Simulations of near real-time EOP estimation from a future VGOS network

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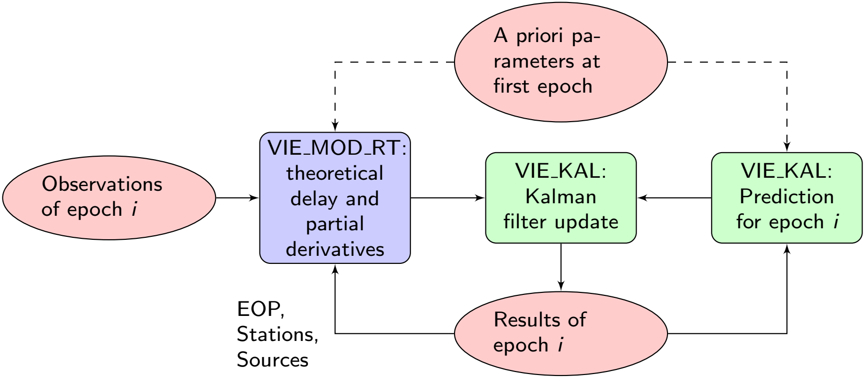
Introduction

- One of the goals of VGOS is to reduce the latency between observation and availability of the results to less than one day
  - Ideally the results should be available in real-time
- Real-time availability is challenging, since it requires:
  - Real-time e-transfer from stations to the correlator
  - Real-time correlation and post-correlation analysis
  - Automated real-time data analysis
- To meet the challenge for the data analysis part, we have implemented a real-time capable Kalman filter in the VieVS@GFZ software (*Nilsson et al., 2015*)
- In this work we test the software through simulations

Real-time VLBI data analysis with VieVS@GFZ



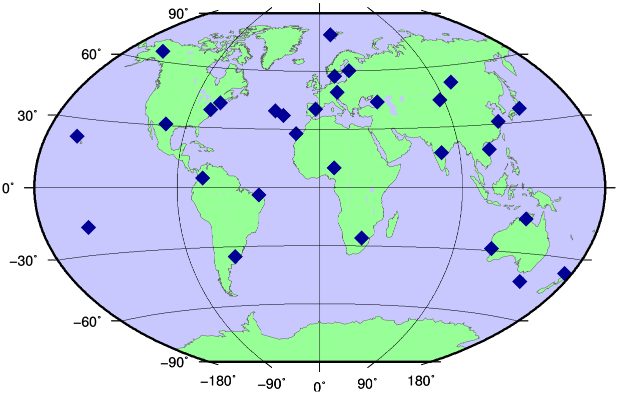
Kalman filter setup

- In the Kalman filter we estimate the following parameters:
  - All 5 EOP (polar motion, UT1-UTC, celestial pole offsets): integrated random walk processes
  - Station coordinates: random walk processes (highly constrained) + NNT/NNR
  - Radio source coordinates: constant + NNR
  - Zenith wet delays: random walk processes
  - Tropospheric gradients: random walk processes
  - Clocks: integrated random walk + random walk processes

Simulations

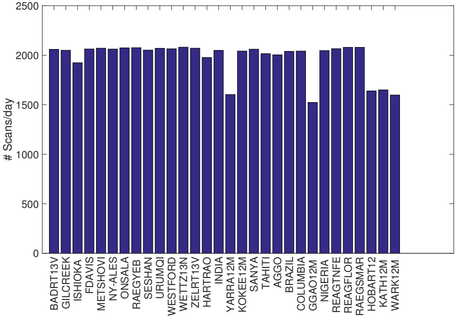
- We have tested the Kalman filter through simulations (*Pany et al, 2011*)
- 25 days of observations from a potential future 30 station VGOS network were simulated
- The following random error sources were considered:
  - Troposphere (station-specific parameters, *Nilsson and Haas, 2010*)
  - Clocks (ASD 10^{-14} @ 50 min)
  - Observation noise (white noise, 10 ps)

Simulation network



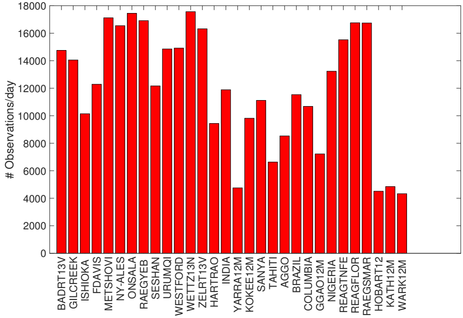
- 30 VGOS stations
- Slew rates:
  - Australian sites, Warkworth, and GGAO: 5°/s in azimuth, 1.2°/s in elevation (actual values)
  - Others: 12°/s in azimuth, 6°/s in elevation
- Only single telescopes

Schedules



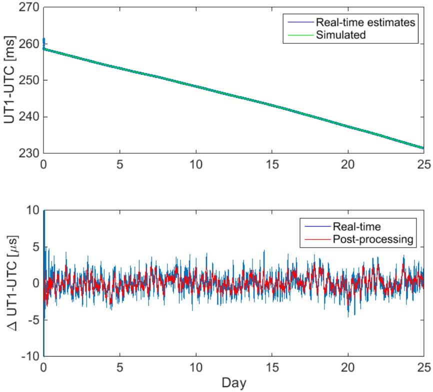
- Schedules generated with the VIE_SCHED software
  - Sources-based scheduling, 4 sources observed simultaneously
  - Recording rate: 8 Gbit/s
- The very fast antennas (12°/s) make about 2000 scans/day, the others (5°/s) about 1600 scans/day

Schedules



- Schedules generated with the VIE_SCHED software
  - Sources-based scheduling, 4 sources observed simultaneously
  - Recording rate: 8 Gbit/s
- The very fast antennas (12°/s) make about 2000 scans/day, the others (5°/s) about 1600 scans/day
- The very fast antennas make up to about 17000 observations/day, the others about 4000 observations/day

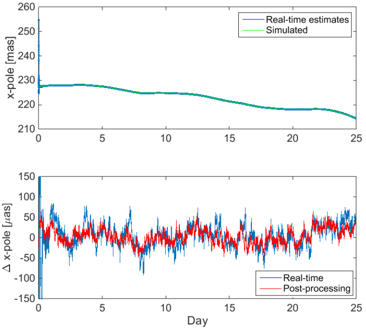
Results: UT1-UTC



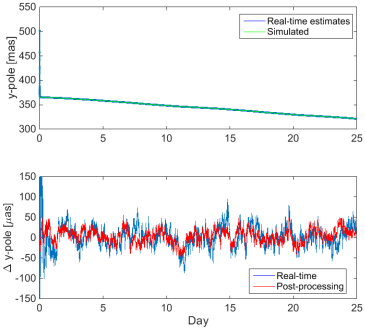
- Upper plot: UT1-UTC estimated from the simulations (blue) and the time series used for generating the simulated delays (green)
- Large differences for the first couple of scans due to bad a priori values at the first epoch
- Lower plot: UT1-UTC error (estimated-simulated) for the real-time forward Kalman filter (blue) and a post-processed Kalman filter solution (forward + backward + smoothing, red)

Results: polar motion

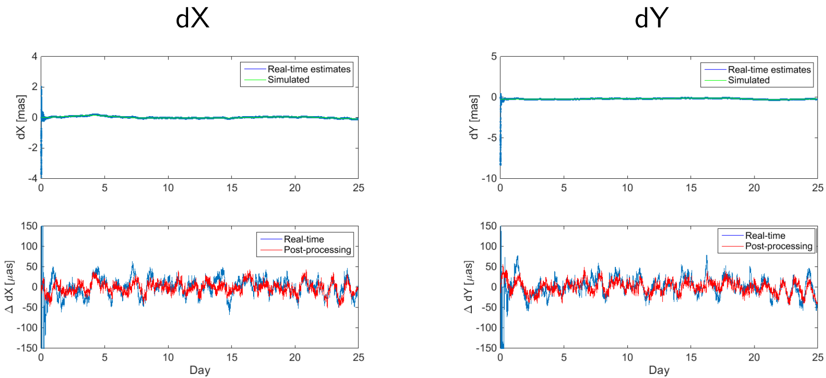
x-pole



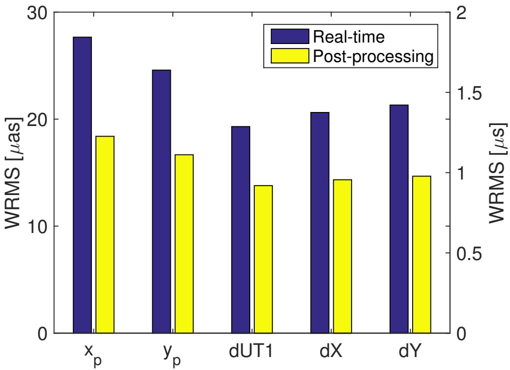
y-pole



Results: nutation

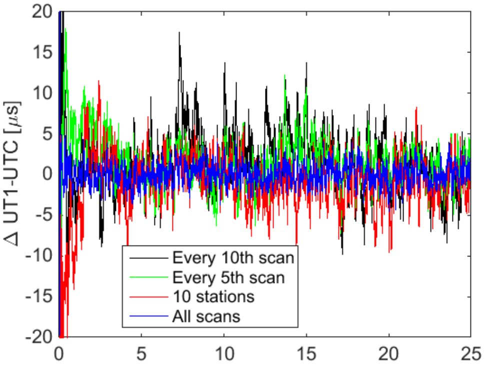


Results: summary



- WRMS errors for the estimated EOP
- The WRMS values of real-time estimates are 40–50% higher than the post-processing ones

Reduced data set



- It may be difficult for all 30 stations to e-transfer all the data in real-time
- Thus we made three tests where we reduced the data available in real-time:
  1. Only every 5th scan available in real-time
  2. Only every 10th scan available in real-time
  3. Only the data from 10 core stations* available in real-time

*: Ishioka, Fort Davis, Onsala, Yebes, Seshan, Westford, Wettzell, HartRAO, Kokee, Hobart

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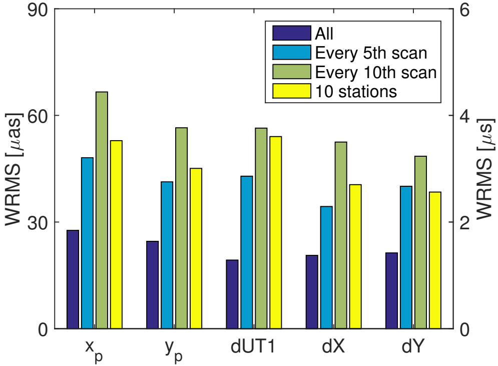

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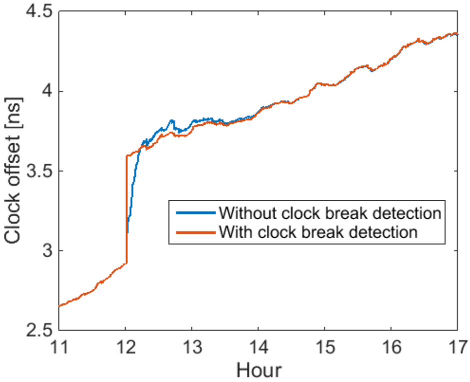
Clock breaks and other problems

- Real-time analysis requires automated detection and correction of several problems, e.g. clock breaks, in real-time
- We have implemented an automated clock break and outlier detector in the Kalman filter:
  - For each epoch, the differences between the predicted and observed delays are calculated
  - If at least one absolute difference is larger than threshold (5σ)
    - Wait for the next couple of scans (next 5 minutes)
    - Run the Kalman filter without data assimilation to get predicted delays for these scans
    - Calculate the differences between the observed and predicted delays
    - If all differences for one station are large and of similar size: clock break
    - Only large differences at the initial epoch: outlier
  - If clock break detected: reinitialize the clocks
  - If outliers detected: remove these observations

Test of the clock break detection



- A clock break of 0.66 ns at 12:00 at one station was simulated
- Automated clock break detects and corrects this break correctly

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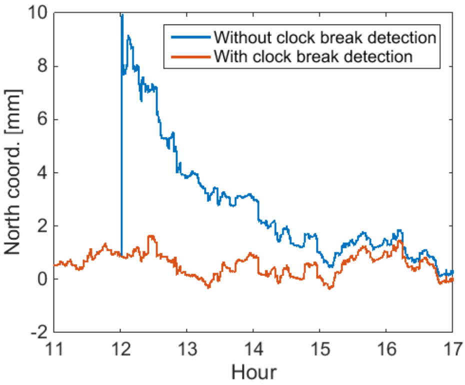

- A clock break of 0.66 ns at 12:00 at one station was simulated
- Automated clock break detects and corrects this break correctly
- If not corrected, the clock break has a clear effect on other estimated parameters, like the station coordinates

Conclusions and outlook

- The Kalman filter is able to estimate all EOP with a precision of 20–30 μas in real-time from a 30 station VGOS network
- Problems, like clock breaks, can be handled autonomously
- Future work:
  - Test with real data
  - Improved stochastic modeling of the estimated parameters, such as better separation of polar motion and celestial pole offsets

Thank you for your attention

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