Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag

Simulation Studies to Evaluate the Impact of Receiver Clock Modelling in Flight Navigation

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Context & Introduction

- ❑ Global Navigation Satellite Systems (GNSS): One-way ranging systems, receiver (Rx) and satellites clocks need to be synchronized w.r.t GNSS time scale
- ❑ Satellite clock corrections: Obtained from GNSS broadcast navigation message or calculated using clock products of International GNSS service (IGS)
- ❑ GNSS Rx internal quartz oscillator: Limited long term frequency stability and poor accuracy. Hence, Rx clock error has to be estimated epoch-by-epoch. It results in high correlations of up to 0.99 between the parameters (Fig. 1) depending on the elevation angle

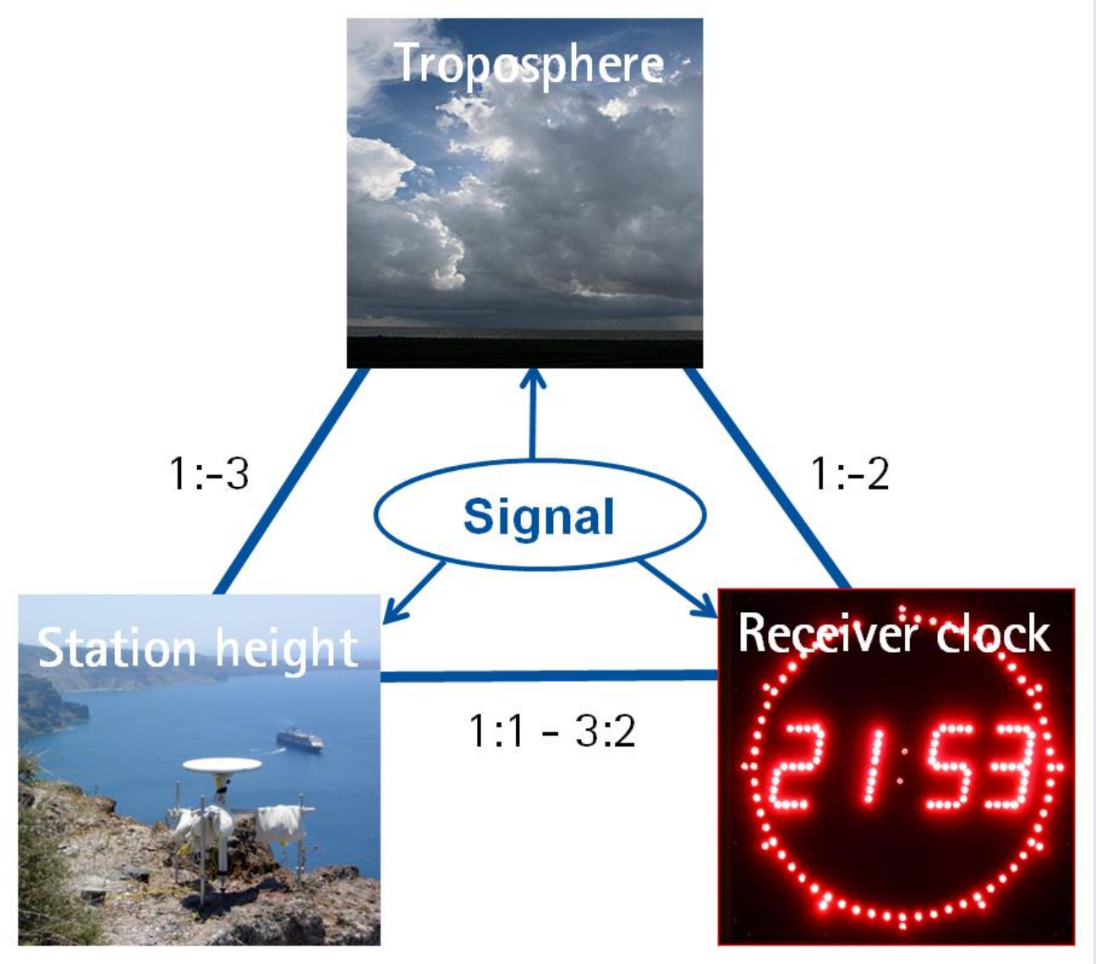

Fig. 1: Relationship between the parameters: tropospheric delay, station height and receiver clock error

- ❑ Up-component estimated less precisely than horizontal coordinates
- ❑ **Clock modelling** improves the parameter estimation by incorporation of external clock information
- ❑ **Goal**: Evaluate the gain in performance by receiver clock modelling (RCM) in code-based GNSS flight navigation where the height component is of relevance

Receiver Clock Modelling

- ❑ RCM: Replacing the receiver internal oscillator with a more stable external clock and modelling its physical behavior in a physically meaningful manner (Weinbach, 2013)
- ❑ Miniaturized atomic clocks (MACs): Low power consumption, low priced, small form factor makes its feasible for usage in kinematic GNSS applications
- ❑ Two different MACs used for this study: Microsemi SA.45s Chip Scale Atomic Clocks (CSACs) and Stanford Research System (SRS) PRS10
- ❑ RCM prerequisite: accumulated time error due to random frequency fluctuations of oscillator is smaller than receiver noise
- ❑ **Clock noise < receiver noise**
- ❑ Physically meaningful RCM possible over time intervals over which previous statement holds true
- ❑ Microsemi SA.45s: maximum RCM interval (GPS L1 C/A code) is ≈ 1.6 hours (Fig. 2)
- ❑ SRS PRS10: maximum RCM interval (GPS L1 C/A code) is ≈ 4.3 hours (Fig. 2)

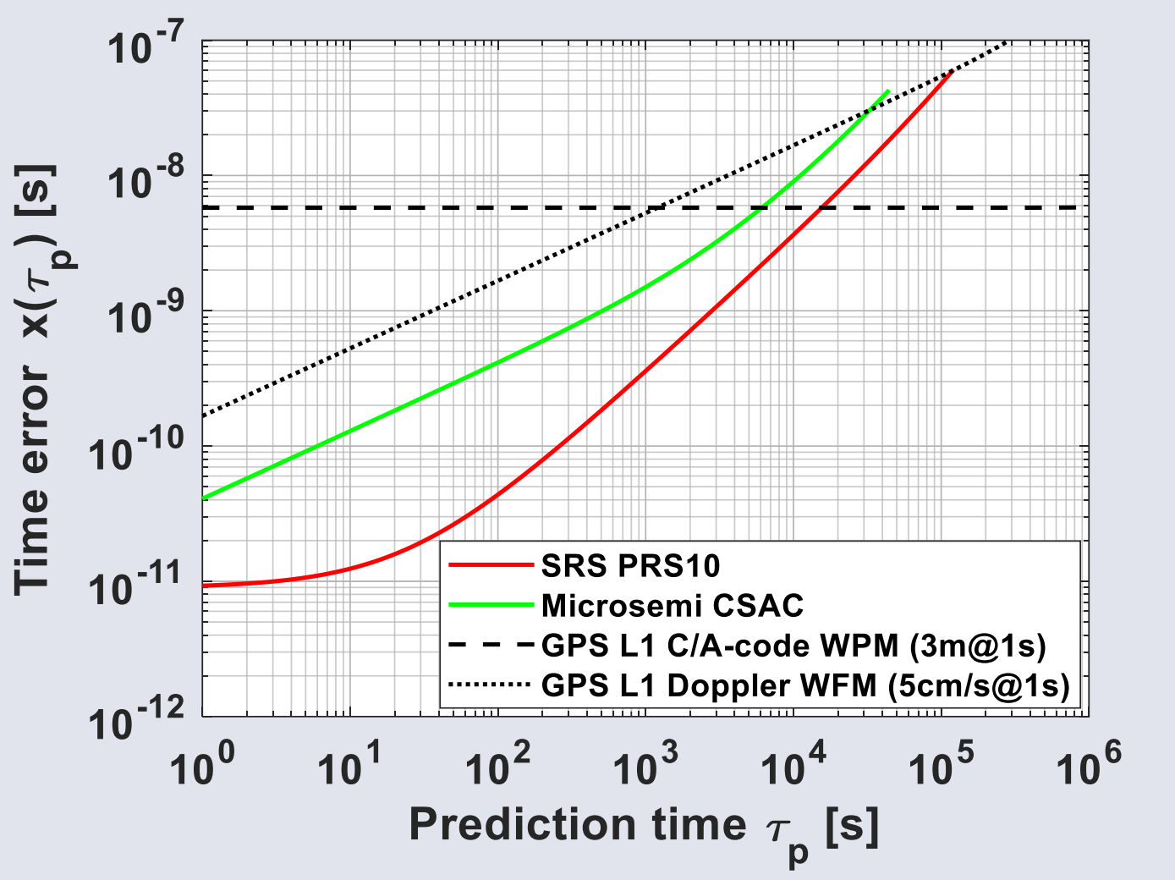

Fig. 2: Time prediction errors for SRS PRS 10 and Microsemi CSAC; GPS L1 C/A code and Doppler observation noise modelled as WPM and WFM, respectively (adapted from Krawinkel, 2018)

Simulated Flight Trajectories

- ❑ Three different reference flight trajectory snapshots generated using trapezoidal rule in navigation frame (Input: start point coordinates; velocity & attitude information over different intervals), high flight dynamics introduced by varying the attitude information
- ❑ GPS & Galileo code and Doppler observations simulated for reference flight trajectories; satellite constellation simulated for 30th January, 2019 using different products of IGS
- ❑ GNSS observation errors caused by oscillator's clock (Microsemi SA.45s & PRS10) are simulated based on the spectral density h_α coefficients of the respective clocks

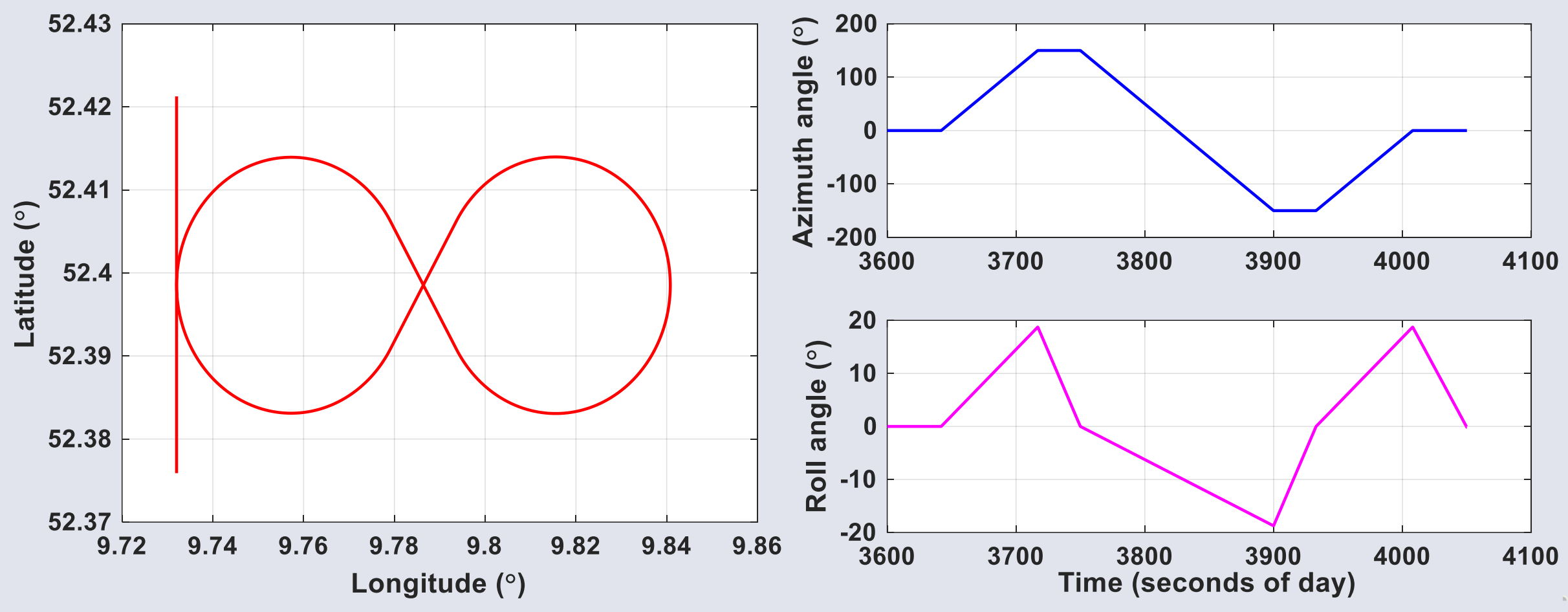

Fig. 3: Reference trajectory 1 snapshot (left), azimuth and roll angles of aircraft (right), zero pitch

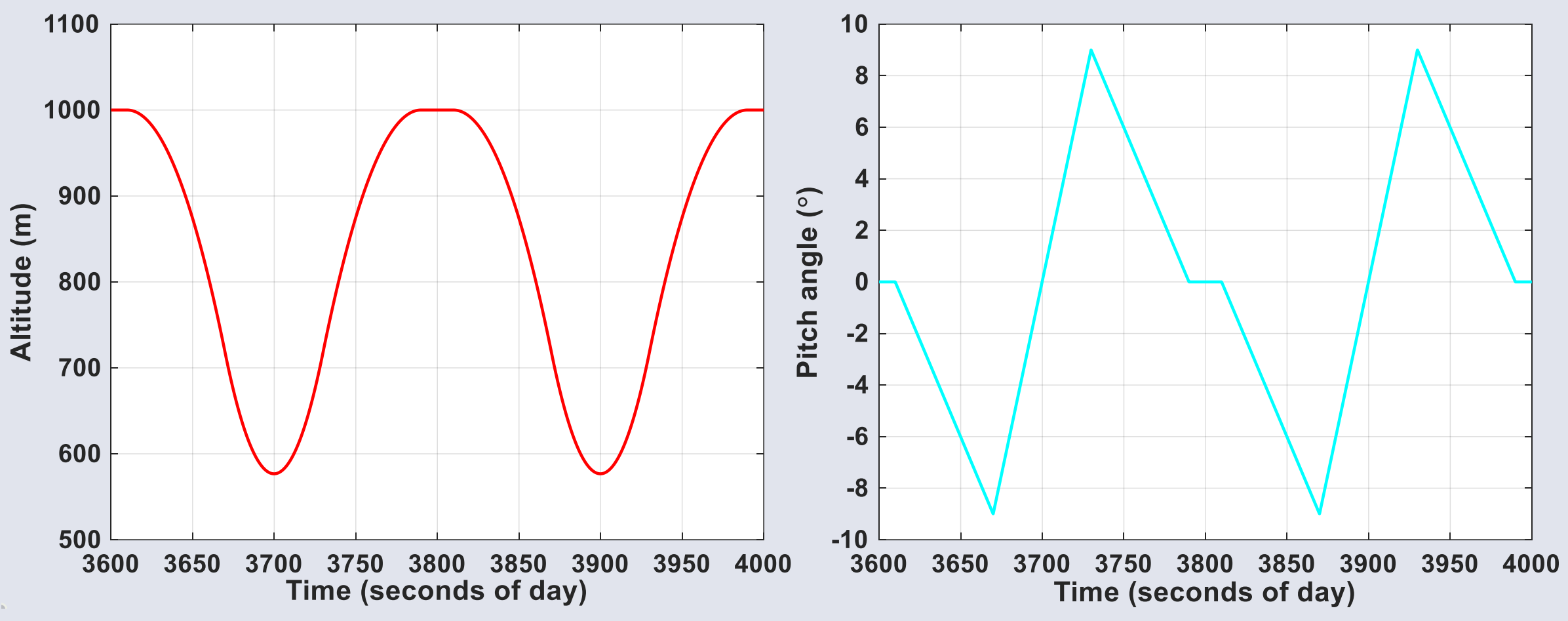

Fig. 4: Reference trajectory 2 height (left), pitch angle of aircraft (right), fixed azimuth and zero roll

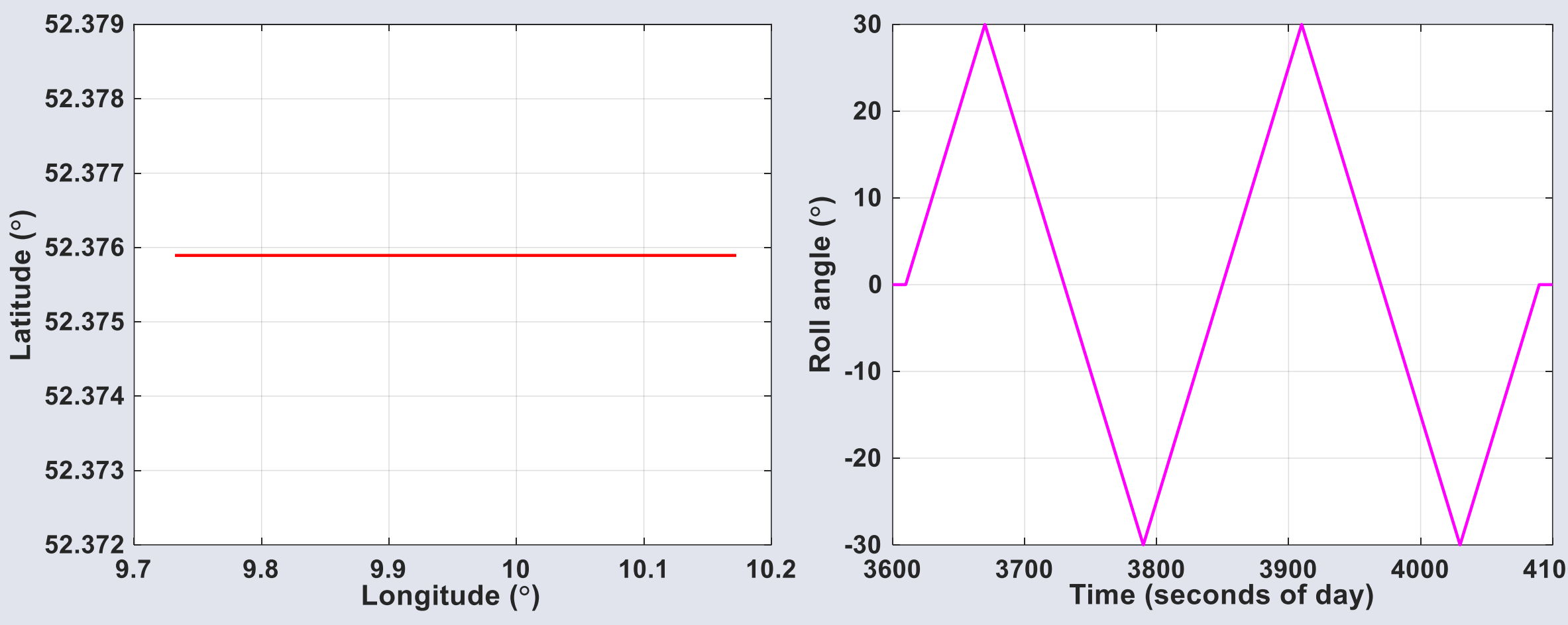

Fig. 5: Reference trajectory 3 snapshot (left), roll angle of aircraft (right), fixed azimuth and zero pitch

- ❑ Navigation solution computed using a linearized Kalman filter (LKF) with and without (w/o) RCM, processing mode: position-velocity-time (PVT), elevation cut off angle: 10°
- ❑ With RCM: process noise modelled using spectral characteristics of clock (van Dierendonck et al. 1984); w/o RCM: process noise modelled as random ramp process

Flight Navigation Performance Analyses (code-based)

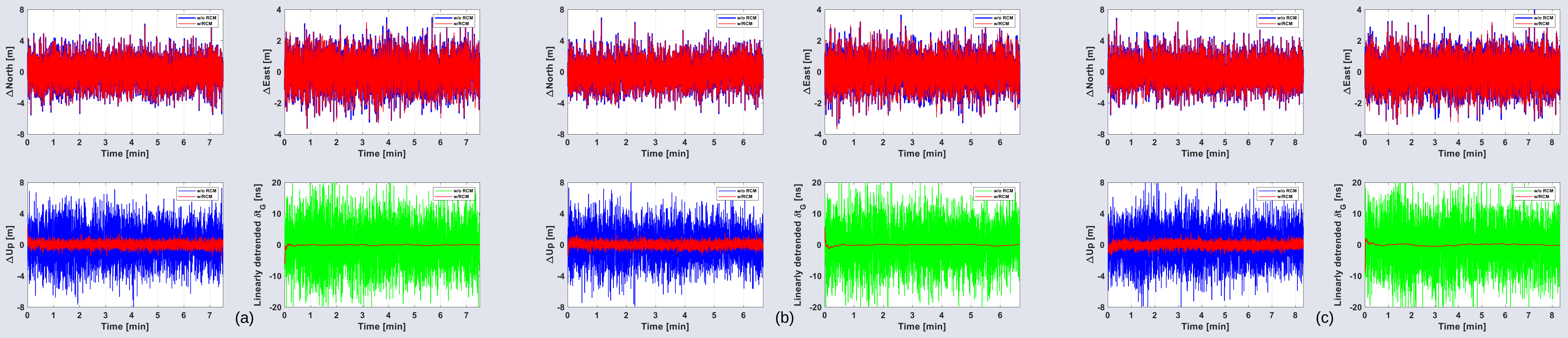

Fig. 6: Topocentric coordinate deviations w.r.t. reference trajectories & clock errors after straight line fit. Results w/o RCM are depicted in blue and green & with RCM (PRS10) in red

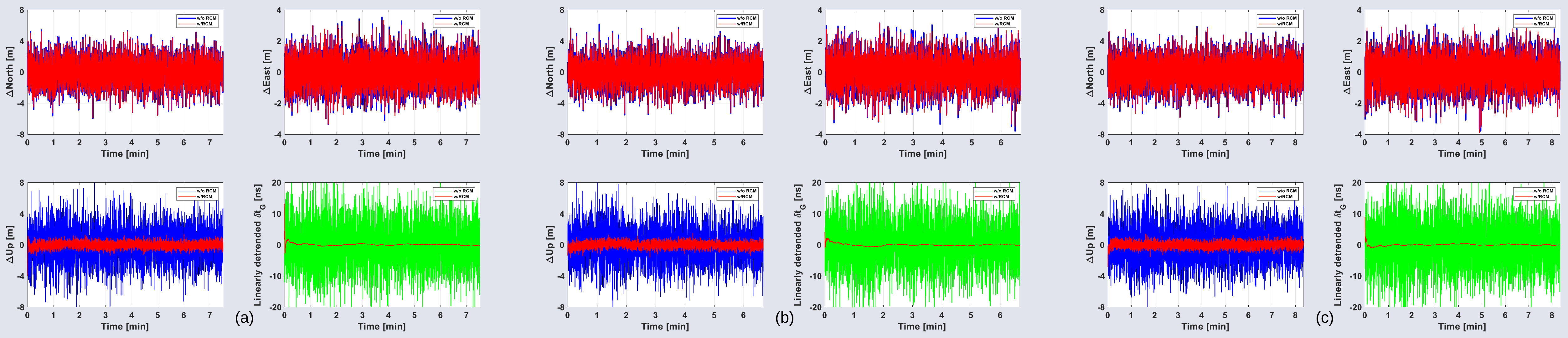

Fig. 7: Topocentric coordinate deviations w.r.t. reference trajectories & clock errors after straight line fit. Results w/o RCM are depicted in blue and green & with RCM (CSAC) in red

Precision and Accuracy

- ❑ GPS L1 C/A-code observation used to compute positions
- ❑ Signals which are blocked due to the flight dynamics are discarded when computing the position estimates.
- ❑ RCM leads to considerable improvement in clock estimates
- ❑ Smaller deviations of the up-coordinates from the reference solution (SRS PRS10: 83% and Microsemi CSAC: 82%)
- ❑ RCM has no effects on horizontal coordinates
- ❑ In a realistic flight scenario, vibrations and others forces acting may degrade the results

Note: (a), (b) and (c) in both Fig. 6 & Fig. 7 represents solutions for reference trajectory snapshot 1, 2 and 3, respectively.

Summary

- ❑ Multiple flight trajectories simulated with different flight dynamics.
- ❑ Precision of up-coordinates enhanced by approximately 80% using both external atomic clocks used in this study.
- ❑ The feasibility of using MACs together with clock modelling in code-based navigation is illustrated.
- ❑ **Future work**: To validate the usage of MACs in code-based flight navigation by conducting a real flight experiment.

References

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Acknowledgement

This work has received funding from the Federal Ministry of Economics and Technology of Germany, following a resolution of the German Bundestag (project no.: 50NA1321)

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Frontiers of Geodetic Science 2019
Stuttgart | 17th – 19th September, 2019

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