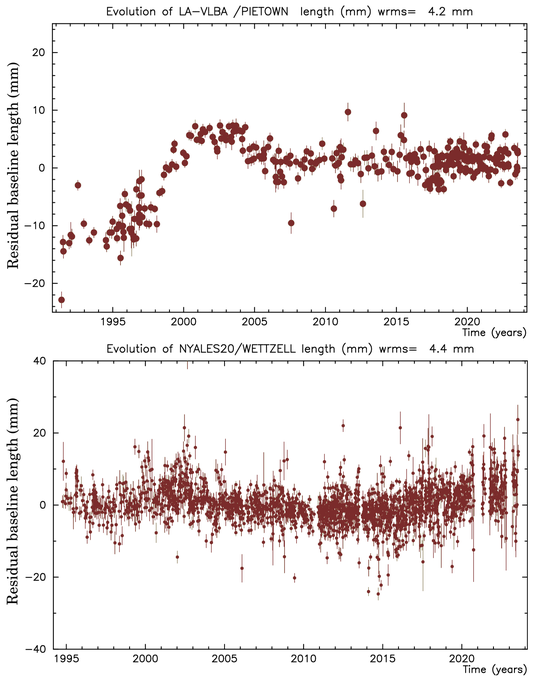
Improvements in VLBI data analysis for advances in geodesy

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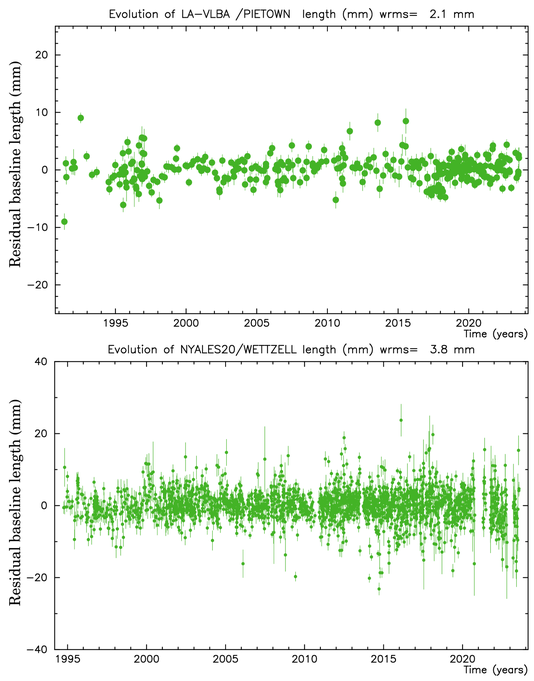
Motivation:

- The qualtity of IERS/ITRF solution is still poor. It reveals limitations of the analysis technique used in solutions reported by IERS/ITRF.
- Analysis of residuals reveals unexplained "noise".

Residuals wrt **ITRF2020**



Residuals wrt **NASA GSFC solution**



Advanced data reduction models:

- The use of slant path delay derived from NASA GEOS-FPIT and MERRA numerical weather models **https://atmospheric-propagation.smce.nasa.gov** for processing **all** observations
- The use of 3D atmospheric pressure loading from NASA GEOS-FPIT and MERRA numerical weather models **https://massloading.smce.nasa.gov** computed at degree/order 21599 for processing all observations
- The use of 3D land water mass storage loading from NASA GEOS-FPIT and MERRA numerical weather models **https://massloading.smce.nasa.gov** computed at degree/order 21599 for processing all obs
- The use of 3D non-tidal mass loading from MPIOM07 ocean circulation model **https://massloading.smce.nasa.gov** computed at degree/order 21599 for processing all observations
- The use of 3D tidal mass ocean loading from FES-2014b ocean tide model **https://massloading.smce.nasa.gov** computed at degree/order 21599 for processing all observations

Reference:

Petrov & Kovalev, "The Radio Fundamental Catalog", 2025, ApJS in press, arxiv:2410.11794.

Advanced parameter estimation models:

- Station motion model

$$\vec{x}(t) = \vec{\mathbf{x}}_0(\mathbf{t_0}) + \dot{\vec{\mathbf{x}}}(\mathbf{t-t_0}) + \sum_{\mathbf{i=1}}^{\mathbf{i=N}} \vec{\mathbf{x}}_\mathbf{i}^{\,\mathbf{c}} \cos \mathbf{f_i}\,(\mathbf{t-t_0}) + \sum_{\mathbf{i=1}}^{\mathbf{i=N}} \vec{\mathbf{x}}_\mathbf{i}^{\,\mathbf{s}} \sin \mathbf{f_i}\,(\mathbf{t-t_0}) + \sum_{\mathbf{j=1-n}}^{\mathbf{j=n-1}} \vec{\mathbf{x}}_\mathbf{i}^{\,\mathbf{b}}\, \mathbf{B}_\mathbf{i}^\mathbf{m}(\mathbf{t})$$

where

- **linear motion**
- **harmonic variations** in site positions
- **B-spline model** that describes an-harmonic non-linear motion with possible breaks

parameters f_i and sequences of B-splines knots $t_1, t_2, \ldots t_n$ are selected for each station individually. Decorrelation constraints between groups of parameters are imposed.

- Estimation of the vector of small perturbation in Earth rotation as

$$\vec{q}_e(t) = \begin{pmatrix} \sum_{\mathbf{k=-2}}^{\mathbf{n-1}} \mathbf{e_{1k}}\, \mathbf{B}_\mathbf{k}^\mathbf{3}(\mathbf{t}) + \sum_{j}^{N} \left(\mathbf{P}_\mathbf{j}^\mathbf{c} \cos \omega_\mathbf{m}\, \mathbf{t} + \mathbf{P}_\mathbf{j}^\mathbf{s} \sin \omega_\mathbf{j}\, \mathbf{t}\right) + \mathbf{t}\, (\mathbf{S}^\mathbf{c} \cos{-}\Omega_\mathbf{n}\, \mathbf{t} + \mathbf{S}^\mathbf{s} \sin{-}\Omega_\mathbf{n}\, \mathbf{t}) \\ \sum_{\mathbf{k=-2}}^{\mathbf{n-1}} \mathbf{e_{2k}}\, \mathbf{B}_\mathbf{k}^\mathbf{3}(\mathbf{t}) + \sum_{j=1}^{N} \left(\mathbf{P}_\mathbf{j}^\mathbf{c} \sin \omega_\mathbf{j}\, \mathbf{t} - \mathbf{P}_\mathbf{j}^\mathbf{s} \cos \omega_\mathbf{j}\, \mathbf{t}\right) + \mathbf{t}\, (\mathbf{S}^\mathbf{c} \sin{-}\Omega_\mathbf{n}\, \mathbf{t} - \mathbf{S}^\mathbf{s} \cos{-}\Omega_\mathbf{n}\, \mathbf{t}) \\ \sum_{\mathbf{k=-2}}^{\mathbf{n-1}} \mathbf{e_{3k}}\, \mathbf{B}_\mathbf{k}^\mathbf{3}(\mathbf{t}) + \sum_{j=1}^{N} \left(\mathbf{E}_\mathbf{j}^\mathbf{c} \cos \omega_\mathbf{j}\, \mathbf{t} + \mathbf{E}_\mathbf{j}^\mathbf{s} \sin \omega_\mathbf{j}\, \mathbf{t}\right) \end{pmatrix},$$

where

- **B-spline model** that describes an-harmonic non-linear evolution of EOPs;
- **harmonic variations** in EOP that include so-called nutations and high-frequency variations in EOP at tidal frequencies, frequencies sampled at the Nyquist frequency within RFC and PIFCN bands, and ad hoc frequencies (cusps around major tides and ter-diurnal signals).
- **the cross terms** that correspond to precession and secular change in obliquity.

No EOP time series!

Advanced stochastic models:

- Applying additive re-weighting of group delays:

$$1/w_i = \sqrt{\sigma_i^2 + b^2 + (s\tau_{w1})^2 + (s\tau_{w2})^2}$$

where

- σ_i group delay uncertainty derived by fringe fitting
- b baseline-dependent weight correction determined from processing post-fit residuals
- τ_{wi} a priori wet path delay for the i station of a baseline
- s scaling factor

- Applying additive re-weighting of fringe phases for computation of σ_i

$$1/w_j = \sqrt{\sigma_p^2 + c^2}$$

where

- σ_p a priori uncertainty of segmented fringe phases
- c correction determined from processing post-fit residuals of fringe phases