Rigorous propagation of Galileo-based terrestrial scale

Susanne Glaser[1], Paul Rebischung[2,3], Zuheir Altamimi[2,3], Harald Schuh[1,4]

[1]GFZ German Research Centre for Geosciences, Potsdam, Germany
[2]Université de Paris, Institut de physique du globe de Paris, CNRS, IGN, Paris, France
[3]ENSG-Géomatique, IGN, Marne-la-Vallée, France
[4]Technische Universität Berlin, Chair of Satellite Geodesy, Berlin, Germany

Tour de l'IGS

Technical Mini-Workshop Series

June 02, 2021

Outline

Outline

Rigorous propagation of Galileo-based terrestrial scale – Background

Scale of previous ITRF solutions

- So far available GNSS satellite phase center offsets (PCOs) estimated with fixed ITRF scale, and depend conventionally on SLR and VLBI scale

Rigorous propagation of Galileo-based terrestrial scale – Background

Scale of previous ITRF solutions

- So far available GNSS satellite phase center offsets (PCOs) estimated with fixed ITRF scale, and depend conventionally on SLR and VLBI scale

→ No independent scale realization possible by GNSS

Rigorous propagation of Galileo-based terrestrial scale – Background

Scale of previous ITRF solutions

- So far available GNSS satellite phase center offsets (PCOs) estimated with fixed ITRF scale, and depend conventionally on SLR and VLBI scale

→ No independent scale realization possible by GNSS

Unique opportunity

- European GNSS Agency disclosed metadata including z-PCOs for Galileo satellites

→ Realize independent scale in multi-GNSS solutions and possibly contribute to ITRF2020 scale

Preliminary work

Shortcoming of igsR3.atx z-PCOs

- A single correction to all igs14.atx GPS z-PCOs was estimated (same for GLONASS) based on preliminary multi-GNSS solutions for the period 2017-2018.
- Like in all other ANTEX files, satellite z-PCOs are constant (except for R730 & R737), with no uncertainties available.

Preliminary work

Shortcoming of igsR3.atx z-PCOs

- A single correction to all igs14.atx GPS z-PCOs was estimated (same for GLONASS) based on preliminary multi-GNSS solutions for the period 2017-2018.
- Like in all other ANTEX files, satellite z-PCOs are constant (except for R730 & R737), with no uncertainties available.

$\rightarrow$ No constraining with appropriate weighting possible (satellite z-PCOs fixed in repro3 solutions).

Rigorous propagation of Galileo-based terrestrial scale

New approach in this study

Rigorous propagation of Galileo-based terrestrial scale

New approach in this study

- Fit deterministic and stochastic model to time series of GPS/GLONASS z-PCO estimates of repro3 AC solutions
- Derive piecewise linear models of z-PCOs

Rigorous propagation of Galileo-based terrestrial scale

New approach in this study

- Fit deterministic and stochastic model to time series of GPS/GLONASS z-PCO estimates of repro3 AC solutions
- Derive piecewise linear models of z-PCOs

→ Introduce time-variable z-PCOs with realistic uncertainties for scale estimation

Outline

Data

IGS repro3 SINEX solutions of four ACs

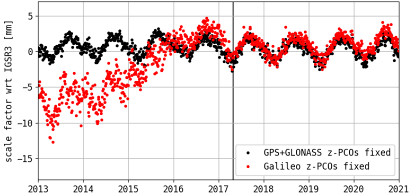
- CODE (Center for Orbit Determination in Europe): 1994-01-02 to 2019-12-31
  - From 2002-01-01 GLONASS; From 2013-01-01 Galileo
- ESA (European Space Agency): 1995-01-01 to 2020-12-31
  - From 2009-01-01 GLONASS; From 2015-01-01 Galileo
- GFZ (GeoForschungsZentrum): 1994-01-02 to 2020-12-31
  - From 2012-01-01 GLONASS; From 2013-12-21 Galileo
- GRGS (Groupe de Recherche en Géodésie Spatiale): 2000-05-03 to 2020-12-31
  - From 2008-11-04 GLONASS; From 2016-12-31 Galileo

[IGSMAIL-8026]

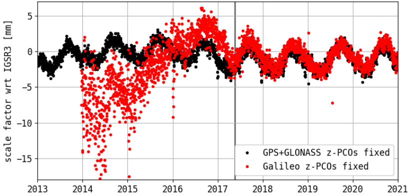
Preliminary step: When does Galileo-based scale become precise and stable enough?

Preliminary step: When does Galileo-based scale become precise and stable enough?

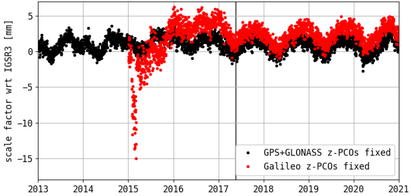
CODE



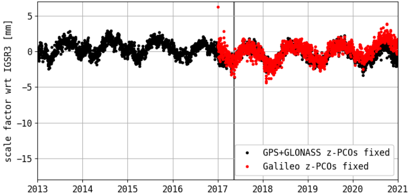
GFZ



ESA

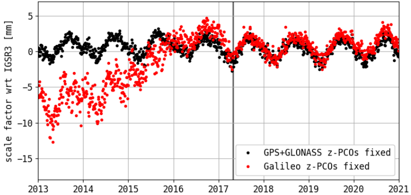


GRGS

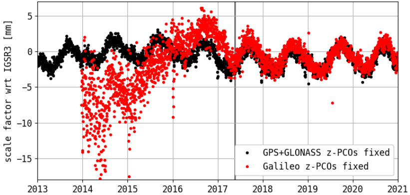


Preliminary step: When does Galileo-based scale become precise and stable enough?

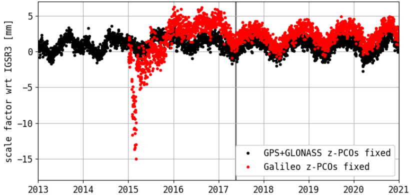
CODE



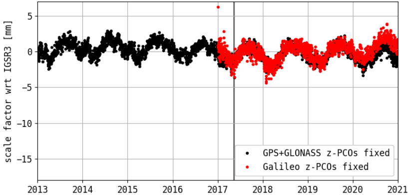
GFZ



ESA



GRGS



→ Steady level after May 2017 when at least 17 Galileo satellites are included

z-PCO time series

Determination of time series of GPS+GLONASS satellite z-PCO estimates

z-PCO time series

Determination of time series of GPS+GLONASS satellite z-PCO estimates

- After May 2017
  - Fix Galileo satellite z-PCOs (except for E102)
- Before May 2017
  - "no-net-translation" constraints of selected GPS and GLONASS satellite z-PCOs w. r. t. igsR3.atx

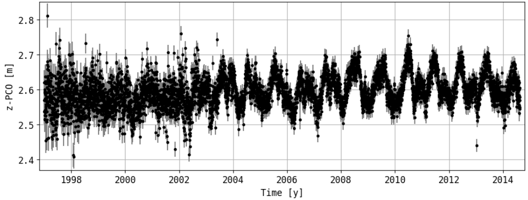
z-PCO time series

Determination of time series of GPS+GLONASS satellite z-PCO estimates

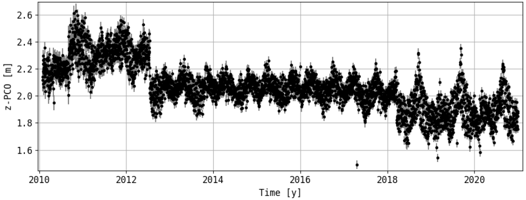
- After May 2017
  - Fix Galileo satellite z-PCOs (except for E102)
- Before May 2017
  - "no-net-translation" constraints of selected GPS and GLONASS satellite z-PCOs w. r. t. igsR3.atx
- Initial screening procedure: elimination of data before 1997, data with large formal errors, short time spans

Time series plots of individual satellites – Examples ESA AC

G033



R730



→ Diverse features: periodicities, offsets, outliers, slow non-linear variations

Fit deterministic and stochastic models to all z-PCOs

Initial model: Single linear trend + variable white noise

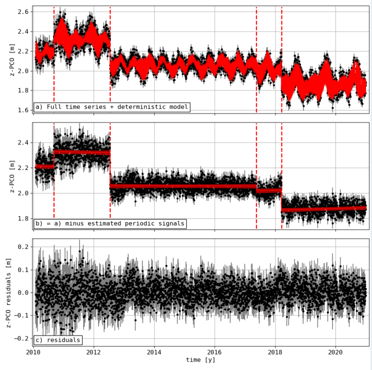
Then: Iterative model refinement by adding more deterministic and noise components

Fit deterministic and stochastic models to all z-PCOs

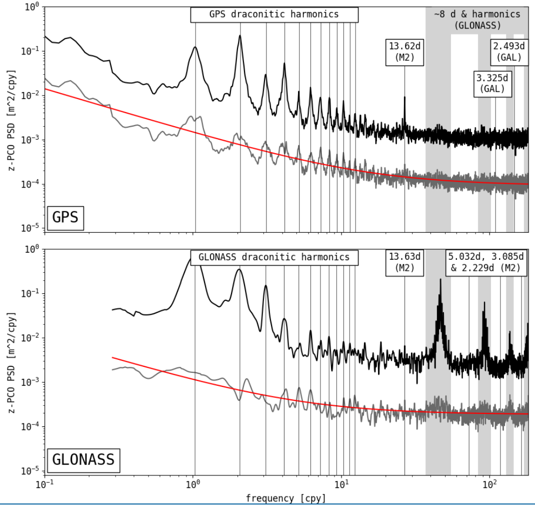
Initial model: Single linear trend + variable white noise

Then: Iterative model refinement by adding more deterministic and noise components

Example ESA AC R730 – Fit after 33 iterations



Model fit – periodogram: GFZ



- grey: average periodograms of residuals from complete deterministic models
- red: white + flicker noise fit
- black: average periodograms of residuals from piecewise linear models

Back-substitution

Back-substitution

Long-term stacking of GPS+GLONASS z-PCO time series

- Estimation of daily “transformation parameter” before May 2017 to remove initial “no-net-translation” constraint and get piecewise linear z-PCO models independent from igsR3.atx, with realistic uncertainties

Back-substitution

Long-term stacking of GPS+GLONASS z-PCO time series

- Estimation of daily "transformation parameter" before May 2017 to remove initial "no-net-translation" constraint and get piecewise linear z-PCO models independent from igsR3.atx, with realistic uncertainties
- New piecewise linear z-PCO models are then back-substituted into the daily AC SINEX solutions, and their scale is compared to that of the IGSR3 reference frame

Back-substitution

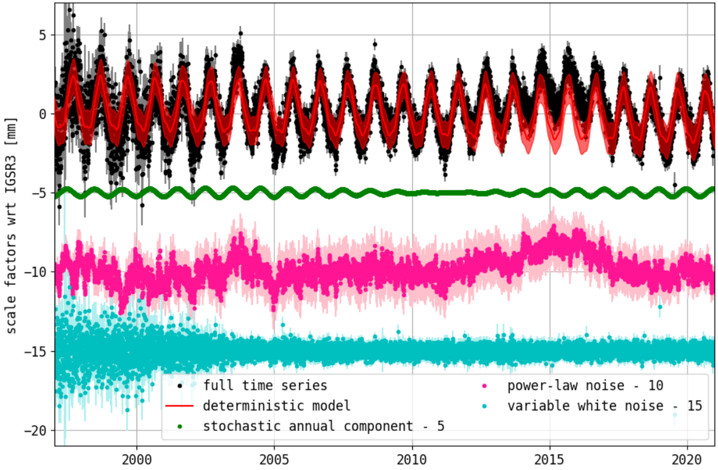
Long-term stacking of GPS+GLONASS z-PCO time series

- Estimation of daily "transformation parameter" before May 2017 to remove initial "no-net-translation" constraint and get piecewise linear z-PCO models independent from igsR3.atx, with realistic uncertainties
- New piecewise linear z-PCO models are then back-substituted into the daily AC SINEX solutions, and their scale is compared to that of the IGSR3 reference frame

→ Result: Galileo-based scale independent of igsR3.atx (and SLR/VLBI)

Outline

Scale fit w. r. t. IGSR3, Example: GFZ



Scale factors w. r. t. IGSR3

IGSR3 reference frame - repro3 solution based on igsR3.atx file

Mean scale offsets at epoch 2010.0 and scale rates w. r. t. IGSR3

AC	scale offset @2010.0 [mm]	scale rate [mm/yr]
cod	-0.1 +/- 0.7	0.04 +/- 0.05
esa	0.8 +/- 0.8	0.06 +/- 0.07
gfz	0.5 +/- 0.9	-0.04 +/- 0.07
grg	-0.1 +/- 0.8	0.01 +/- 0.07

Scale factors w. r. t. ITRF2014

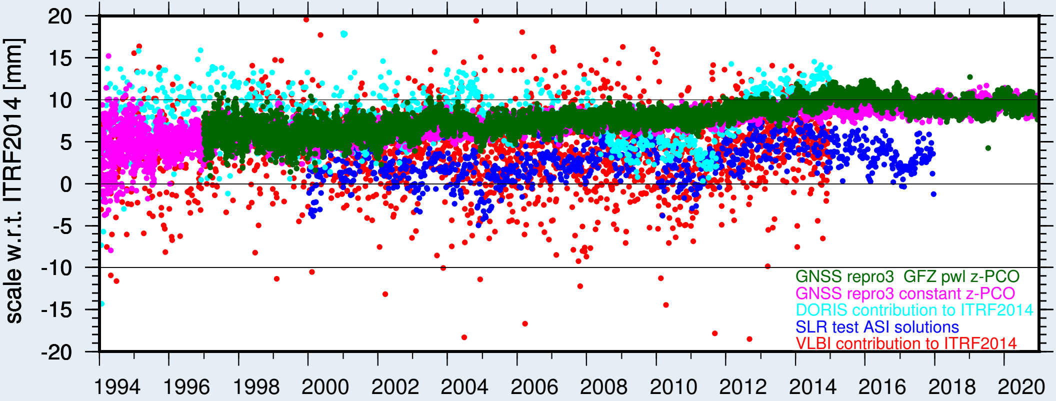
Mean scale offsets at epoch 2010.0 and scale rates w. r. t. ITRF2014

AC	scale offset @2010.0 [mm]	scale rate [mm/yr]
IGS repro 3	7.6 +/- 0.2	0.20 +/- 0.02
cod	7.8 +/- 0.7	0.23 +/- 0.05
esa	8.7 +/- 0.8	0.25 +/- 0.07
gfz	8.4 +/- 0.9	0.15 +/- 0.07
grg	7.8 +/- 0.8	0.20 +/- 0.07

$\rightarrow$ 4 ACs agree within 1 mm for scale offset; 0.1 mm/yr for scale rate

Scale factors w. r. t. ITRF2014

Comparison with the other space geodetic techniques



Outline

Conclusions

Rigorous re-evaluation of all GPS and GLONASS satellite z-PCOs

Conclusions

Rigorous re-evaluation of all GPS and GLONASS satellite z-PCOs

- Piecewise linear models of GPS and GLONASS z-PCOs (vs. igsR3.atx with constant z-PCOs)

Conclusions

Rigorous re-evaluation of all GPS and GLONASS satellite z-PCOs

- Piecewise linear models of GPS and GLONASS z-PCOs (vs. igsR3.atx with constant z-PCOs)
- Back-substitution to repro3 solutions → refined Galileo-based scale:

Conclusions

Rigorous re-evaluation of all GPS and GLONASS satellite z-PCOs

- Piecewise linear models of GPS and GLONASS z-PCOs (vs. igsR3.atx with constant z-PCOs)
- Back-substitution to repro3 solutions → refined Galileo-based scale:
  - Differences to igsR3.atx-based scale are essentially linear
  - 4 ACs (CODE, ESA, GFZ, GRGS) agree within 1 mm for scale offset; 0.1 mm/yr for scale rate w. r. t. ITRF2014
  - Refined AC-specific estimates agree with scale of IGS repro3 solutions within same level

Conclusions

Rigorous re-evaluation of all GPS and GLONASS satellite z-PCOs

- Piecewise linear models of GPS and GLONASS z-PCOs (vs. igsR3.atx with constant z-PCOs)
- Back-substitution to repro3 solutions → refined Galileo-based scale:
  - Differences to igsR3.atx-based scale are essentially linear
  - 4 ACs (CODE, ESA, GFZ, GRGS) agree within 1 mm for scale offset; 0.1 mm/yr for scale rate w. r. t. ITRF2014
  - Refined AC-specific estimates agree with scale of IGS repro3 solutions within same level

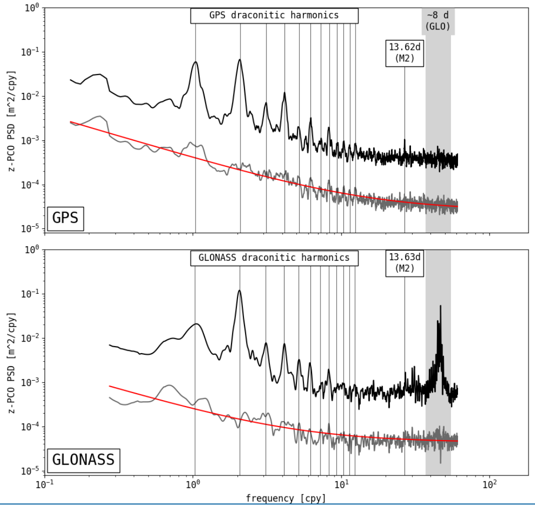
→ Contribution to ITRF2020 scale?

Thank you very much for your attention.

susanne.glaser@gfz-potsdam.de

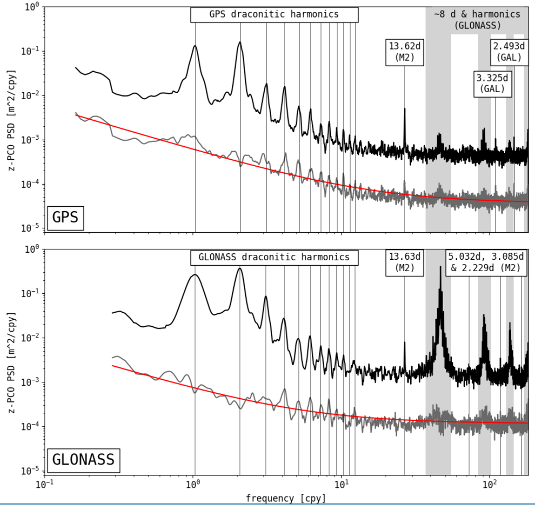
paul.rebischung@ign.fr

Model fit – periodograms: CODE



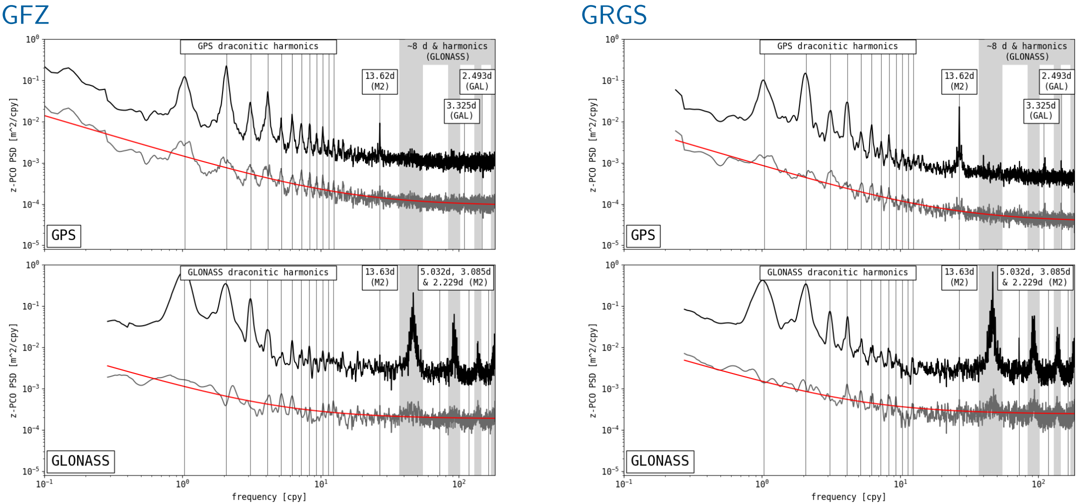
- grey: average periodograms of residuals from complete deterministic models
- red: white + flicker noise fit
- black: average periodograms of residuals from piecewise linear models

Model fit – periodograms: ESA



- black: average periodograms of residuals from piecewise linear models
- grey: average periodograms of residuals from complete deterministic models
- red: white + flicker noise fit

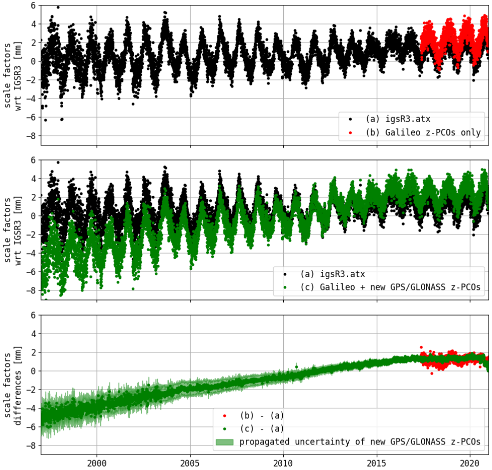
Model fit – periodograms: GFZ, GRGS



Free vs. constrained scale

Free scale

- Unreliable scale trends which differ a lot among ACs
- Reasons:
  - Remaining trends in z-PCOs?
  - 3.6 yr Galileo too short for 20 yr time span?

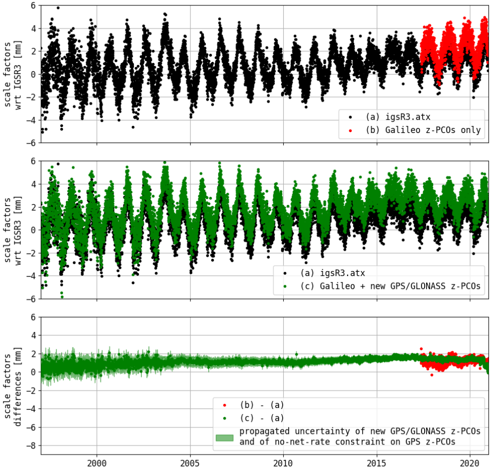


Example: ESA

Free vs. constrained scale

Constrained scale

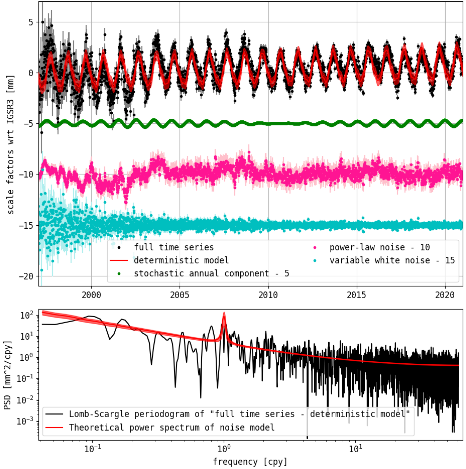
- Additional assumption: no-net-rate constraint over selected subset of GPS z-PCOs
- Shortcoming? In case of actual non-zero average trend → propagation of these trends into scale



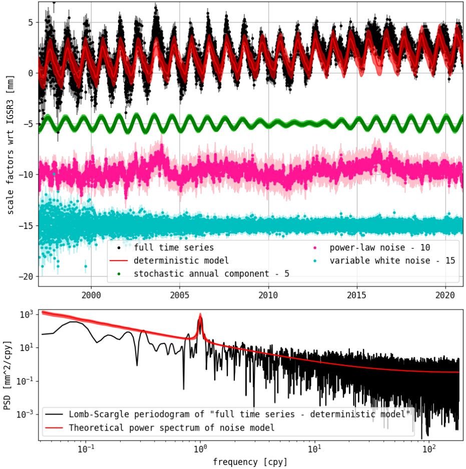
Example: ESA

Scale factors w. r. t. IGSR3

CODE

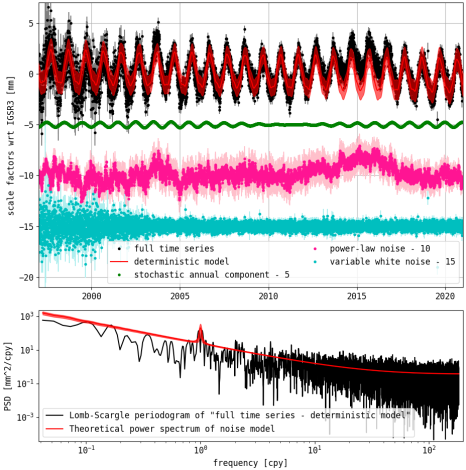


ESA



Scale factors w. r. t. IGSR3

GFZ



GRGS