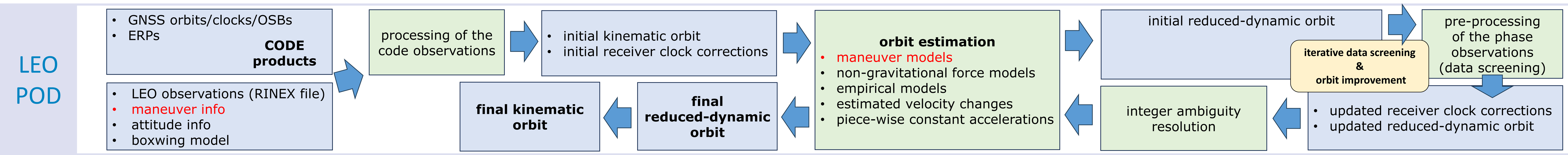
Precise orbit determination for the maneuvering satellites

EGU24-16732
European Geosciences Union
General Assembly 2024
14-19 April, Vienna, Austria

M. Kalarus[1] , D. Arnold[1] , S. Padovan[2] , R. Dach[1] , and A. Jäggi[1]

[1] University of Bern, Astronomical Institute, Bern, Switzerland
[2] European Organisation for the Exploitation of Meteorological Satellites, EUMETSAT



Introduction

Routine and occasional/emergency orbital maneuvers are essential for many satellites to maintain their optimal trajectory and to achieve a wide range of operational objectives in a continuous way. However, incorrectly modelled highly dynamic changes of the orbit during maneuvers can significantly reduce the accuracy of precise orbit determination (POD) to an extent that is unacceptable for scientific requirements. The aim of this study is to investigate strategies for maneuver handling of Low Earth Orbiting (LEO) satellites based on observations from on-board GNSS receivers complemented by a priori knowledge of thrust intensity and maneuver epochs that are provided by telemetry data.

Assuming that the initial information is subject to instrumental biases, corrections for the maneuver accelerations are estimated together with nominal deterministic and pseudo-stochastic orbit parameters such as instantaneous velocity changes and piecewise constant accelerations.

Several estimation strategies are tested using recent developments in the Bernese GNSS Software, which is continuously maintained and further developed at the Astronomical Institute of the University of Bern (AIUB). In particular, the test cases cover single long/short maneuvers as well as consecutive maneuvers within one orbital arc.

Maneuver modelling in the Bernese GNSS Software

Depending on the length of the maneuver and the number of observations, available, different polynomial functions (up to degree 2) can be used to model the thrust acceleration. Some additional pseudo-stochastic parameters (e.g. estimated velocity changes) can also be set at the beginning, at the end or during the manoeuvre to account for unexpected thrust variations, incorrect satellite attitude or incorrect information about the maneuver start/end epoch.
Among many possible configurations, the following two (see Figure 1) were tested in this study to maintain a reasonable balance between the number of available observations, the number of estimated parameters and the quality of the estimated orbit.

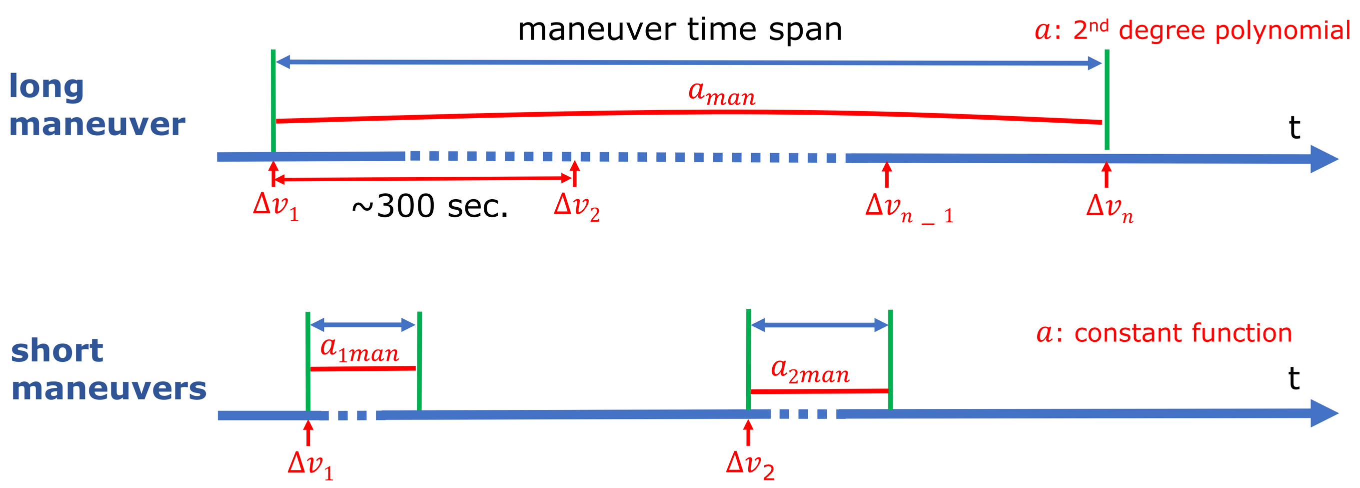


Figure 1. Modelling of the long and short maneuvers

Application to Sentinel-3A

In 2023, the Sentinel-3A satellite performed 18 short and 3 long maneuvers, implying that for 20 days (see the double maneuver on day 211) good quality dynamic orbit could not be provided without explicit maneuver handling.
Maneuver-related parameters must be directly introduced into the equation of motion, which is numerically integrated to get the continuous reduced-dynamic solution.

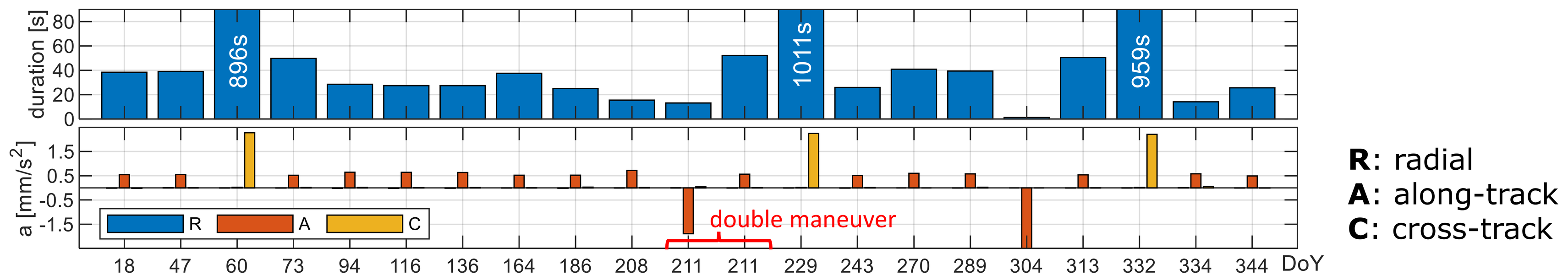


Figure 3. Maneuvers performed by Sentinel 3A satellite in 2023 (duration and acceleration)

Internal assessment of Sentinel-3A orbits

The quality of the solution (orbit modelling with explicit maneuver handling) was evaluated internally by comparing it to the days without maneuvers and by checking the consistency between the reduced dynamic and kinematic orbit (which is not directly affected by the orbital dynamics).

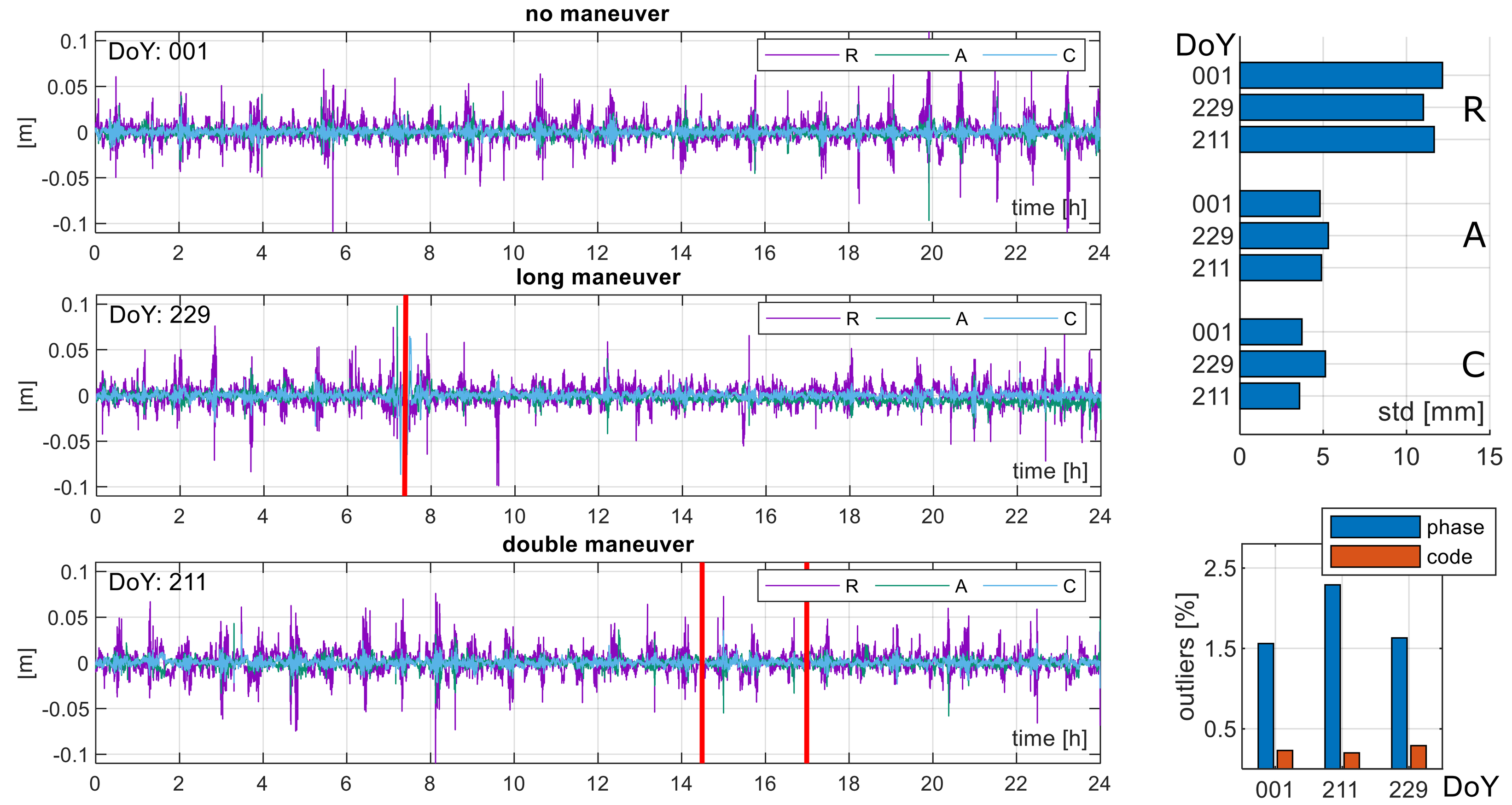


Figure 4. Kinematic vs reduced-dynamic orbit

The standard deviations of the corresponding differences in the radial, along-track and cross-track directions are comparable for days with and without maneuvers.
In general, there is no clear evidence of incorrect modelling, but a closer analysis shows small mismodeling problems leading to more outliers close to the maneuvers. However, as the maneuvers are relatively short this is not seen in the global (calculated for the whole arc) statistics.

Comparison with other products

In general, the AIUB solution for Sentinel-3A is in a good agreement with other products computed in the frame of the Copernicus Quality Working Group. However, comparison during maneuvers is more challenging as some orbits are significantly degraded with local differences of more than 20 meters.

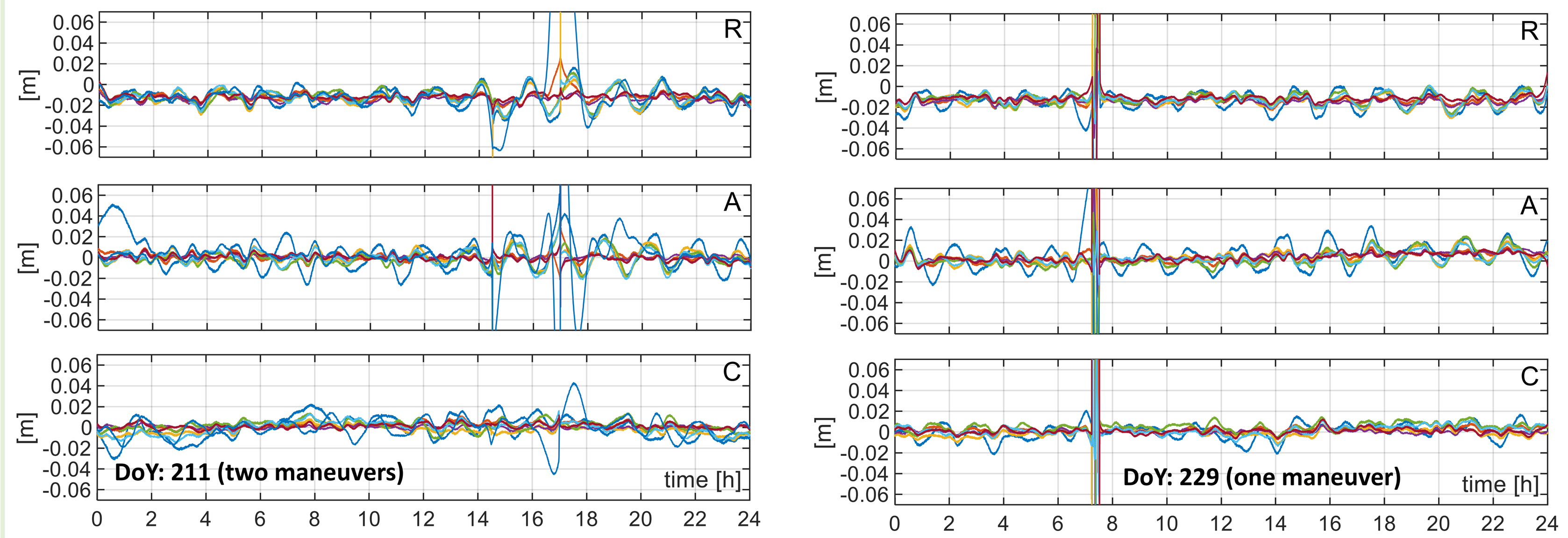


Figure 5. Comparison of AIUB solution with other products (different colors represent different Analysis Centers)

Application to METOP-B

Explicit maneuver handling was tested for a selected challenging day with five consecutive thruster activations performed within less than one hour. In this case a second-degree polynomial function was chosen for acceleration modelling, single velocity change were set at the end of four "short" maneuvers while the "long" maneuver was handled by 3 velocity changes (see Figure 2).
The modelling performance before and after the maneuver series is satisfactory. However, due to the relatively small number of observations (GPS-only data) and several thruster pulses within a short period of time, parameter estimation becomes challenging. During the maneuver the differences (not shown here) between reduced-dynamic orbit and kinematic coordinates reach the order of tens of meters.
In this case there is still room for improvement, but the development of the general setup that automatically covers a variety of different maneuvers (or series of maneuvers) is challenging.

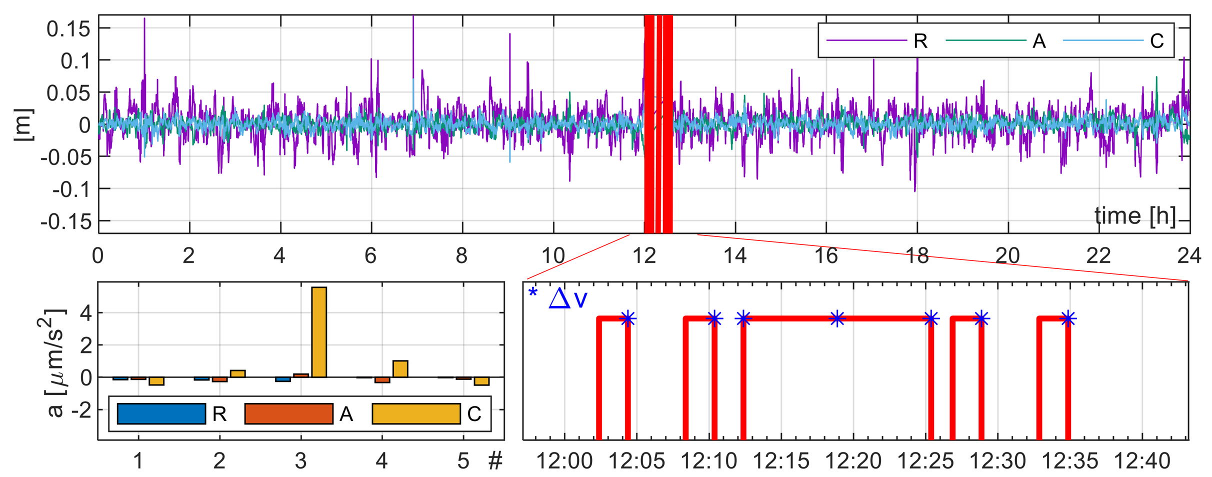


Figure 2. Kinematic vs reduced-dynamic orbit; maneuver acc. and duration

Conclusions

- Proper modelling of the satellite maneuvers allows the estimated orbit to be used for scientific purposes, which is particularly important for frequently maneuvering satellites.
- The quality of the solution with maneuver modelling is the same as for the days without maneuvers.
- The maneuver acceleration can be estimated without a priori knowledge of the thrust intensity. However, the maneuver start/end epoch must be provided.
- Maneuver modelling requires GNSS observations of good quality. Too many screened or missing observations can lead to estimation problems as relatively more parameters are estimated during the maneuver.
- Automatic adjustment and proper constraining for long, short, single and multiple maneuvers are envisaged as further improvement.

Contact address

Maciej Kalarus
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
maciej.kalarus@unibe.ch