Terrestrial frame solutions from the third IGS reprocessing: the IGS contribution to ITRF2020

Paul Rebischung

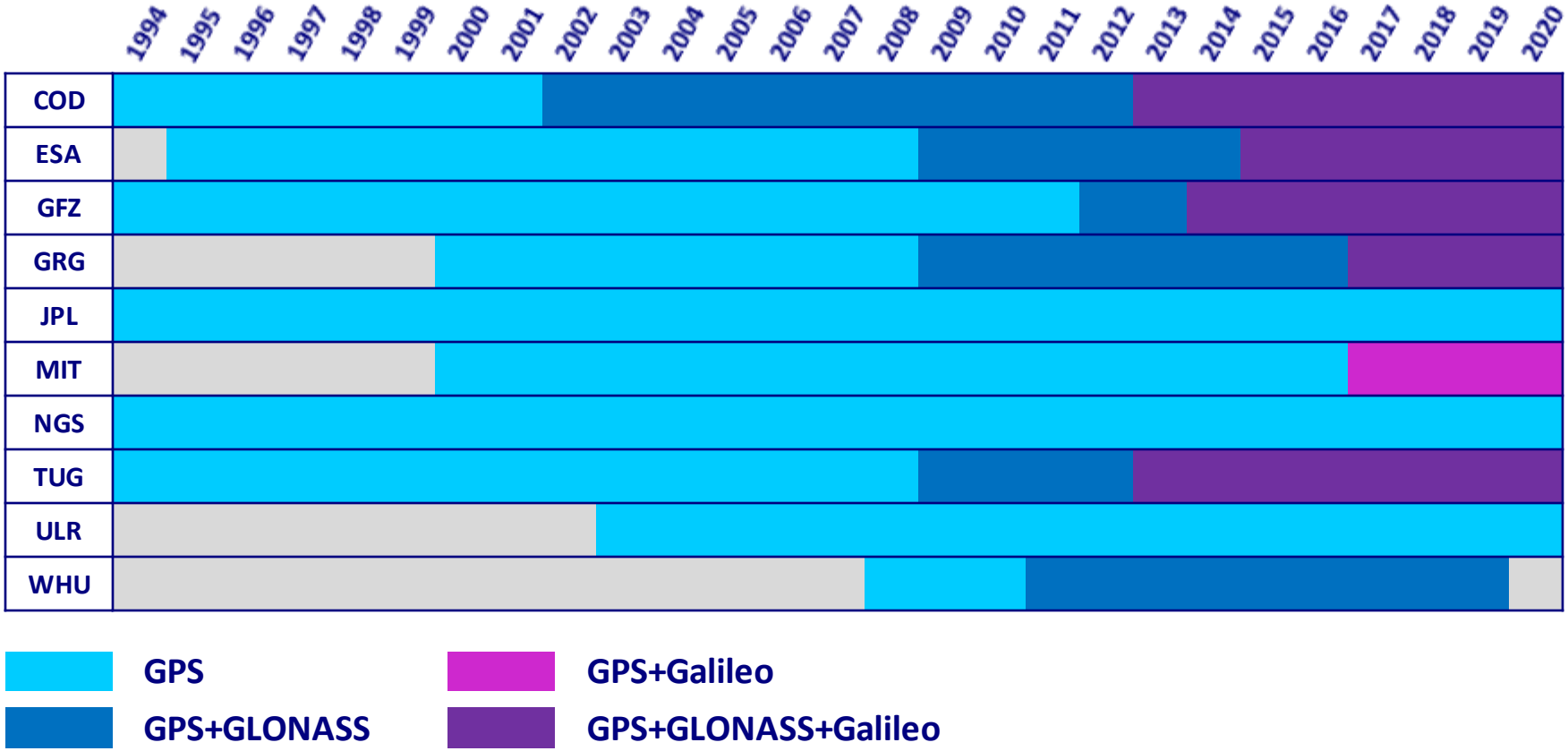
based on contributions from:

COD	Centre for Orbit Determination in Europe, Bern, Switzerland	MIT	Massachusetts Institute of Technology, Cambridge, Mass., USA
ESA	European Space Agency, Darmstadt, Germany	NGS	National Geodetic Survey, Silver Springs, Maryland, USA
GFZ	Geoforschungszentrum, Potsdam, Germany	TUG	Graz University of Technology, Graz, Austria
GRG	Groupe de Recherche en Géodésie Spatiale, Toulouse, France	ULR	Université de la Rochelle, la Rochelle, France
JPL	Jet Propulsion Laboratory, Pasadena, California, USA	WHU	Wuhan University, Wuhan, Hubei, China

The third IGS reprocessing campaign (repro3)

- Re-analysis of the data collected by a global GNSS network over the period 1994-2020 using the latest available models and methodology by ten IGS Analysis Centers (ACs)
- Main purpose: provide the IGS input to ITRF2020
- Main updates since repro2:
  - Galileo & GLONASS observations processed by a majority of ACs
  - New multi-GNSS calibrations for several ground antenna types (from Geo++) → repro3-specific ANTEX file « igsR3.atx »
  - Re-evaluated GPS & GLONASS satellite z-PCOs based on Galileo satellite z-PCOs published by GSA → repro3-specific ANTEX file « igsR3.atx »
  - → For the first time, IGS repro3 solutions have an ITRF-independent, Galileo-based terrestrial scale.
  - Ground antenna calibrations rotated to match actual antenna orientations
  - New IERS secular pole model
  - Sub-daily EOP tide model from Desai & Sibois (2016)
  - Modern ocean tide loading models
  - Improved solar radiation pressure models
  - Time-variable gravity field models
- More details in [IGSMAIL-8026]: https://lists.igs.org/pipermail/igsmail/2021/008022.html

AC contributions to repro3



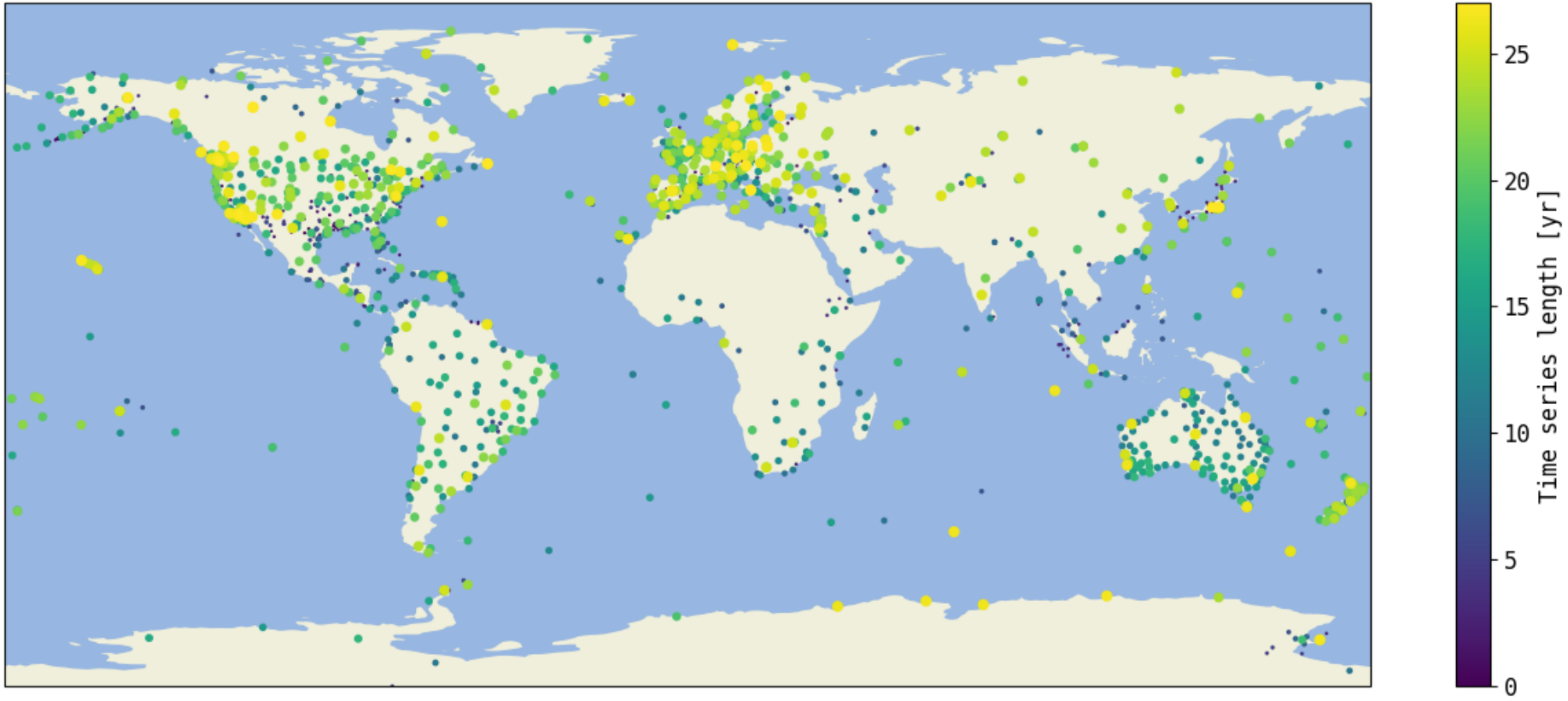
Part 1:

Daily repro3 SINEX combinations

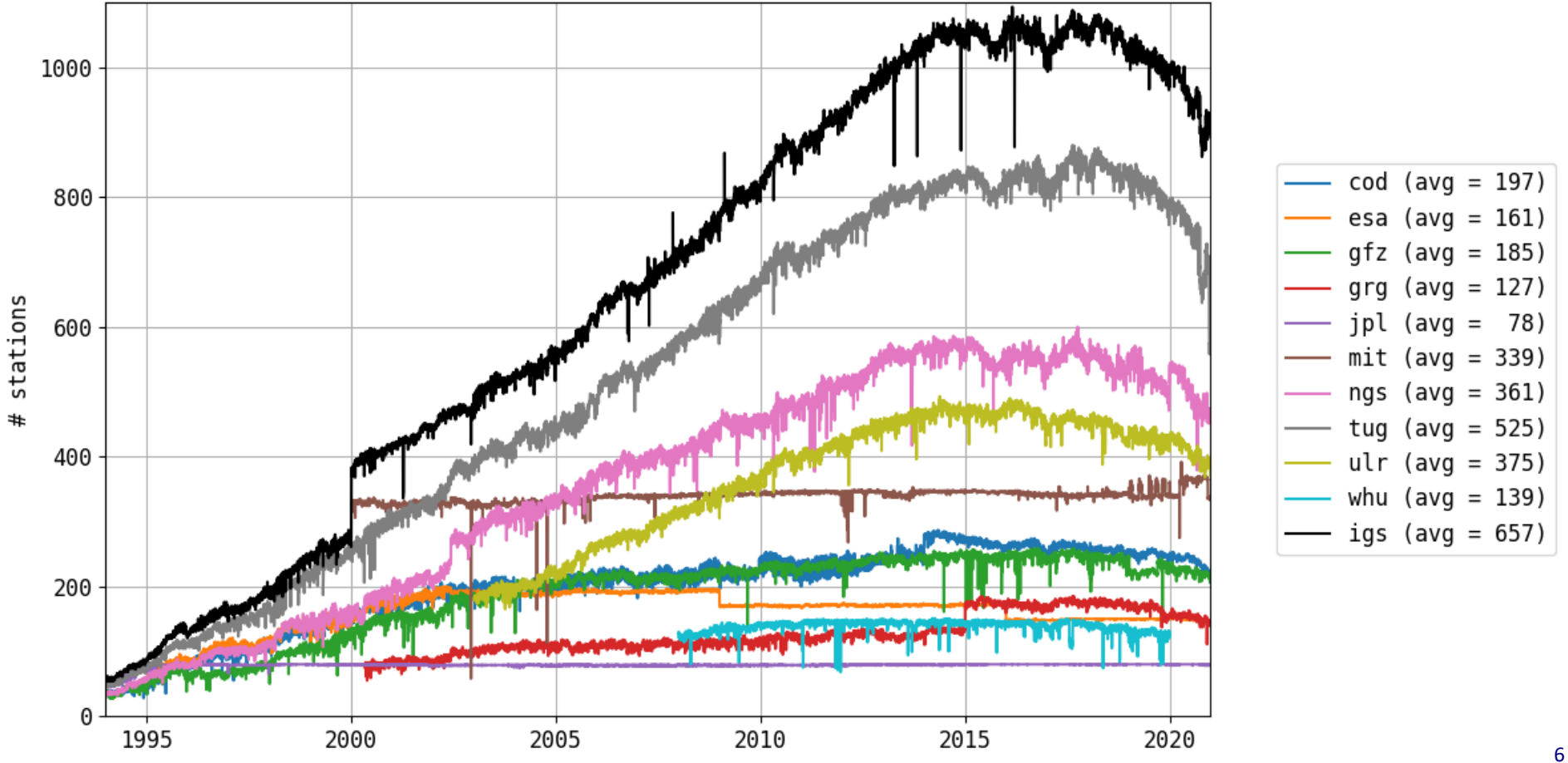
- **The daily terrestrial frame (SINEX) solutions provided by the different ACs were combined.**
  - **Similar combination strategy as for repro2 (Rebischung et al., 2016) with some minor adjustments**
  - **Daily combined solutions aligned in origin & orientation to repro3-specific reference frame « IGSR3 »**
  - **Scale inherited from Galileo-based igsR3.atx satellite z-PCOs**
  - **SINEX combination products publicly released on April 10, 2021 at ftp://igs-rf.ign.fr/pub/repro3, now also available at CDDIS**
  - **More details in [IGSMAIL-8026]: https://lists.igs.org/pipermail/igsmail/2021/008022.html**
  - **Daily combined repro3 SINEX solutions = IGS input to ITRF2020**

- **The following slides show results from the daily repro3 SINEX combinations.**

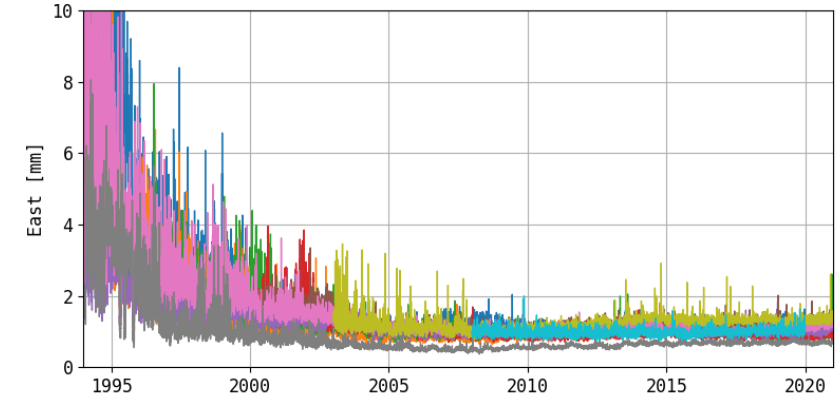
repro3 station network

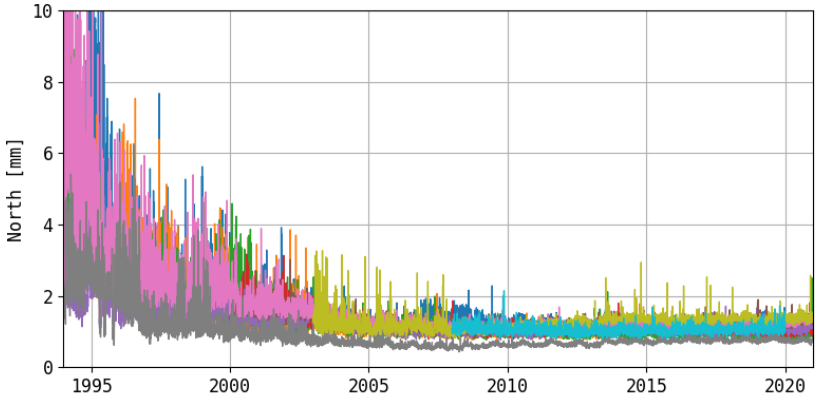


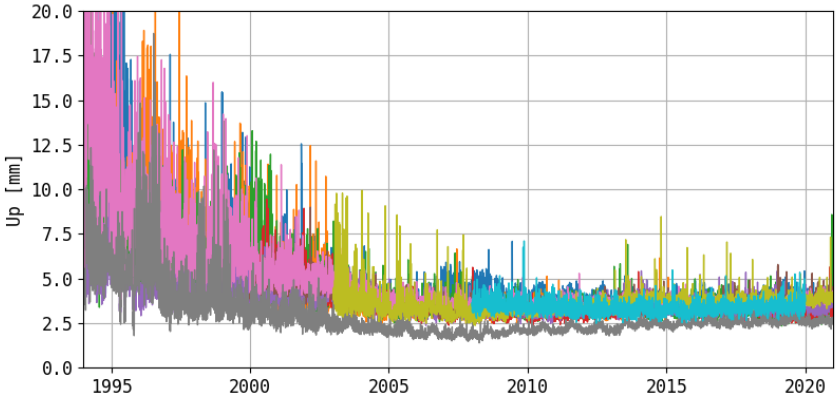
Number of stations in daily AC & combined solutions



Daily median formal errors of station positions





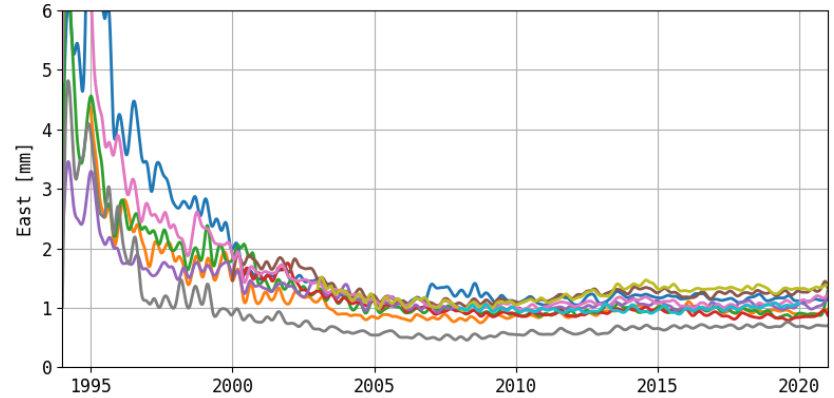


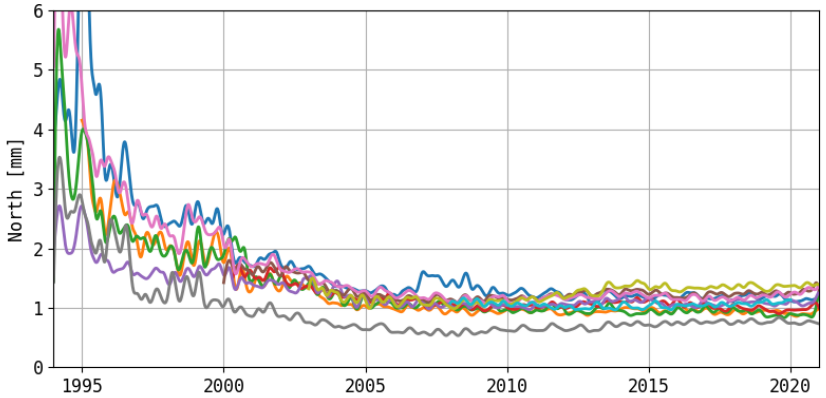
cod (E: 1.2 mm; N: 1.3 mm; H: 4.2 mm)
esa (E: 0.9 mm; N: 1.0 mm; H: 3.3 mm)
gfz (E: 1.0 mm; N: 1.0 mm; H: 3.5 mm)
grg (E: 0.9 mm; N: 1.1 mm; H: 3.3 mm)
jpl (E: 1.1 mm; N: 1.2 mm; H: 3.6 mm)
mit (E: 1.2 mm; N: 1.2 mm; H: 3.7 mm)
ngs (E: 1.1 mm; N: 1.3 mm; H: 3.9 mm)
tug (E: 0.7 mm; N: 0.7 mm; H: 2.5 mm)
ulr (E: 1.2 mm; N: 1.2 mm; H: 3.6 mm)
whu (E: 1.0 mm; N: 1.0 mm; H: 3.3 mm)

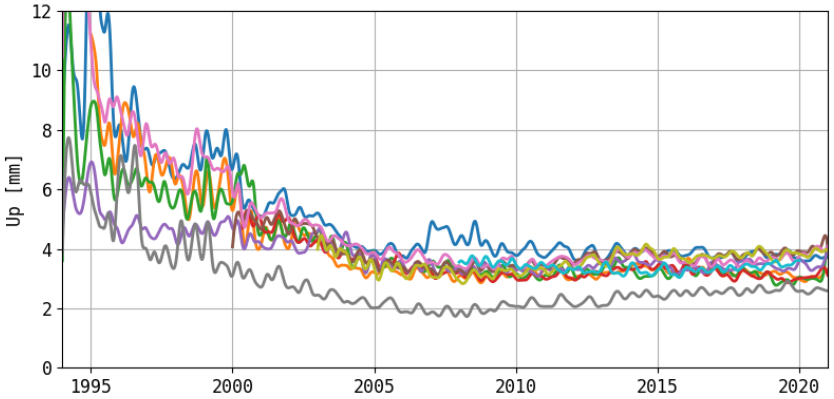
Numbers in the legend are medians of the time series of daily median formal errors.

- **The displayed median formal errors are those in the daily AC solutions after they have been optimally weighted for the combination.**
- **They reflect the level of agreement between daily AC solutions and are a proxy for the AC weights in the daily combinations.**

Smoothed daily median formal errors of station positions







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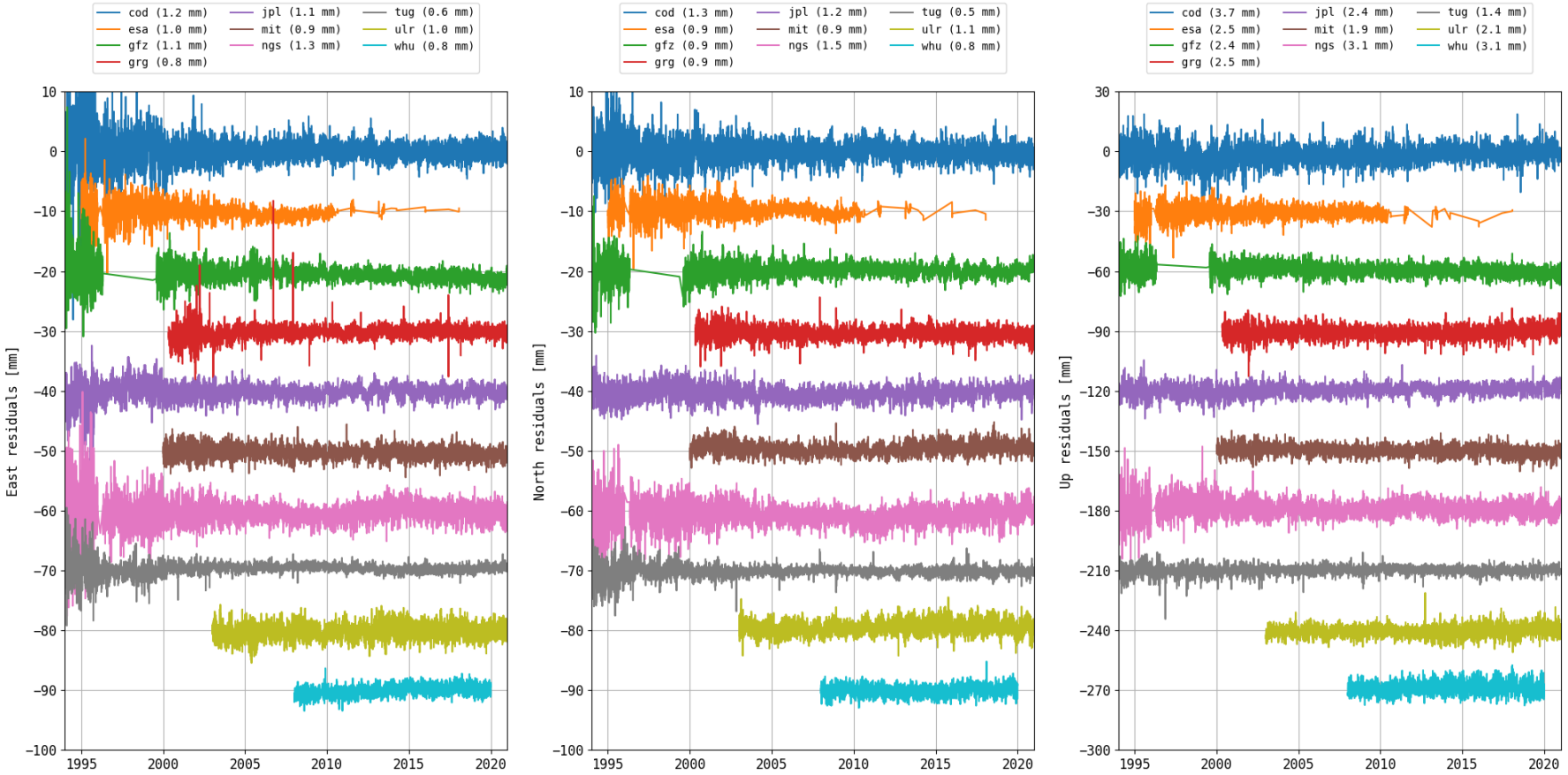
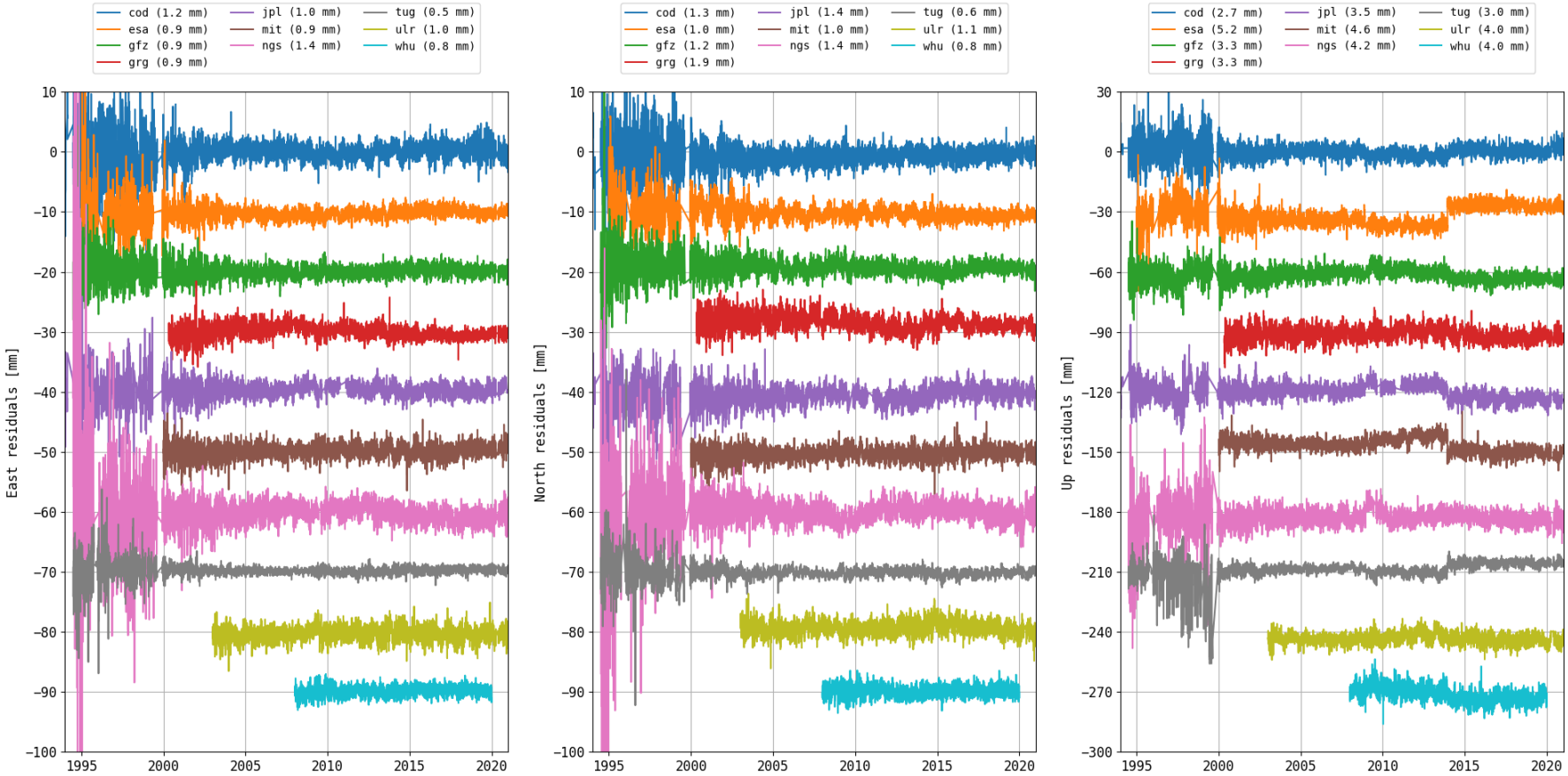
Example of station position residuals – STJO (St. John's, Canada)



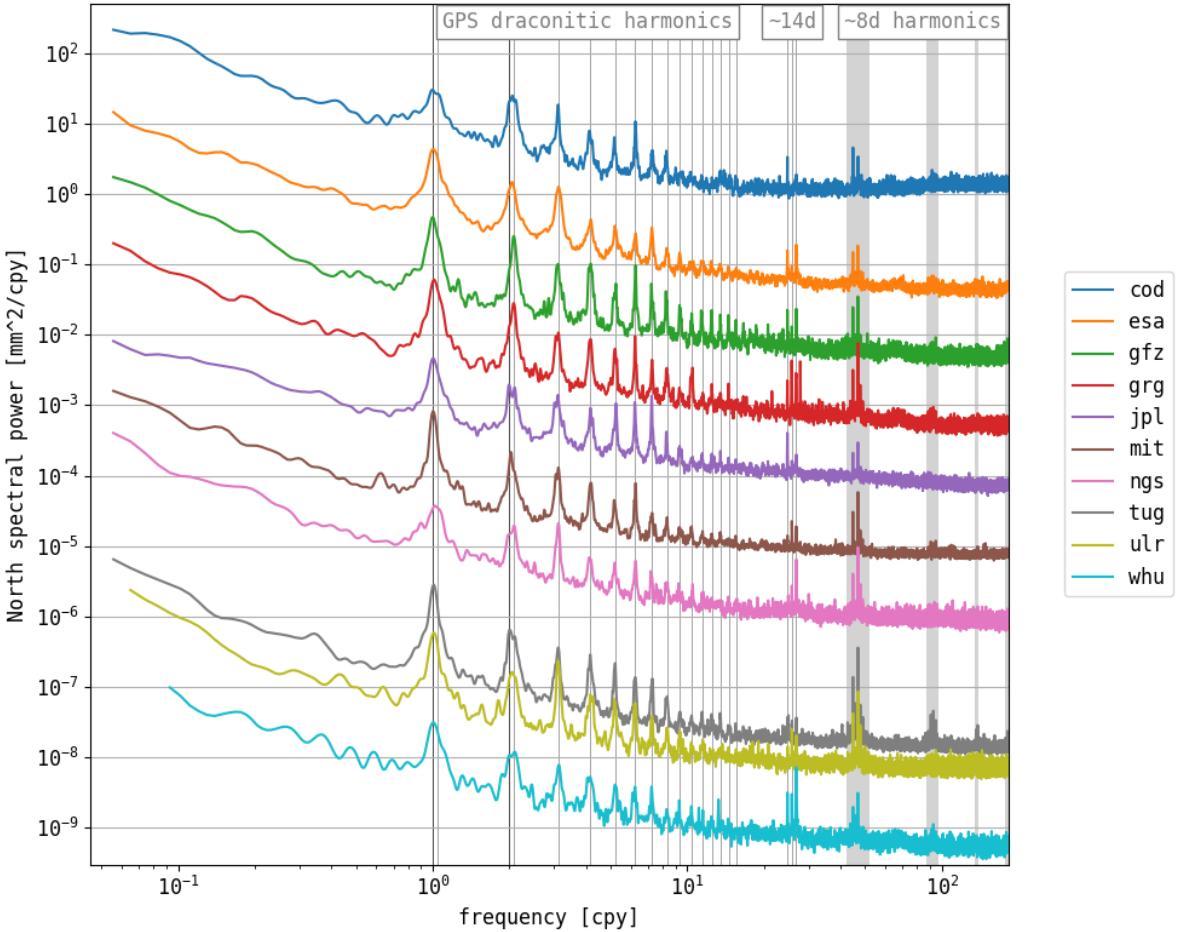
– **Numbers in the legends are WRMS of the station position residual time series.**

Example of station position residuals – CAS1 (Casey, Antarctica)



– **Note inter-AC biases in Up, which change with 2008-12-03 receiver change and 2013-12-11 antenna change.**

Average periodograms of station position residuals – North

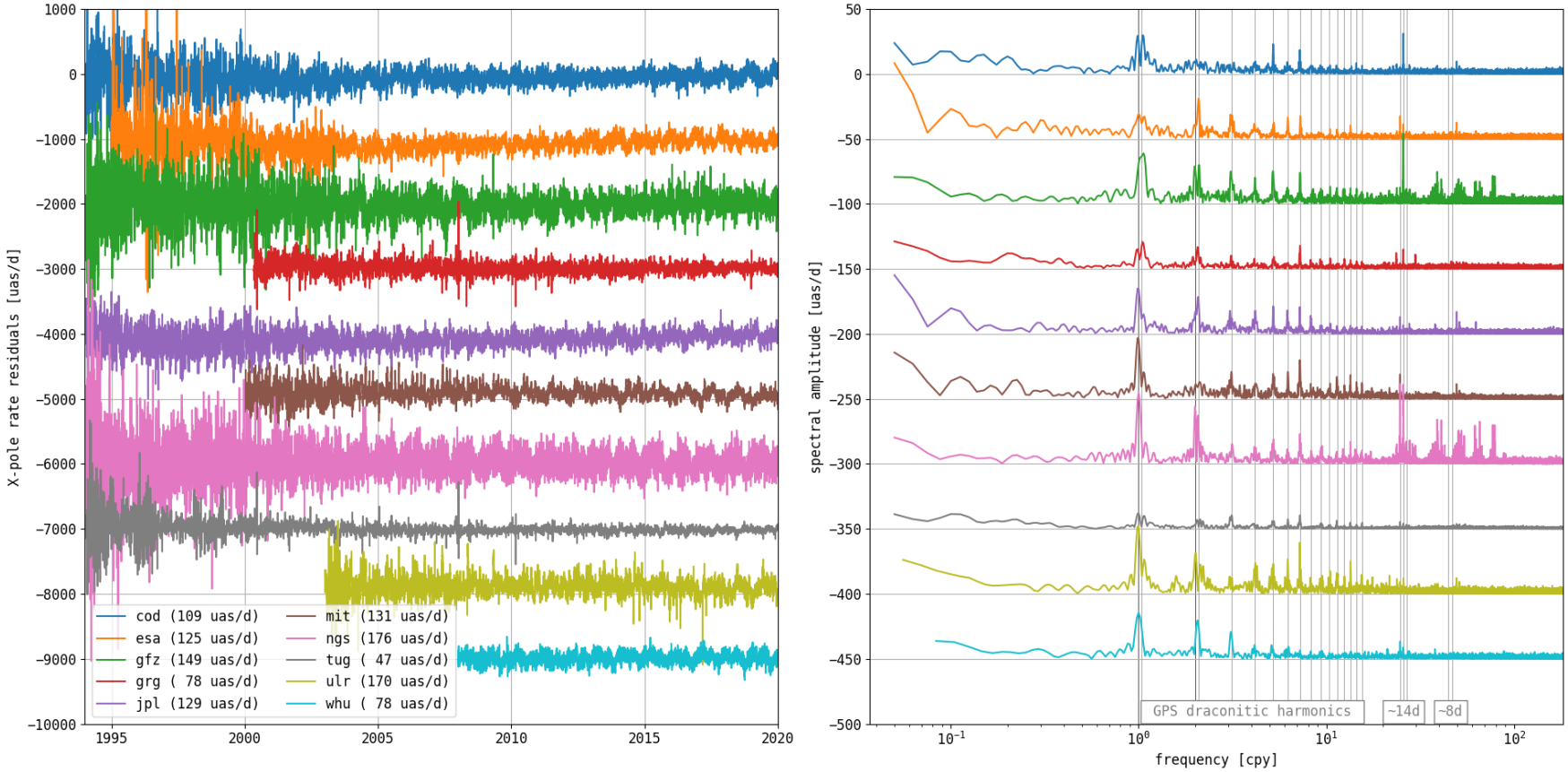


- Only post-2001 residuals were used.
- Only residual time series with at least 700 daily points were used.
- A series of length T only contributes to frequencies > 1/T of the averaged periodogram.

- Similar pictures in East and Up
- Similar picture as in repro2, except for new clusters of GLONASS-related spectral peaks around 8 d and harmonics
- Note that these peaks are larger for ACs who do not use or downweight GLONASS (GRG, MIT, NGS, ULR).

- Interpretation of combination residuals complicated by the fact that AC solutions are compared to their weighted mean.
- Comparative study of 'absolute' errors in AC repro3 station position time series will follow.

X-pole rate residuals

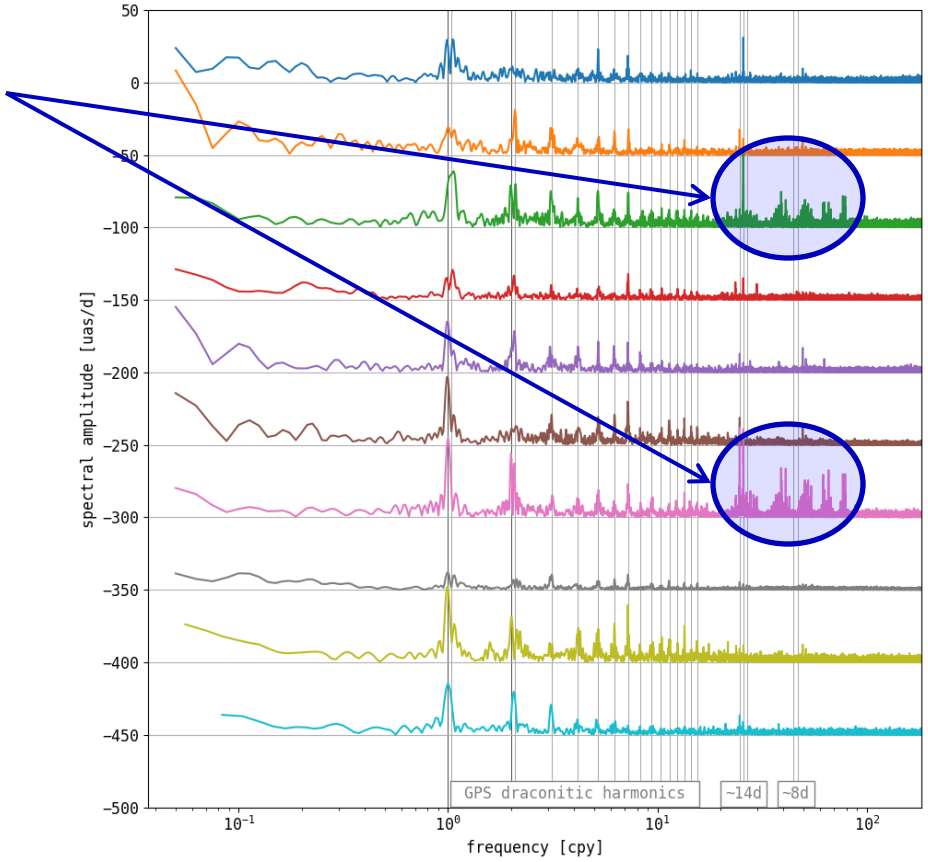


– **Numbers in the legend are WRMS of the X-pole rate residual time series. Spectra were computed from post-2001 residuals only.**

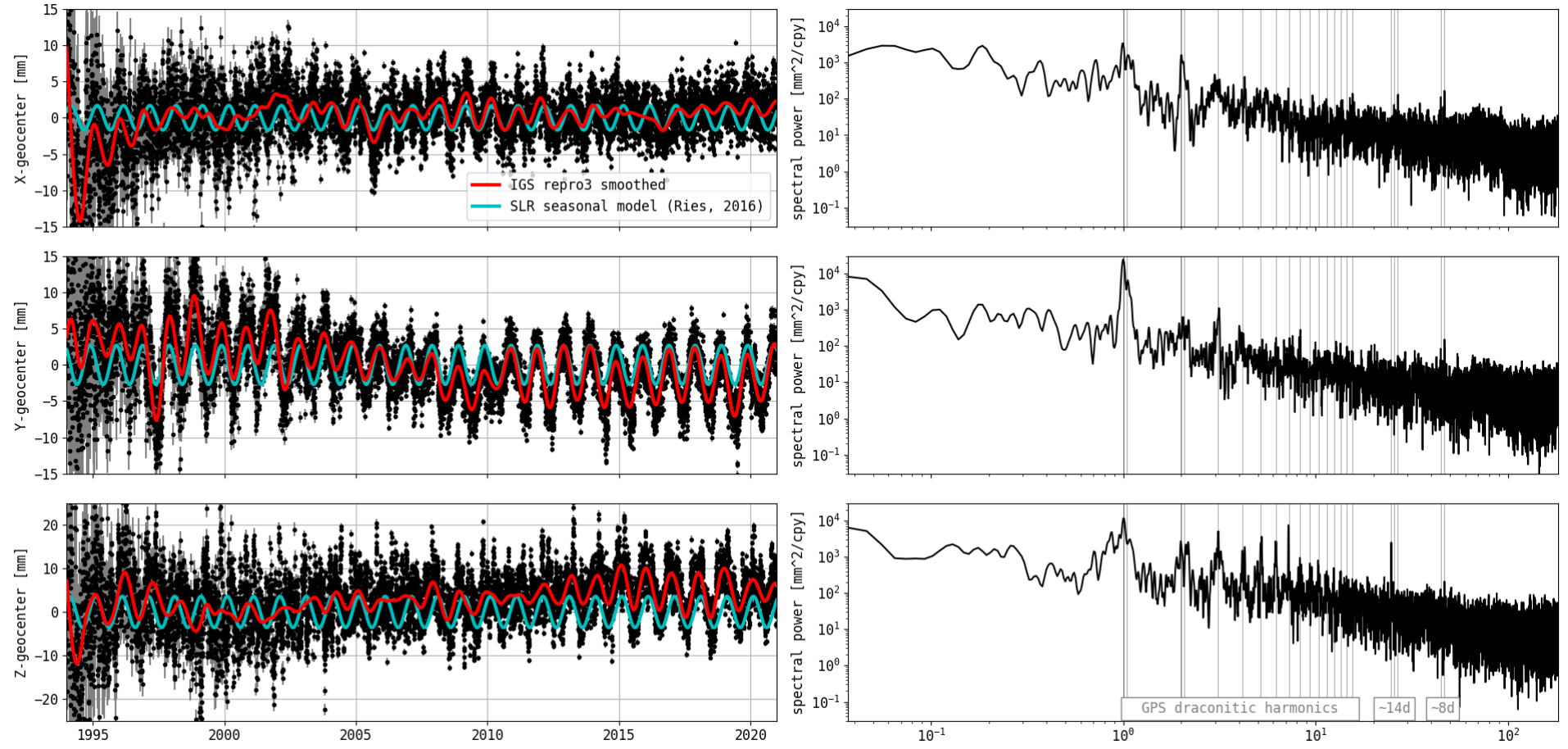
X-pole rate (and other ERP) residuals

- Large fortnightly peaks + clusters of peaks around ~9 d, ~7 d, ~5.7 d and ~4.7 d in GFZ and NGS pole rate residuals
- Errors in implementing new sub-daily EOP tide model?
- Otherwise similar picture as in repro2; for other ERPs as well
- Overall inter-AC agreement on ERPs however noticeably improved from repro2 to repro3:

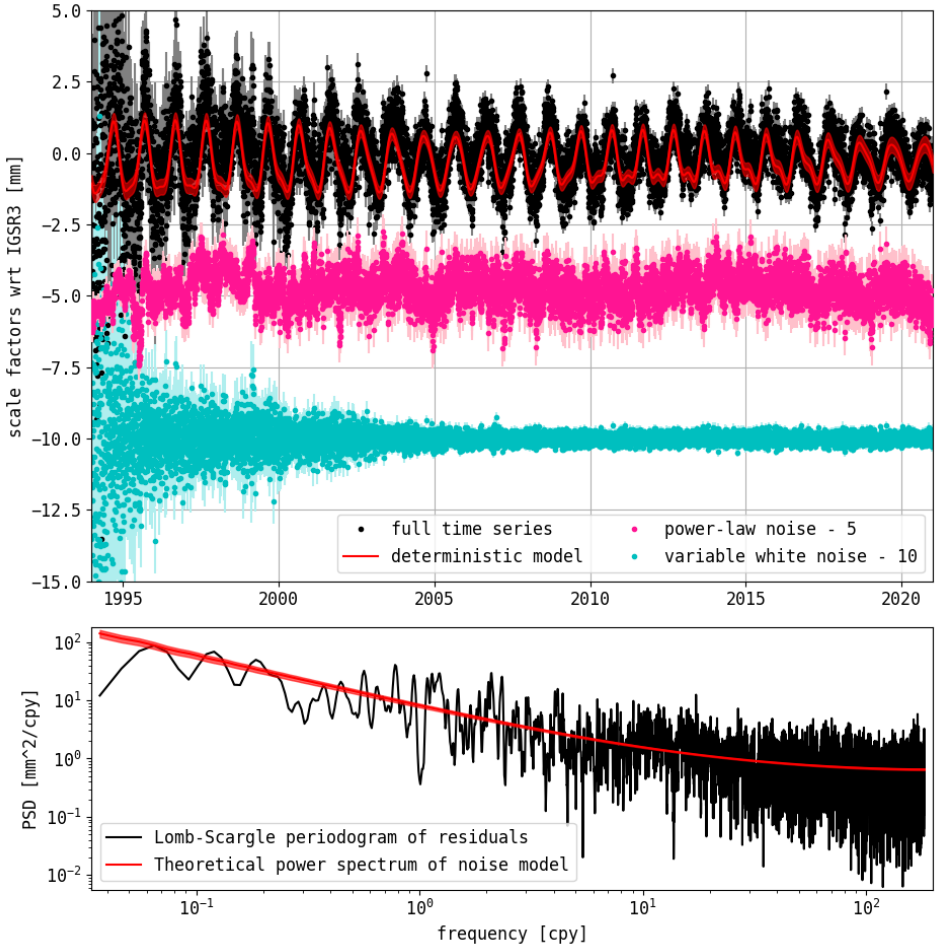
ERP	overall WRMS of AC residuals	
	in repro2	in repro3
X-pole	25.8 µas	19.9 µas
Y-pole	24.8 µas	17.7 µas
X-pole rate	122 µas/d	98 µas/d
Y-pole rate	129 µas/d	110 µas/d
LOD	6.6 µs	5.2 µs



Combined geocenter coordinates (in IGSR3 reference frame)



Scale of daily combined solutions



- **Scale factor time series modeled as the sum of:**
  - linear trend + annual, semi-annual, draconitic & semi-draconitic sine waves;
  - power-law noise;
  - variable white noise
- **Estimated linear trend wrt IGSR3:**
  - –0.3 +/- 0.2 mm @ epoch 2010.0
  - 0.00 +/- 0.02 mm/yr
- **Estimated linear trend wrt ITRF2014:**
  (obtained by adding the IGSR3/ITRF2014 transformation)
  - +7.6 +/- 0.2 mm @ epoch 2010.0
  - +0.19 +/- 0.02 mm/yr

controlled by Galileo satellite z-PCOs

controlled by the assumption of constant (GPS) satellite z-PCOs

- **Also note excellent inter-AC agreement on scale**
  (< 1 mm ; < 0.1 mm/yr)

Part 2:

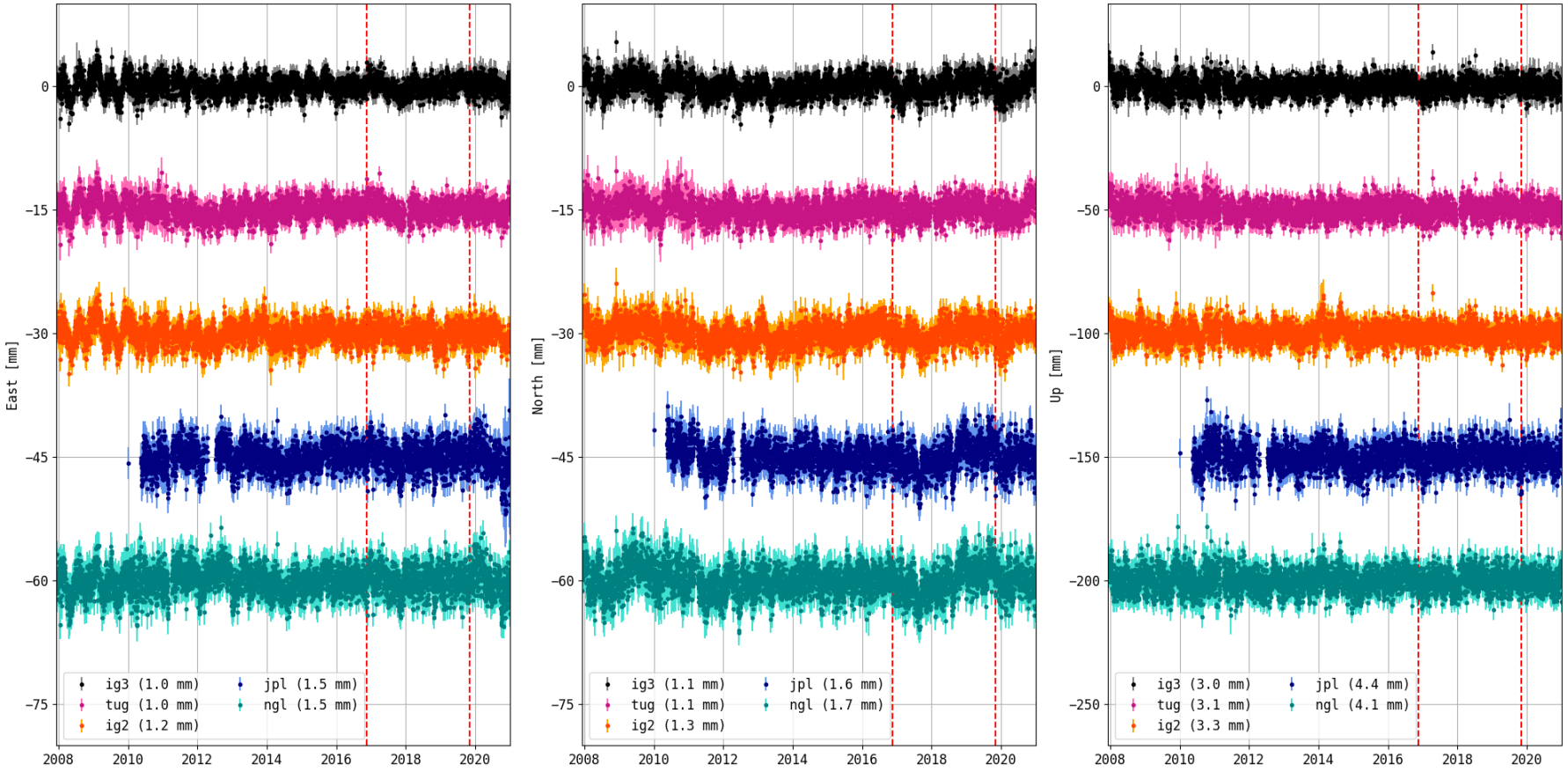
Comparison of station position time series

- **Station position time series from five sources are compared:**
  - **'ig3'** IGS repro3 combined solutions
  - **'tug'** TU Graz contribution to IGS repro3 (as the 'best' contributing AC)
  - **'ig2'** IGS repro2 / operational solutions
  - **'jpl'** JPL PPP time series (https://sideshow.jpl.nasa.gov/post/series.html; Heflin et al., 2020)
  - **'ngl'** NGL PPP time series (http://geodesy.unr.edu; Blewitt et al., 2018)

- **For each station among a selection of 215 IGSR3 stations:**
  - Remove IGSR3 post-seismic deformation model from the five time series, when applicable
  - Adjust the same {piecewise linear + annual & semi-annual sine waves} model to the five time series
  - Discontinuity dates taken from IGSR3 discontinuity list + a few additions
  - Exception: additional discontinuity on 2017-01-29 (date of IGb08 → IGS14 switch) for all 'ig2' series

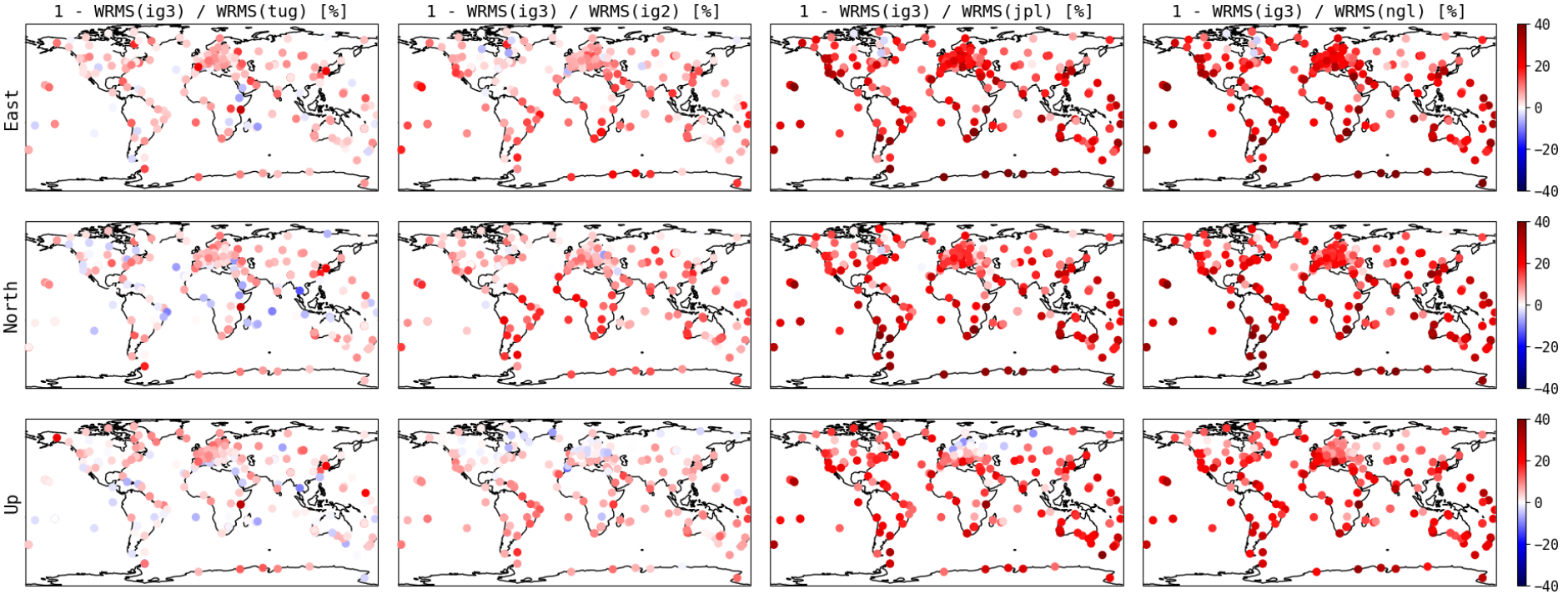
- **Compare the residuals from the five series of adjustments, their WRMS and averaged spectra**

Example: CHTI (Chatham Island, New Zealand)

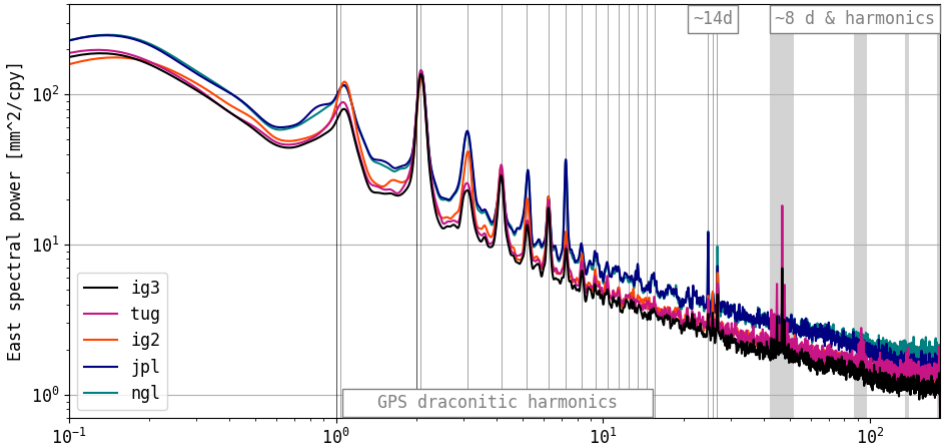


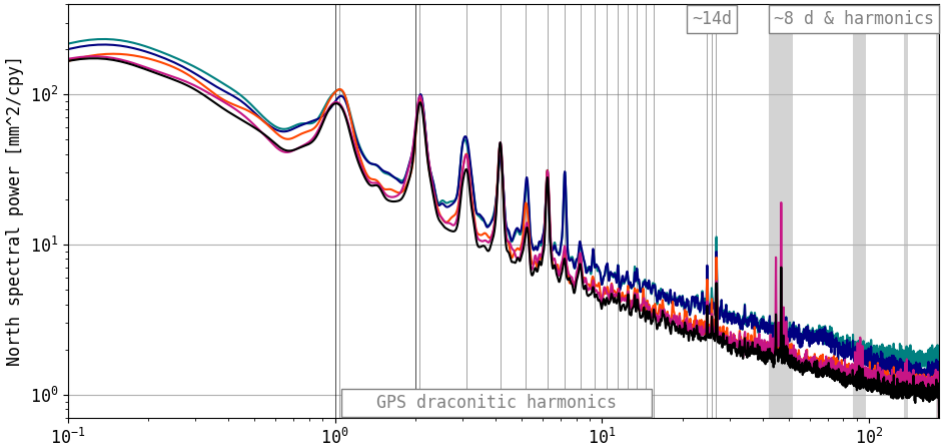
– **Numbers in the legends are WRMS of the residual time series.**

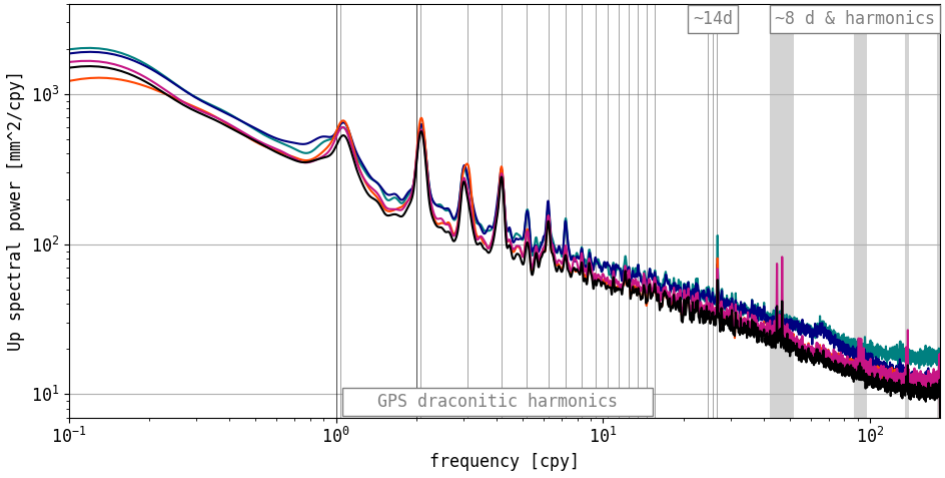
Relative WRMS differences



Smoothed averaged periodograms

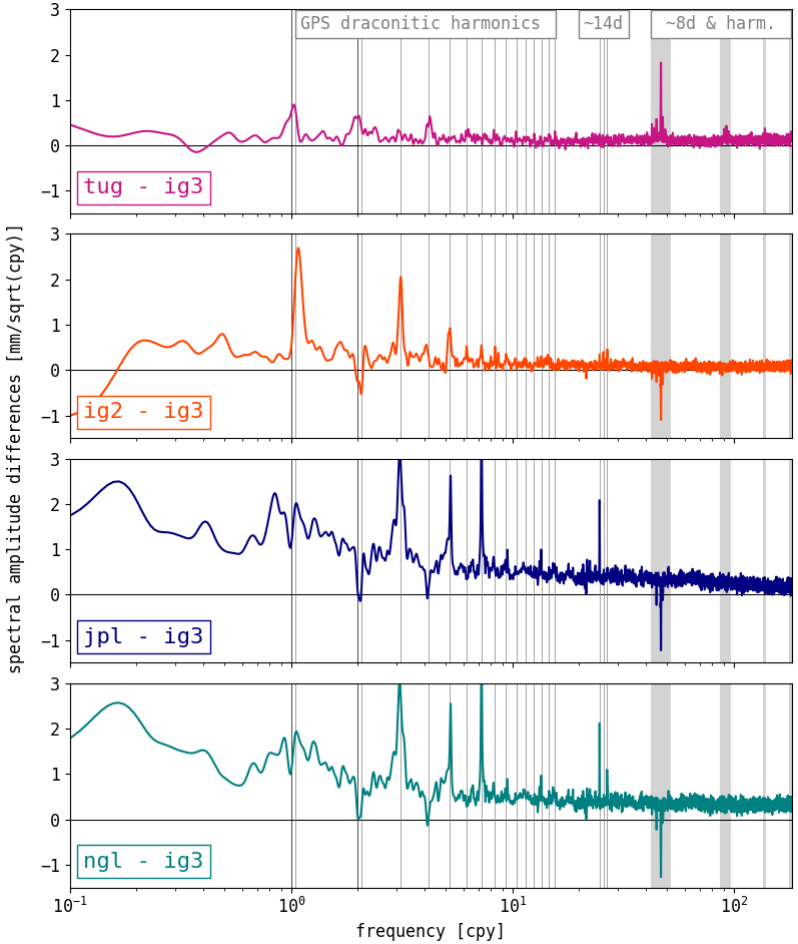






Be careful not to over-interpret apparent flattening at very low frequencies, which is likely an artifact due to recurring offsets in the time series (Santamaría-Gómez & Ray, 2021).

Smoothed averaged spectral amplitude differences (North)



- Background noise smallest in ‘ig3’; largest in ‘jpl’ and ‘ngl’ PPP series
- Periodic errors also generally smallest in ‘ig3’
  - Except for GLONASS-related ~8 d signals, which are obviously absent from GPS-only series
  - Draconitic and fortnightly errors in particular reduced from ‘ig2’ to ‘ig3’
- Similar pictures in East and Up

Summary

- **Daily repro3 SINEX combinations:**
  - Inter-AC agreement on station positions at similar level as in repro2
  - No more ACs on the tail of the peloton, but a new frontrunner (TU Graz)
  - Draconitic & fortnightly signals still obviously present in station position residuals, with now additional GLONASS-related signals at harmonics of ~8 d
  - Inter-AC agreement on ERPs noticeably improved compared to repro2
  - Draconitic and fortnightly signals still obviously present in ERP residuals
  - Clusters of spectral peaks around ~9 d, ~7 d, ~5.7 d and ~4.7 d in GFZ and NGS pole rate residuals (?)
  - Inter-AC agreement on terrestrial scale at the level of +/- 1 mm
  - (ITRF-independent, Galileo-based) scale of combined repro3 solutions extremely precise and stable
  - → Possible contribution of GNSS to the definition of the ITRF2020 scale?

- **Comparison of station position time series:**
  - Average (non-seasonal) scatter reduction of ~0.12 mm (~8%) in horizontal; ~0.24 mm (~5%) in vertical from repro2 to repro3
  - Background noise, draconitic & fortnightly signals reduced from repro2 to repro3, but new spurious GLONASS-related signals at harmonics of ~8 d present in repro3 series
  - IGS repro3 series unambiguously 'cleaner' than PPP series considered in this comparison, but only marginally compared to TUG series
  - → To which extent are the improvements from repro2 to repro3 just due to the presence of TUG in repro3?

Next steps

- **Currently:**
  - Identification of discontinuities in repro3 station position time series
  - Modeling of post-seismic displacements
- **Later:**
  - Investigate apparent higher precision of TUG solutions
  - Try repro3 combinations without TUG
  - Investigate inter-AC station position biases
  - Extend comparison of station position time series to more stations and all ACs
  - Compare geocenter motion estimates from the different ACs

Thanks for your attention!