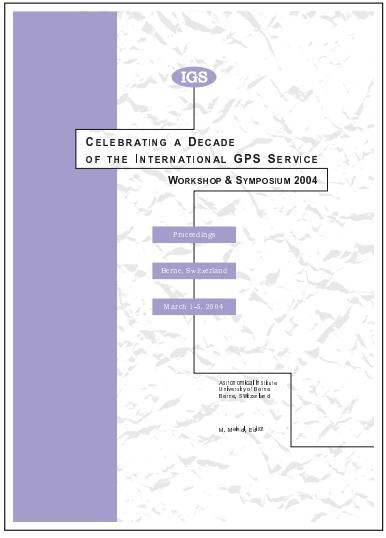
Earth's Center of Mass Handling for GNSS Orbit Determination and PPP

Rolf Dach, Stefan Schaer, Daniel Arnold, Elmar Brockmann,
Maciej Kalarus, Martin Lasser, Pascal Stebler, Adrian Jäggi

Astronomical Institute, University of Bern, Switzerland

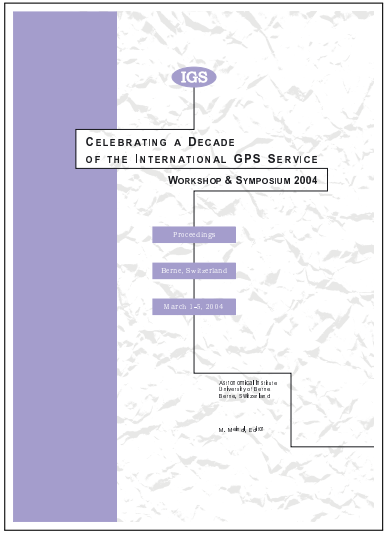
IGS Symposium & Workshop
1–5. July 2024, Bern Switzerland

IGS Workshop 2004



Recommendations:

IGS Workshop 2004



Recommendations:

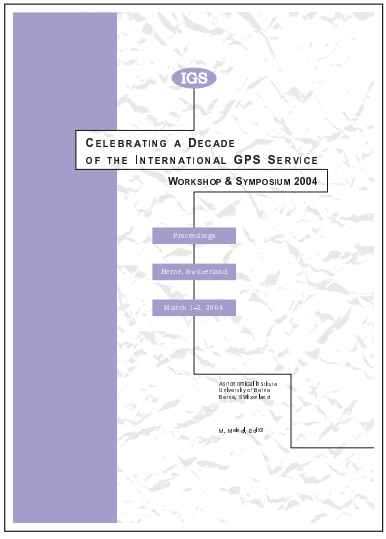
- All IGS satellite clocks should be in ITRF center of network. . . .

  extract from Recommendation 2.10 – IGS Reference Frame Maintenance

- The PPP realization of ITRF using IGS products . . .

  extract from Recommendation 2.11 – IGS Reference Frame Maintenance

IGS Workshop 2004



Recommendations:

- All IGS satellite clocks should be in ITRF center of network. . . .

  extract from Recommendation 2.10 – IGS Reference Frame Maintenance

- The PPP realization of ITRF using IGS products . . .

  extract from Recommendation 2.11 – IGS Reference Frame Maintenance

- *Handling of geocenter motion:*
  $GCRF = P \cdot N \cdot R \cdot W \cdot (ITRF + O(t)) \ldots$
  $O(t)$: "instantaneous" geocenter offset vector

  extract from Recommendation 3.5 – Other Reference Issues

The clear theory

Something unexpected

Explanation for the surprise

Discussion

Illustration of the problem

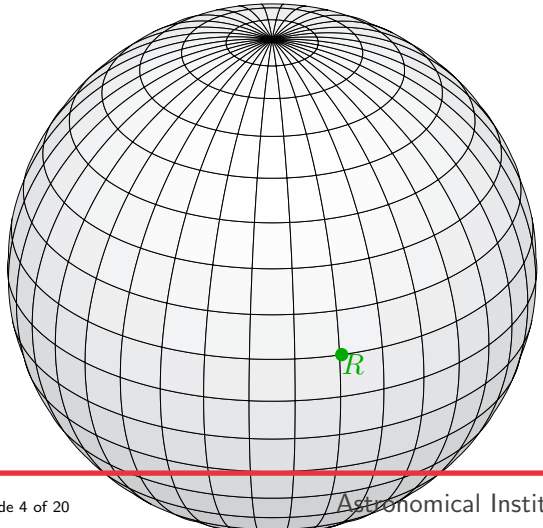


Illustration of the problem

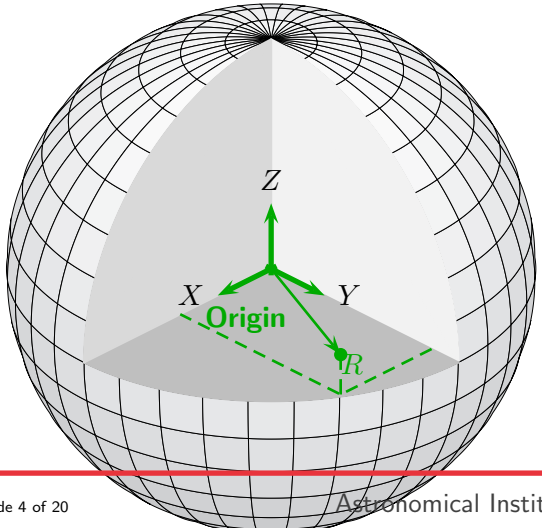


Illustration of the problem

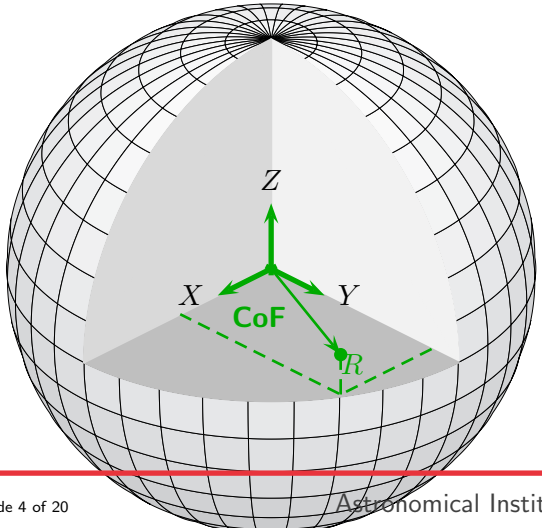


Illustration of the problem

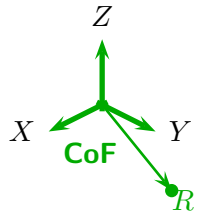


Illustration of the problem

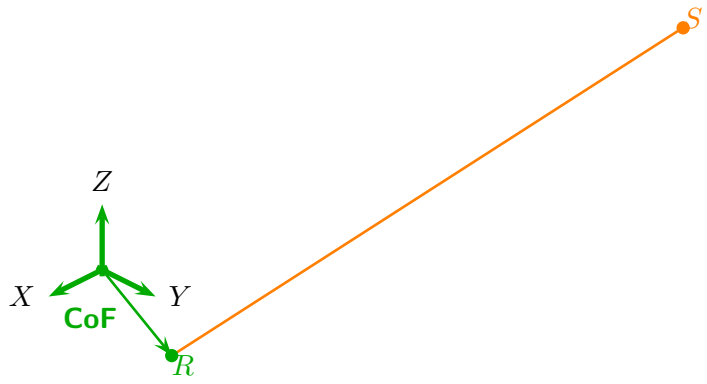


Illustration of the problem

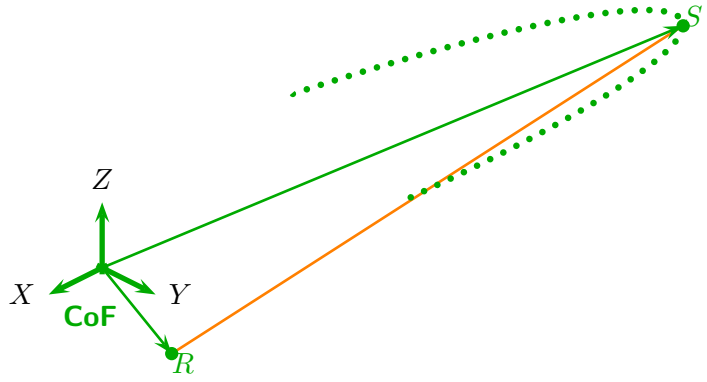


Illustration of the problem

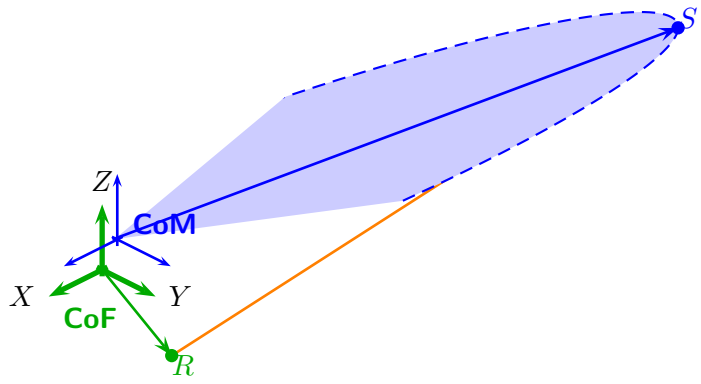
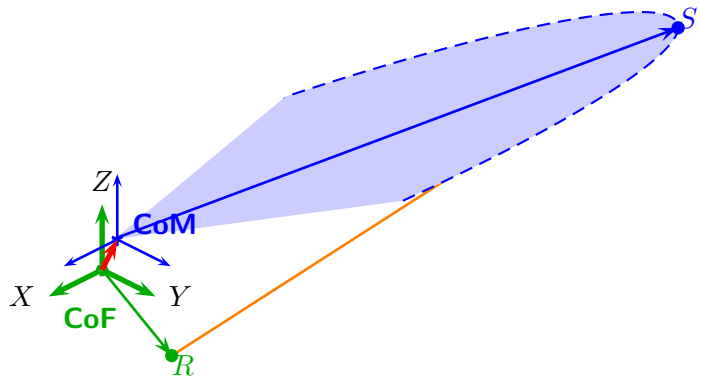


Illustration of the problem



Which reference frames are needed for which purpose?

GNSS station: ITRF (CF-based)

- Earth fixed system with stable origin in time

Satellite positions (for interpolation): ITRF (CF-based)

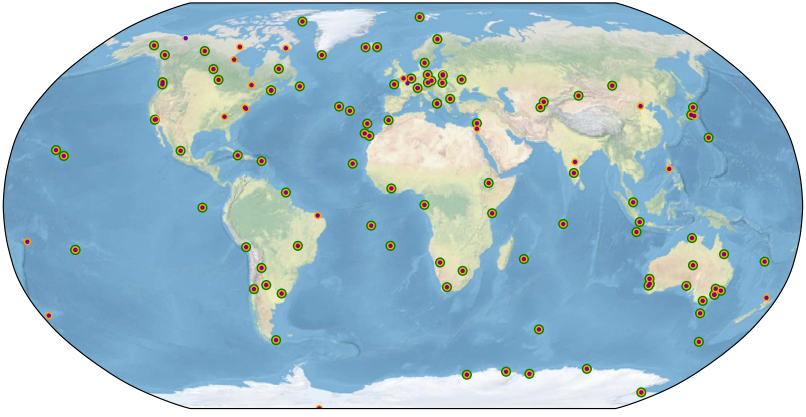
- the same frame as the GNSS stations (for user's convenience)
- realized today in the SP3 orbit product files

Satellite orbits (for orbit modelling): GCRF (CM-based)

- Earth centered system that does not participate in the Earth rotation
- instantaneous center of mass as the origin

We just need a well established ITRF;
GCRF is only needed temporally during the data analysis.

The experiment setup



Network of 120 IGS stations as used by CODE rapid solution.

The experiment setup

Following the CODE processing scheme for the IGS rapid solution:

The experiment setup

Following the CODE processing scheme for the IGS rapid solution:

- one-day orbit solution
  - day 179 to 190 of year 2023
  - ambiguities resolved

The experiment setup

Following the CODE processing scheme for the IGS rapid solution:

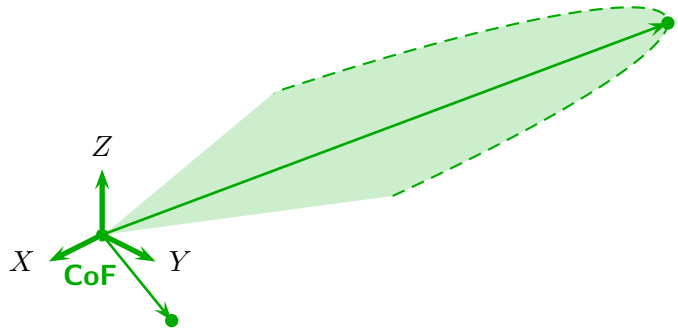
- one-day orbit solution
  - day 179 to 190 of year 2023
  - ambiguities resolved
- three one-day solutions are connected to a long-arc solution
  - day 180 to 189 of year 2023
  - extraction of the middle day
  - datum definition: NNR+NNT condition on a verified set of stations in IGS20 frame

The experiment setup

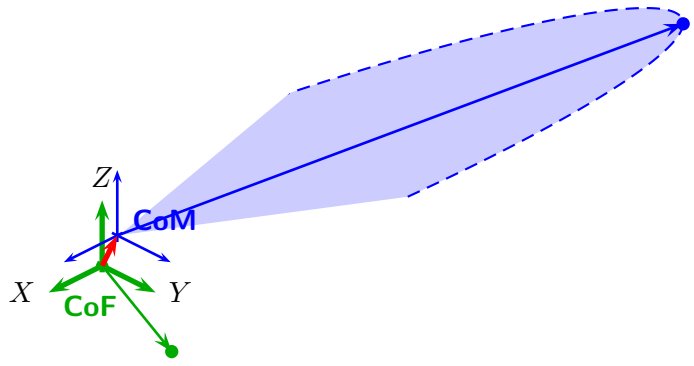
Following the CODE processing scheme for the IGS rapid solution:

- one-day orbit solution
  - day 179 to 190 of year 2023
  - ambiguities resolved
- three one-day solutions are connected to a long-arc solution
  - day 180 to 189 of year 2023
  - extraction of the middle day
  - datum definition: NNR+NNT condition on a verified set of stations in IGS20 frame
- back substitution of the receiver and satellite clock parameter
  - day 180 to 189 of year 2023
  - geometry from the three-day long-arc solution is introduced

The experiment setup: Solution CoF



The experiment setup: Solution CoM



Comparing the CoF- and CoM-based solutions

Station coordinates (in IGS20 frame):

- no significant transformation parameters
- agreement: RMS of differences (without transformation parameters) $< 0.5\,\mathrm{mm}$

Comparing the CoF- and CoM-based solutions

Station coordinates (in IGS20 frame):

- no significant transformation parameters
- agreement: RMS of differences (without transformation parameters) $< 0.5\,\mathrm{mm}$

Satellite positions (in IGS20 frame):

- no significant transformation parameters
- agreement: RMS of differences (without transformation parameters) $< 1\,\mathrm{mm}$
- exception for satellites with repositioning event or short observed interval

Comparing the CoF- and CoM-based solutions

Station coordinates (in IGS20 frame):

- no significant transformation parameters
- agreement: RMS of differences (without transformation parameters) $< 0.5\,\mathrm{mm}$

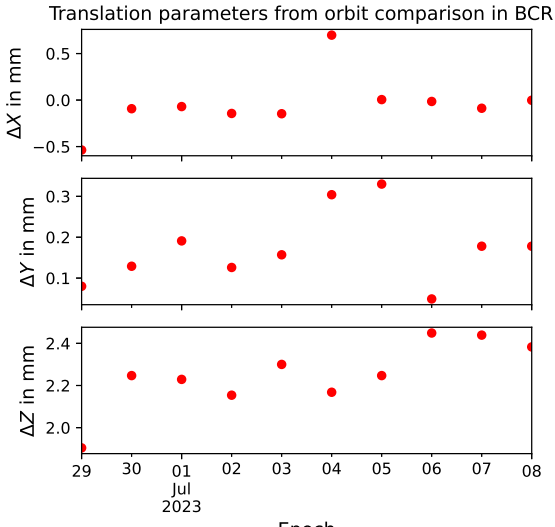
Satellite positions (in IGS20 frame):

- no significant transformation parameters
- agreement: RMS of differences (without transformation parameters) $< 1\,\mathrm{mm}$
- exception for satellites with repositioning event or short observed interval

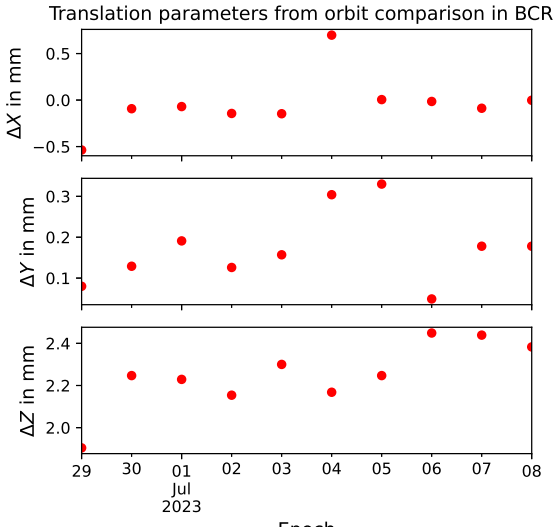
Satellite positions (in GCRF incl. geocenter vector):

- agreement: RMS of differences (with transformation parameters) $\approx 5 \ldots 7\,\mathrm{mm}$

Comparing the CoF- and CoM-based solutions



Comparing the CoF- and CoM-based solutions



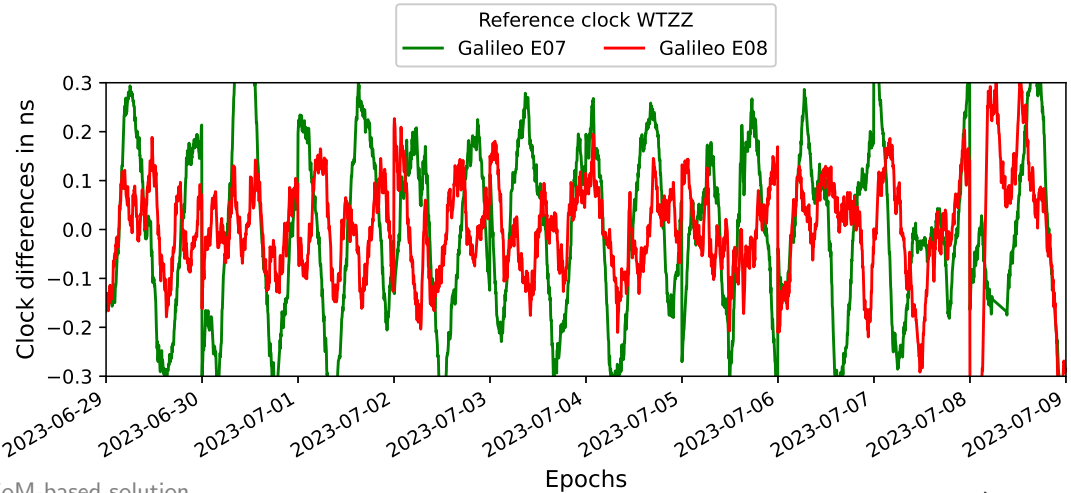
Geocenter correction applied:

- X-component: $0.5\,\mathrm{mm}$
- Y-component: $3.2\,\mathrm{mm}$
- Z-component: $3.2\,\mathrm{mm}$

Geocenter motion model from ITRF2020

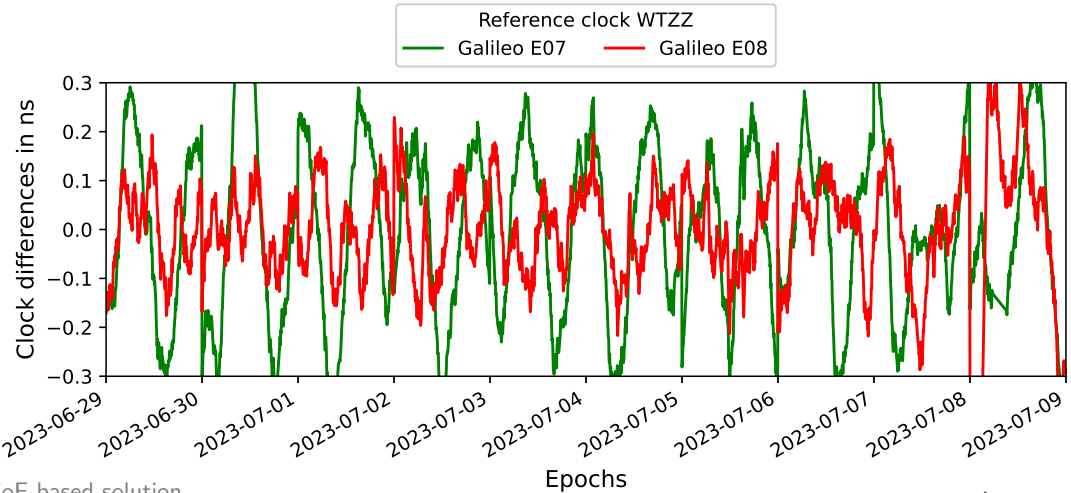
`https://itrf.ign.fr/ftp/pub/itrf/itrf2020/...`
`ITRF2020-geocenter-motion.dat`

Comparing the obtained satellite clock corrections



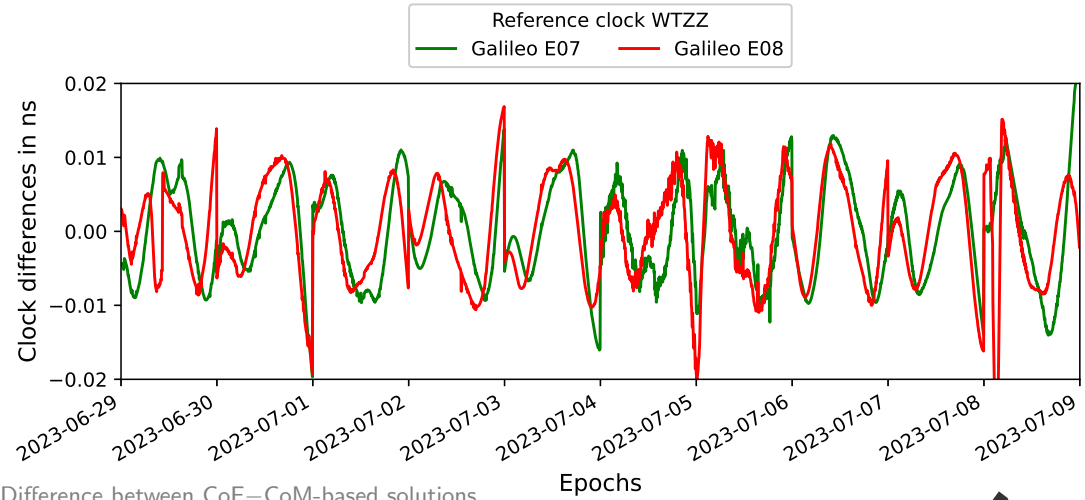
CoM-based solution

Comparing the obtained satellite clock corrections



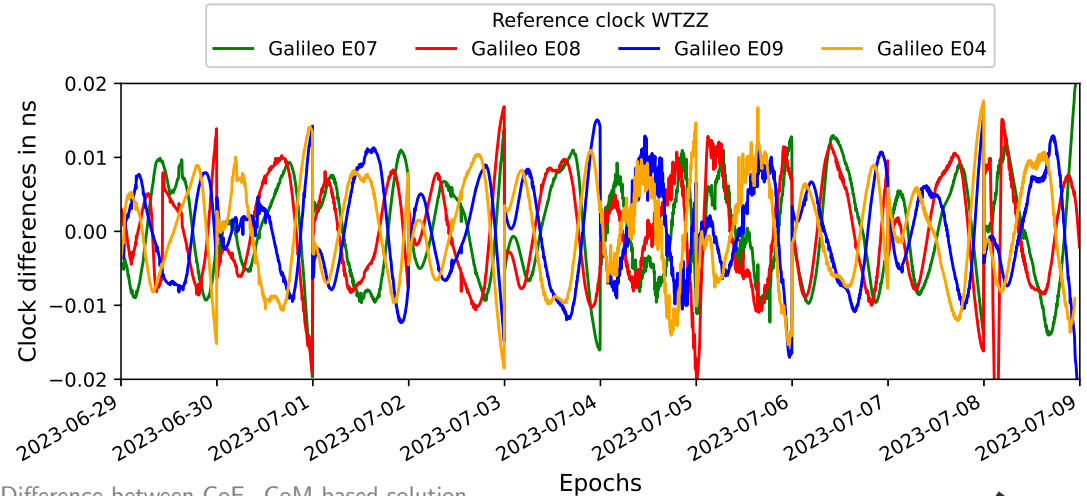
CoF-based solution

Comparing the obtained satellite clock corrections



Difference between CoF−CoM-based solutions

Comparing the obtained satellite clock corrections



Difference between CoF−CoM-based solution

Satellite clock corrections do absorb the Geocenter correction

From the satellite clock differences
the related geocenter vector is extracted:

- X-component: $0.7\,\mathrm{mm}$
- Y-component: $3.5\,\mathrm{mm}$
- Z-component: $2.6\,\mathrm{mm}$

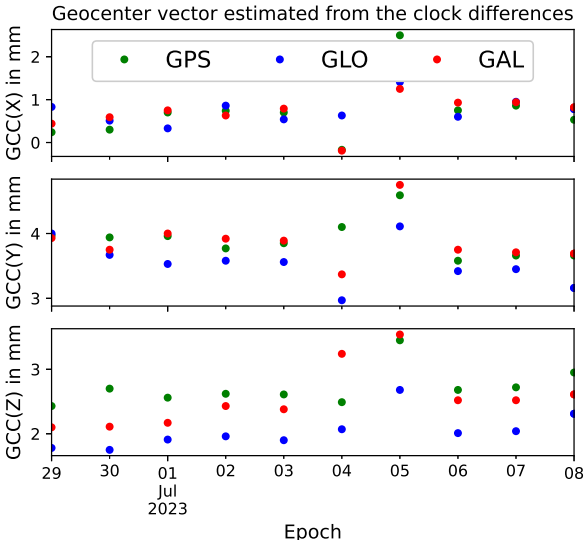
Geocenter correction applied:

- X-component: $0.5\,\mathrm{mm}$
- Y-component: $3.2\,\mathrm{mm}$
- Z-component: $3.2\,\mathrm{mm}$

Geocenter motion model from ITRF2020

`https://itrf.ign.fr/ftp/pub/itrf/itrf2020/...`
`ITRF2020-geocenter-motion.dat`

Satellite clock corrections do absorb the Geocenter correction



Geocenter correction applied:

- X-component: $0.5\,\mathrm{mm}$
- Y-component: $3.2\,\mathrm{mm}$
- Z-component: $3.2\,\mathrm{mm}$

Geocenter motion model from ITRF2020

https://itrf.ign.fr/ftp/pub/itrf/itrf2020/...
ITRF2020-geocenter-motion.dat

How to bring the GNSS orbits into the CoF?

- Any translation vector is absorbed in the satellite clocks.
- The GNSS satellites “know” where the Center of Mass is.

How to bring the GNSS orbits into the CoF?

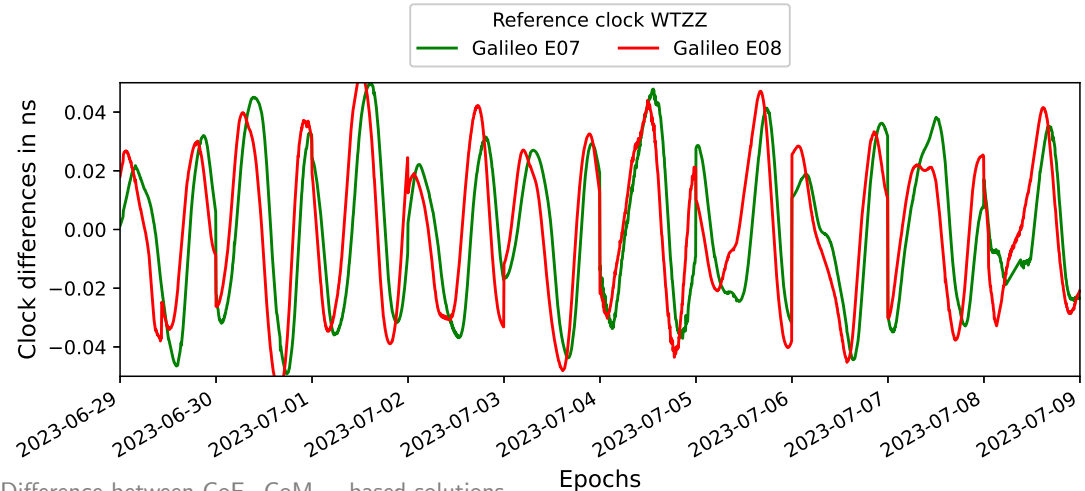
- Any translation vector is absorbed in the satellite clocks.
- The GNSS satellites “know” where the Center of Mass is.
- Adding a translation vector to the solution should give access to the geocenter as realized by the GNSS-satellite orbits.

How to bring the GNSS orbits into the CoF?

- Any translation vector is absorbed in the satellite clocks.
- The GNSS satellites "know" where the Center of Mass is.
- Adding a translation vector to the solution should give access to the geocenter as realized by the GNSS-satellite orbits.

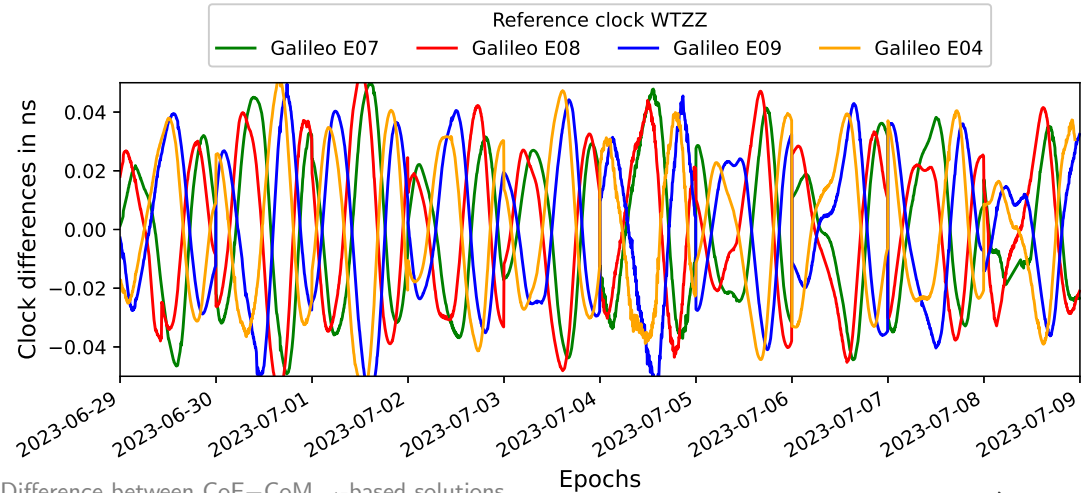
The procedure was repeated a third time with estimated translation vector instead of introducing the ITRF2000-based geocenter corrections.

How to bring the GNSS orbits into the CoF?



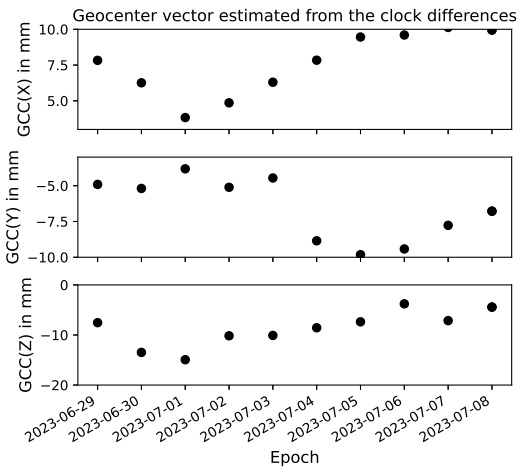
Difference between CoF−CoM$_{est}$-based solutions

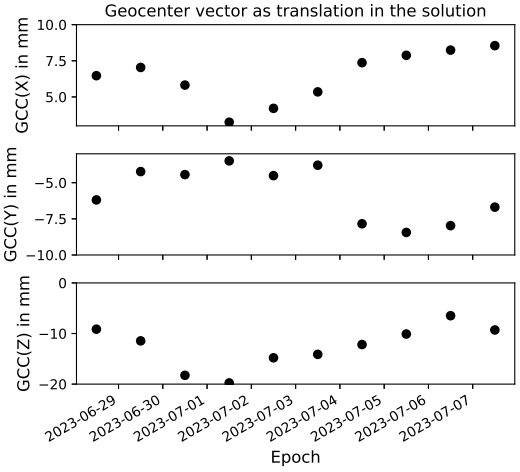
How to bring the GNSS orbits into the CoF?



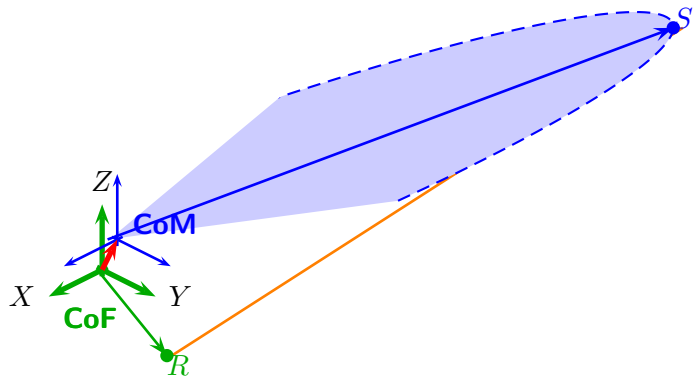
Difference between CoF−CoM$_{est}$-based solutions

How to bring the GNSS orbits into the CoF?

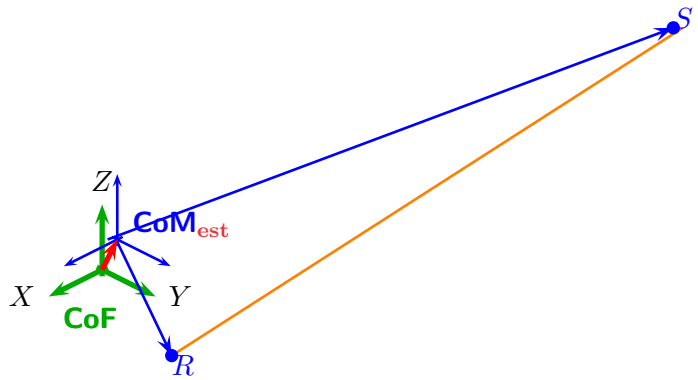




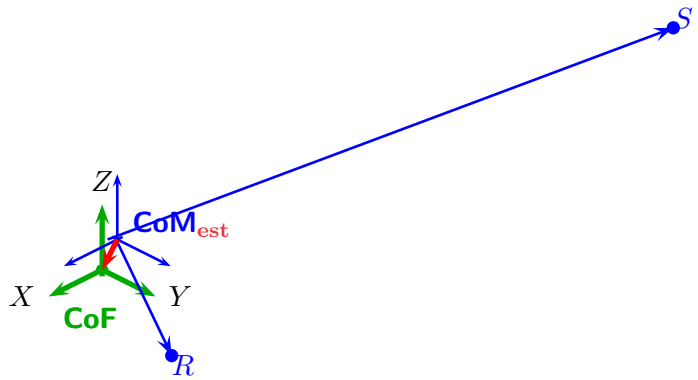
How to bring the GNSS orbits into the CoF?



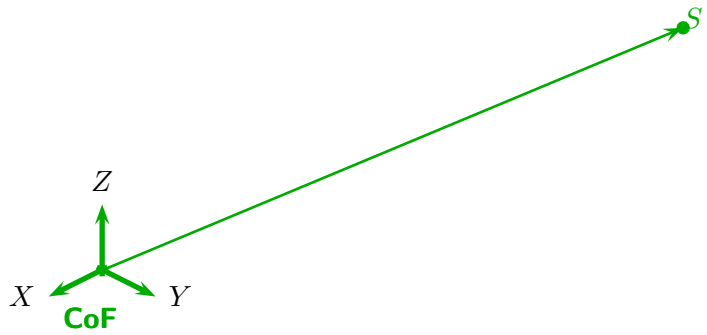
How to bring the GNSS orbits into the CoF?



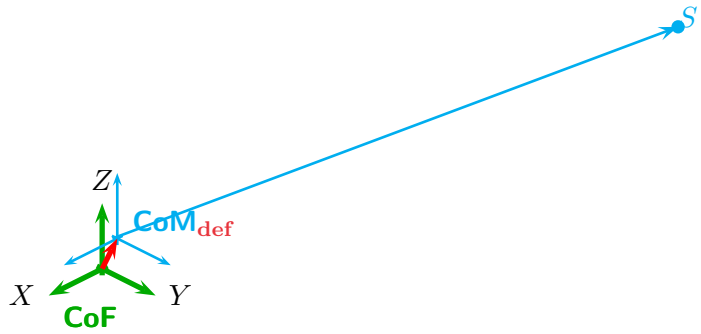
How to bring the GNSS orbits into the CoF?



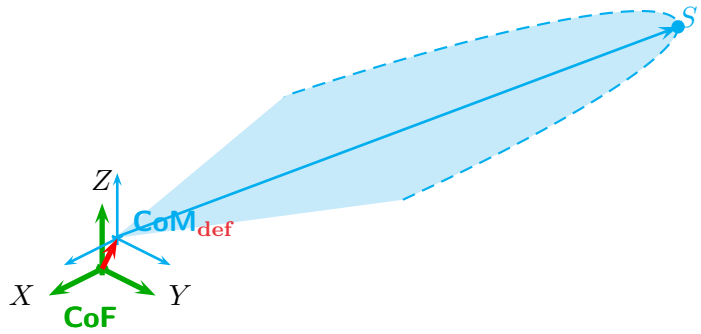
How to bring the GNSS orbits into the CoF?



How to bring the GNSS orbits into the CoF?



How to bring the GNSS orbits into the CoF?



How to bring the GNSS orbits into the CoF?

Going back the applied procedure:

- ...
- three one-day solutions are connected to a long-arc solution
- back substitution of the receiver and satellite clock parameter

How to bring the GNSS orbits into the CoF?

Going back the applied procedure:

- ...
- three one-day solutions are connected to a long-arc solution
- Satellite positions are w.r.t. $\mathrm{COM}_{\mathrm{est}}$
- back substitution of the receiver and satellite clock parameter

How to bring the GNSS orbits into the CoF?

Going back the applied procedure:

- ...
- three one-day solutions are connected to a long-arc solution
- Satellite positions are w.r.t. $\mathrm{COM}_{\mathrm{est}}$

  Remove the estimated geocenter vector
- Satellite positions are w.r.t. COF

- back substitution of the receiver and satellite clock parameter

How to bring the GNSS orbits into the CoF?

Going back the applied procedure:

- ...
- three one-day solutions are connected to a long-arc solution
- Satellite positions are w.r.t. $\mathrm{COM}_{\mathrm{est}}$

  Remove the estimated geocenter vector
- Satellite positions are w.r.t. COF

  Adding a well defined geocenter vector
- Satellite positions are w.r.t. $\mathrm{COM}_{\mathrm{def}}$
- back substitution of the receiver and satellite clock parameter

How to bring the GNSS orbits into the CoF?

Going back the applied procedure:

- ...
- three one-day solutions are connected to a long-arc solution
- Satellite positions are w.r.t. $\mathrm{COM}_{\mathrm{est}}$

  Remove the estimated geocenter vector

  } differences: $1 \ldots 5\,\mathrm{mm}$
- Satellite positions are w.r.t. COF

  Adding a well defined geocenter vector

  } differences: $1 \ldots 2\,\mathrm{mm}$
- Satellite positions are w.r.t. $\mathrm{COM}_{\mathrm{def}}$
- back substitution of the receiver and satellite clock parameter

What about LEOs?

- For LEOs, the geocenter vector cannot be absorbed by the satellite clocks.
- They have to be modelled w.r.t. the CoM.

What about LEOs?

- For LEOs, the geocenter vector cannot be absorbed by the satellite clocks.
- They have to be modelled w.r.t. the CoM.
- Applying the same geocenter vector for GNSS and LEO orbits, solves the issue: all satellites – in particular the LEO – are flying around the CoM.

Conclusions

- If a center of mass correction for the Geocenter vector introduced in the GNSS orbit determination it is completely absorbed by the co-estimated satellite clock corrections.

Conclusions

- If a center of mass correction for the Geocenter vector introduced in the GNSS orbit determination it is completely absorbed by the co-estimated satellite clock corrections.
- The orbits realize a center of mass system in the GCRF independent from introduced vector.

Conclusions

- If a center of mass correction for the Geocenter vector introduced in the GNSS orbit determination it is completely absorbed by the co-estimated satellite clock corrections.
- The orbits realize a center of mass system in the GCRF independent from introduced vector.
- For PPP one has to be careful regarding the consistency.

Conclusions

- If a center of mass correction for the Geocenter vector introduced in the GNSS orbit determination it is completely absorbed by the co-estimated satellite clock corrections.
- The orbits realize a center of mass system in the GCRF independent from introduced vector. GCRF is just a temporary frame realized during the data processing.
- For PPP one has to be careful regarding the consistency.
- Any PPP solution has to end up in the ITRF (CF-based frame).

Conclusions

- If a center of mass correction for the Geocenter vector introduced in the GNSS orbit determination it is completely absorbed by the co-estimated satellite clock corrections.
- The orbits realize a center of mass system in the GCRF independent from introduced vector. GCRF is just a temporary frame realized during the data processing.
- For PPP one has to be careful regarding the consistency.
- Any PPP solution has to end up in the ITRF (CF-based frame).
- There exist alternatives for specific applications, like LEO-POD.

THANK YOU

for your attention

Publications of the satellite geodesy research group:

http://www.bernese.unibe.ch/publist