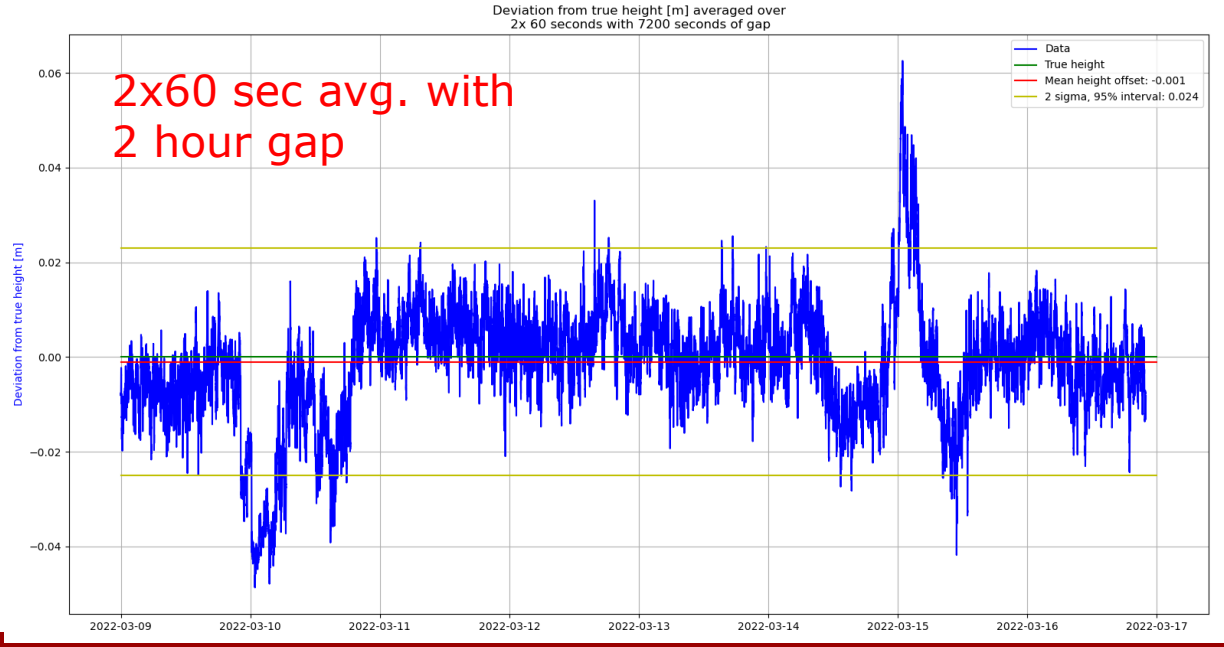
Solutions of lower quality may occur, but are discarded in our investigation

Averaging





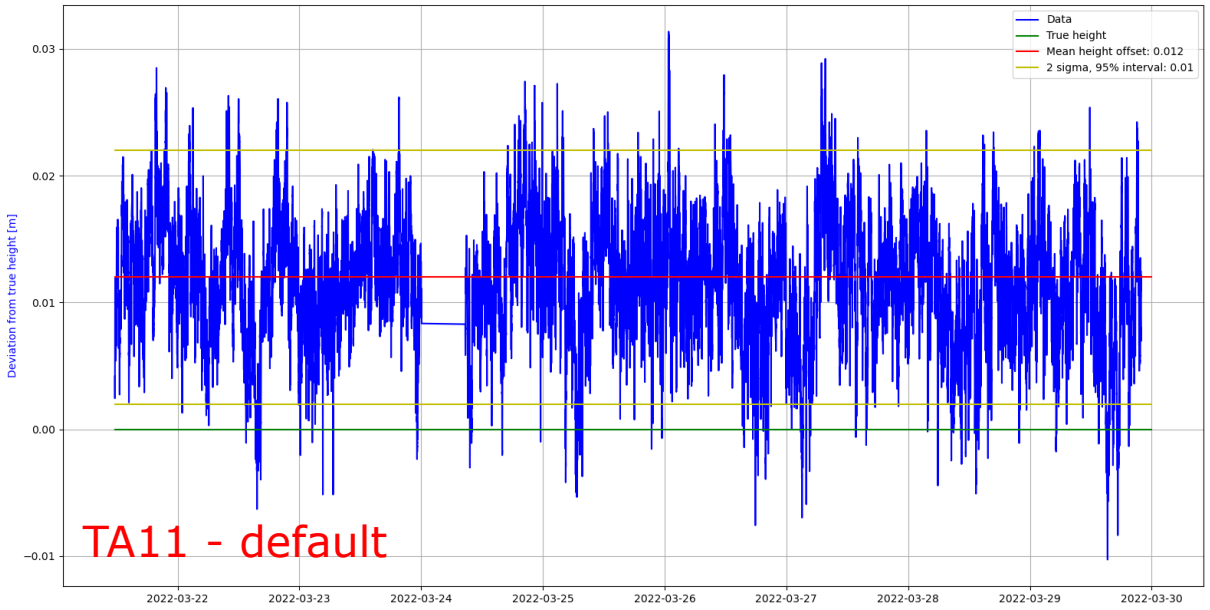
Solution	Avg. Bias [cm]	95% interval [cm]
TA11 – default	0.5	3.0
TA11 – 1hour	0.5	2.4
TA11 – 2x60sec	0.5	2.4

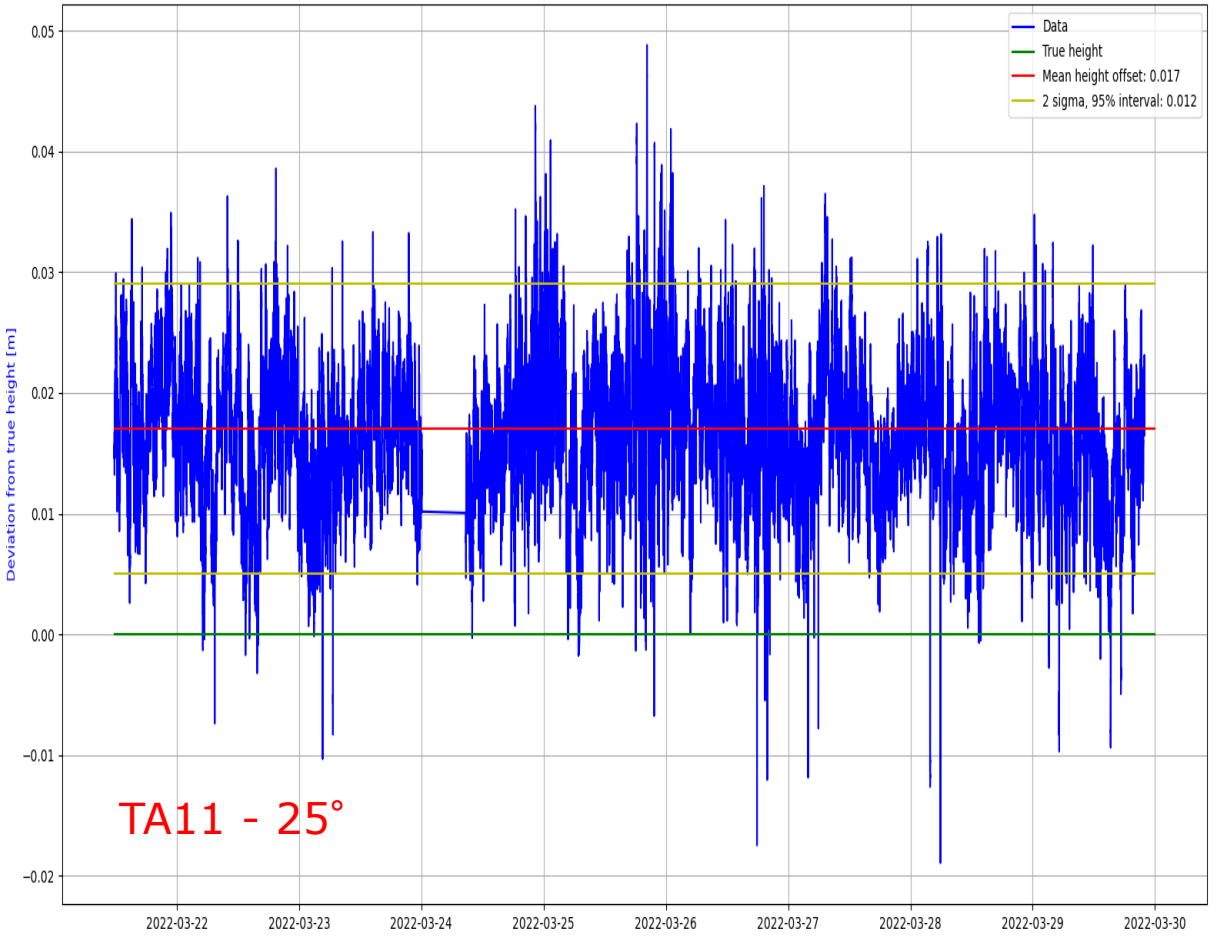


Elevation mask

Solution	Avg. height deviation [cm]	95% interval [cm]
TA11 – default	1.2	1.0
TA11 – 25°	1.7	1.2

Note: The receivers are using a 10 dBHz C/N0 mask





Bias / confidence (95%) [cm]

Solution/Period	1 (March)	2 (March)	3 (April)	4 (May)	5 (June)	6 (July)
TA04 (23km)	2.4/2.0	2.9/1.6	3.0/1.4	3.1/2.4	2.5/2.2	2.5/2.2
TA11 (10km)	1.0/1.2	1.2/1.0	1.6/1.4	1.5/1.6	1.5/1.8	1.4/2.0
TA05 (5km)	1.8/1.0	1.8/1.0	2.1/1.0	2.1/1.2	2.0/1.2	1.9/1.4
TA11+sparse FKP	0.6/1.2	-----	0.5/1.4	0.3/2.0	0.3/1.6	0.2/1.8
TAPAS FKP (3km)	-0.1/0.8	0.4/0.8	0.6/1.0	0.6/1.0	0.7/1.0	0.6/1.2

Explanation:

Station/Period	1 (March)
TA04 (23km)	2.4/2.0

+-2.0 cm 95% confidence interval

2.4 cm offset from our ground truth

Disclaimer: The six periods are of different lenght (8-20 days)

Distance to the nearest reference station

Station/Period	1 (March)	2 (March)	3 (April)	4 (May)	5 (June)	6 (July)
TA04 (23km)	2.4/2.0	2.9/1.6	3.0/1.4	3.1/2.4	2.5/2.2	2.5/2.2
TA11 (10km)	1.0/1.2	1.2/1.0	1.6/1.4	1.5/1.6	1.5/1.8	1.4/2.0
TA05 (5km)	1.8/1.0	1.8/1.0	2.1/1.0	2.1/1.2	2.0/1.2	1.9/1.4
TA11+sparse FKP	0.6/1.2	-----	0.5/1.4	0.3/2.0	0.3/1.6	0.2/1.8
TAPAS FKP (3km)	-0.1/0.8	0.4/0.8	0.6/1.0	0.6/1.0	0.7/1.0	0.6/1.2

There seems to be a station dependent bias on the single station solutions. We're suspecting this has to do with the antenna handling in the receivers

The distance to the nearest station matters.
Std in general improves with the distance to the reference station.
This goes for both single and network solutions.

Network density mostly matters with regards to reference station redundancy.

Network vs. Single station

Station/Period	1 (March)	2 (March)	3 (April)	4 (May)	5 (June)	6 (July)
TA04 (23km)	2.4/2.0	2.9/1.6	3.0/1.4	3.1/2.4	2.5/2.2	2.5/2.2
TA11 (10km)	1.0/1.2	1.2/1.0	1.6/1.4	1.5/1.6	1.5/1.8	1.4/2.0
TA05 (5km)	1.8/1.0	1.8/1.0	2.1/1.0	2.1/1.2	2.0/1.2	1.9/1.4
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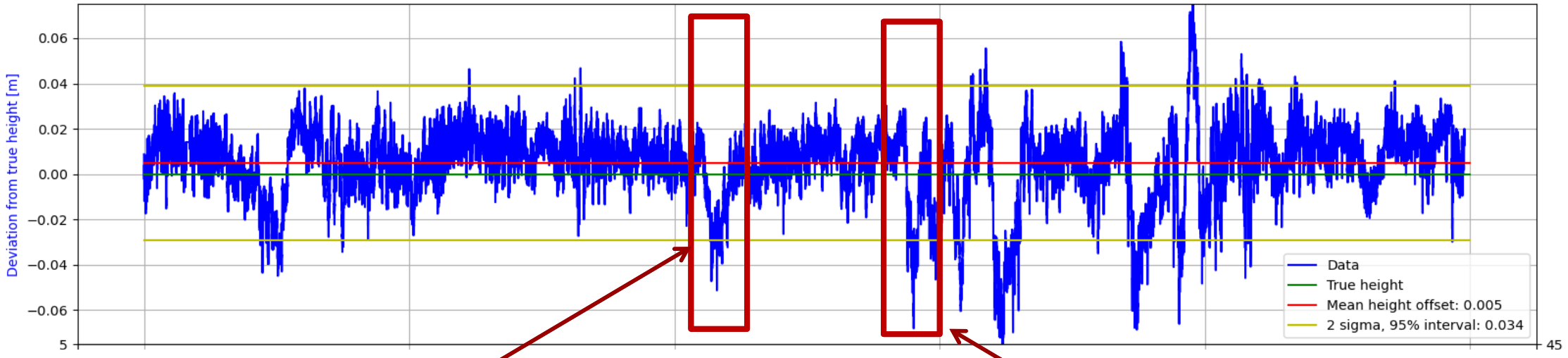
TAPAS FKP (3km)	-0.1/0.8	0.4/0.8	0.6/1.0	0.6/1.0	0.7/1.0	0.6/1.2

In general, the network solution performs better on both bias and std

The general downside to the network solution is that in some cases it may end up in a ”bad” state. In this case the corrections delivered by the network are of low quality, but will still provide a fixed solution in the receiver -> The user has no way of knowing this.

This leads to decreased accuracy in the height and tends to increase especially the std of the solution.

Network issues
A sparse network with a single TAPAS station



Fall-out in the national network leading to a period of decreased accuracy.

A connection issue in the nearest reference station causes a period of decreased accuracy.

The shortest baseline has now gone from 10 to 80km

Conclusions so far

- Currently we can achieve a solution of the height that's:
  - On average ~5mm off true height
  - Has a 95% confidence of less than ±20mm
- This is achieved by:
  - A sparse network FKP solution
  - Averaging over two shorter periods with a 2 hour gap in between (no correlation)
  - 0 elevation mask on the receiver side (dafault network setup)
  - A nearby reference station at 10km.
  - An antenna with a clear view of the sky
  - A multifrequency, multiconstellation receiver

Future Work

- Look into seasonal and daily variations
- Look into the solution bias (could it be caused by antenna offsets?)
- Can we push accuracy even further?

What is the truth?