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Galileo HAS long-term performance statistics

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Outline

- Galileo High Accuracy service
  - Introduction
  - Caveats
  - Applications
- Experiments and performance statistics

Galileo High Accuracy Service

Introduction

- Free of charge service enabling real-time PPP solutions
- SSR correction transmission either on E6-B or via internet
  - Both Galileo and GPS corrections are supported at the moment
  - Multiple frequencies supported
- Global coverage
  - The corrections are also "global": you can retrieve the data anywhere and use it to post-process data from another location
- 95% horizontal/vertical accuracy of 20cm/40cm is expected
- 99% availability expected

Galileo High Accuracy Service

Caveats

- Free correction in SSR format $\Longrightarrow$ relatively little is required from the receiver side
  - Surprising that more receiver manufacturers don't support this yet
- However, triple band antenna/receiver required: E1/E5/E6
  - E6 not needed if the corrections are retrieved from the internet (or some other means)
- The solution is subject to convergence time:
  - Service level 1 (global): 300s
  - Service level 2 (European Coverage Area): 100s

Galileo High Accuracy Service

Applications

- Once devices support this, there is almost no reason not to use HAS
  - Exceptions are the solutions using RTK: provide better accuracy when available
- Prime applications are when high accuracy is needed, but RTK corrections are not available
  - Survey flights in remote areas?
    - Or any drone applications in non-urban areas
  - Land surveying in general?
    - Not as accurate as RTK, but available even with no/poor network connection
  - Useful for mobile phones and personal navigation?
    - No RTK subscription needed, but still reach decimeter level accuracy globally
  - More applications surely to come up as industry learns to utilize this

Galileo High Accuracy Service

Our motivation

- We are very interested in HAS
- We are using HAS in many projects
- Collected continuous HAS data for about one year, and still ongoing, to learn about the characteristics
  - Much of this data has not been analyzed yet
    - This presentation was a good opportunity to dig into this

Galileo High Accuracy Service

How to use HAS?

- Ideally, simply buy a "HAS receiver"
  - Quite rare, and quite expensive at the moment
    - Expect this to change
- Open source solutions for both real-time and post-processing exist
  - This was used to compute the results in this presentation
  - Details can be found in: Prol, Fabricio S., et al. "Enabling the Galileo high accuracy service with open-source software: integration of HASlib and RTKLIB." Gps Solutions 28.2 (2024): 71.

Experiments

Data processing

- RTKLIB and HASlib were used to perform the HAS PPP
- Both are open source libraries
  - https://github.com/tomojitakasu/RTKLIB
  - https://github.com/nlsfi/HASlib
- Post-processing pipeline (with Septentrio receiver):
  - Get RINEX files from receiver (or get RTCM stream, and convert that the RINEXs)
  - Get SBF file with GALRawCNAV blocks (raw bits where the HAS data is)
  - Use HASlib to convert the SBF into RTCM3 format SSR corrections
  - Use RTKLIB (rnx2rtkp or rtkpost) with the RINEX and RTCM3 to compute the HAS PPP
    - Config file needs certain values so the solution is really HAS PPP
- Time taken to process 5 months of data: $\sim$ 30h to get the HAS corrections, followed by $\sim$ 8h to compute the position solutions
  - Getting the HAS corrections should be lighter, but the difference seems to come from programming language differences (HASlib Python vs RTKlib C)

Experiments

Data

- Collected at FGI Otaniemi office (∼9km west of Helsinki center)
  - Septentrio PolaRx-5 receiver used
    - But only the observables and navigation messages are used from it, not the actual Septentrio position solution (since we compute the custom solution)
- Static receiver, known antenna position
- Clear sky visiblity
- Data duration: most of the presented data collected continuously from late October 2024 to late February 2025 (5 months)
  - We have continuous HAS correction data going about 1 year back, though we haven't computed the HAS position solution for all of the early data
  - Few earlier data chunks are presented

```
pos1-soltype        =forward
pos1-elmask         =10
pos1-snrmask        =off
pos1-dynamics       =off
pos1-tidecorr       =on
pos1-ionoopt        =dual-freq
pos1-tropopt        =est-ztd
pos1-sateph         =brdc+ssrapc
pos1-navsys         =gps+gal
file-satantfile     =antfile/igs14.atx
file-rcvantfile     =antfile/igs14.atx
```

Experiments

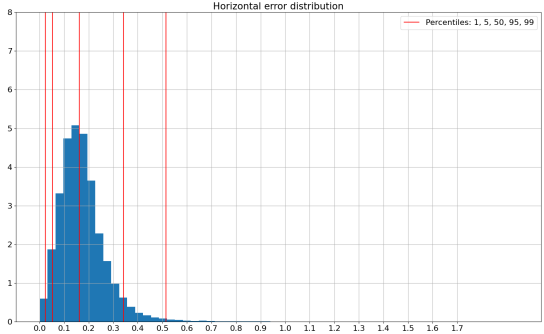
Expected performance reminder

- 95% percentile: 20cm horizontal, 40cm vertical
- 300s convergence time
  - Note that the definition of "convergence time" seems ambiguous:
    - Is this mean/95%/something else?
    - Time to reach the expected HAS accuracy?
    - Time when the position error stabilizes? How to define "stable"?
    - Visually the convergence might be quite clear, but depending on how it is calculated in practice you might even get $\sim$ 10s differences
    - Definition used in calculations: reach HAS-level accuracy
  - Right now the calculated convergence time should be taken as indicative

Experiments

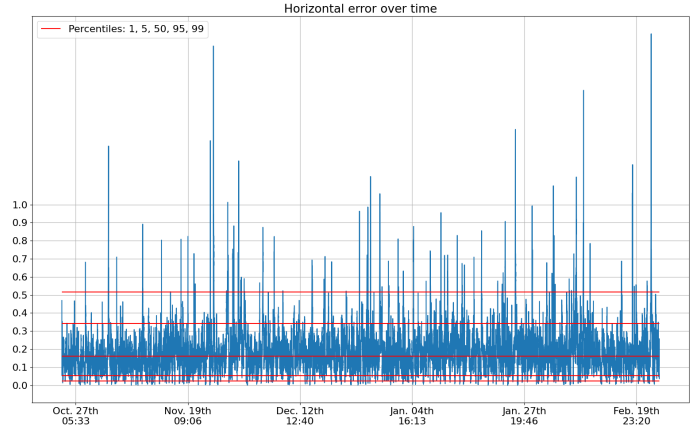
Statistics: Horizontal error

- Mean, std: 17.6cm, 10.2cm
- 95, 99 percentiles: 34.2cm, 51.5cm



Experiments

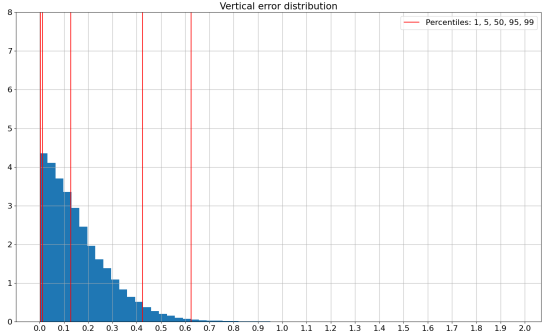
Statistics: Horizontal error over time



Experiments

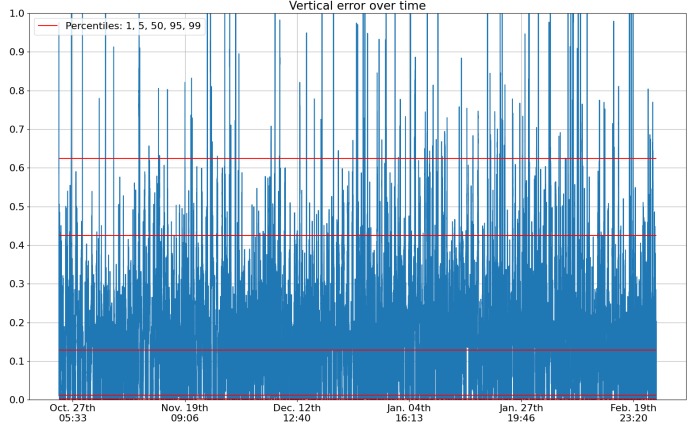
Statistics: Vertical error

- Mean, std: 16.3cm, 14.3cm
- 95, 99 percentiles: 42.5cm, 62.4cm



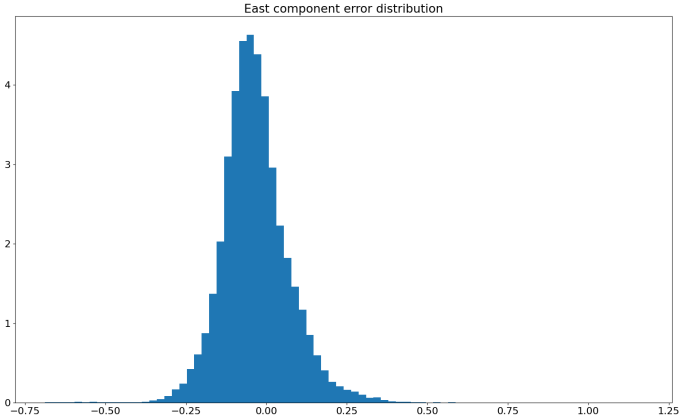
Experiments

Statistics: Vertical error over time



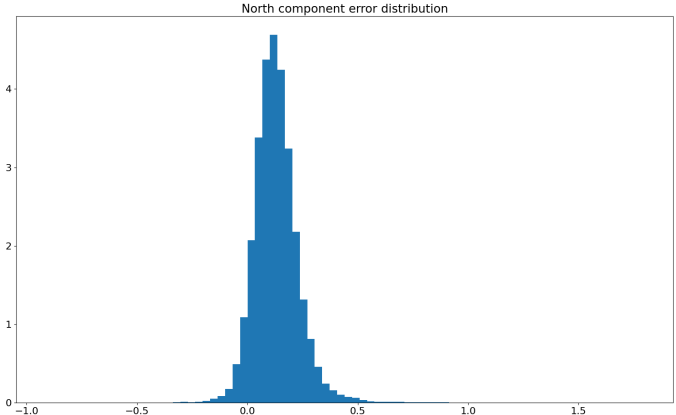
Experiments

Statistics: East-component error distribution



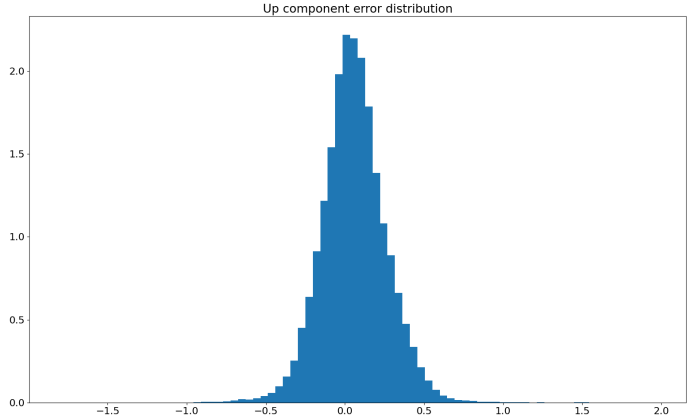
Experiments

Statistics: North-component error distribution



Experiments

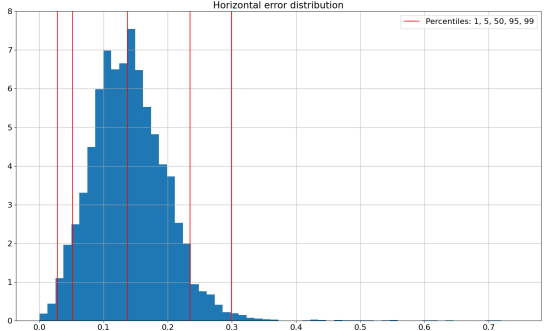
Statistics: Up-component error distribution



Experiments

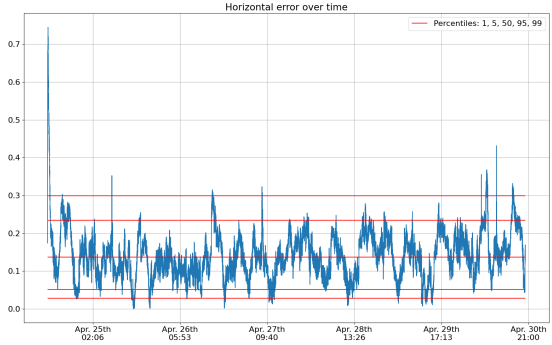
Statistics from one week in April 2024: Horizontal error

- Mean, std: 14.1cm, 6.0cm
- 95, 99 percentiles: 23.5cm, 29.9cm
- Better than the more recent results, but this is just one week of data



Experiments

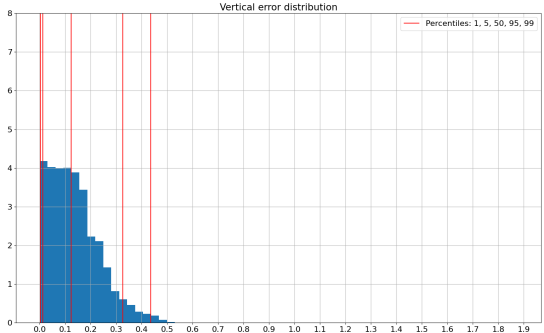
Statistics from one week in April 2024: Horizontal error over time



Experiments

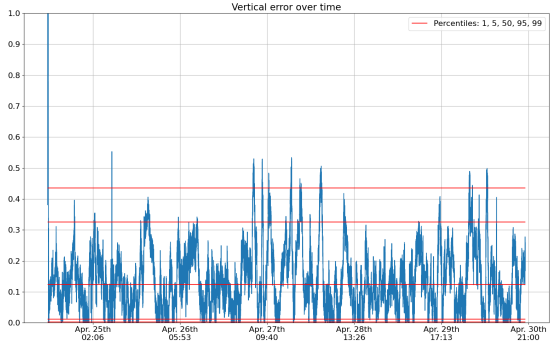
Statistics from one week in April 2024: Vertical error

- Mean, std: 13.9cm, 10.3cm
- 95, 99 percentiles: 32.6cm, 43.6cm



Experiments

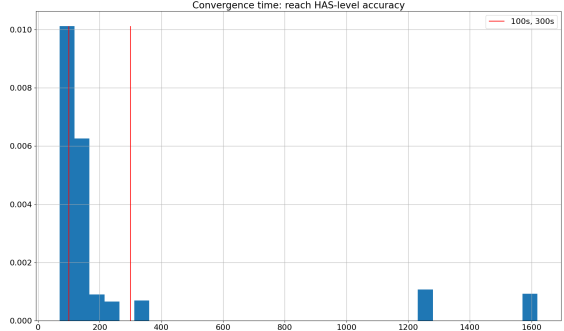
Statistics from one week in April 2024: Vertical error over time



Experiments

Convergence time (from all data)

- Mean: 239.9s, high variance, often below 300s, but also some very large outliers
- No clear trend of getting gradually lower, but this would need further analysis



Conclusion

- HAS enables real-time PPP with decimeter-level accuracy
- Performance that we got is slightly worse than what specification promises:
  - 95% percentile accuracy: 20cm/40cm expected vs 32cm/42cm
  - Convergence time: 300s expected vs 240s (mean, with high variance)
- Interesting to see in what kind of applications this will be used in the future
- We have HAS corrections dating back about one year
  - Let us know if you have some applications in mind or are interested

Questions?

- Thank you for listening!

Advancing together

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