Toward ITRF2020
Enhancing the Modelling of Nonlinear Station Motions

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OUTLINE

- Introduction
- Why do we need a reference frame?
- Reference frame definition & representations
- ITRF Construction / combination model

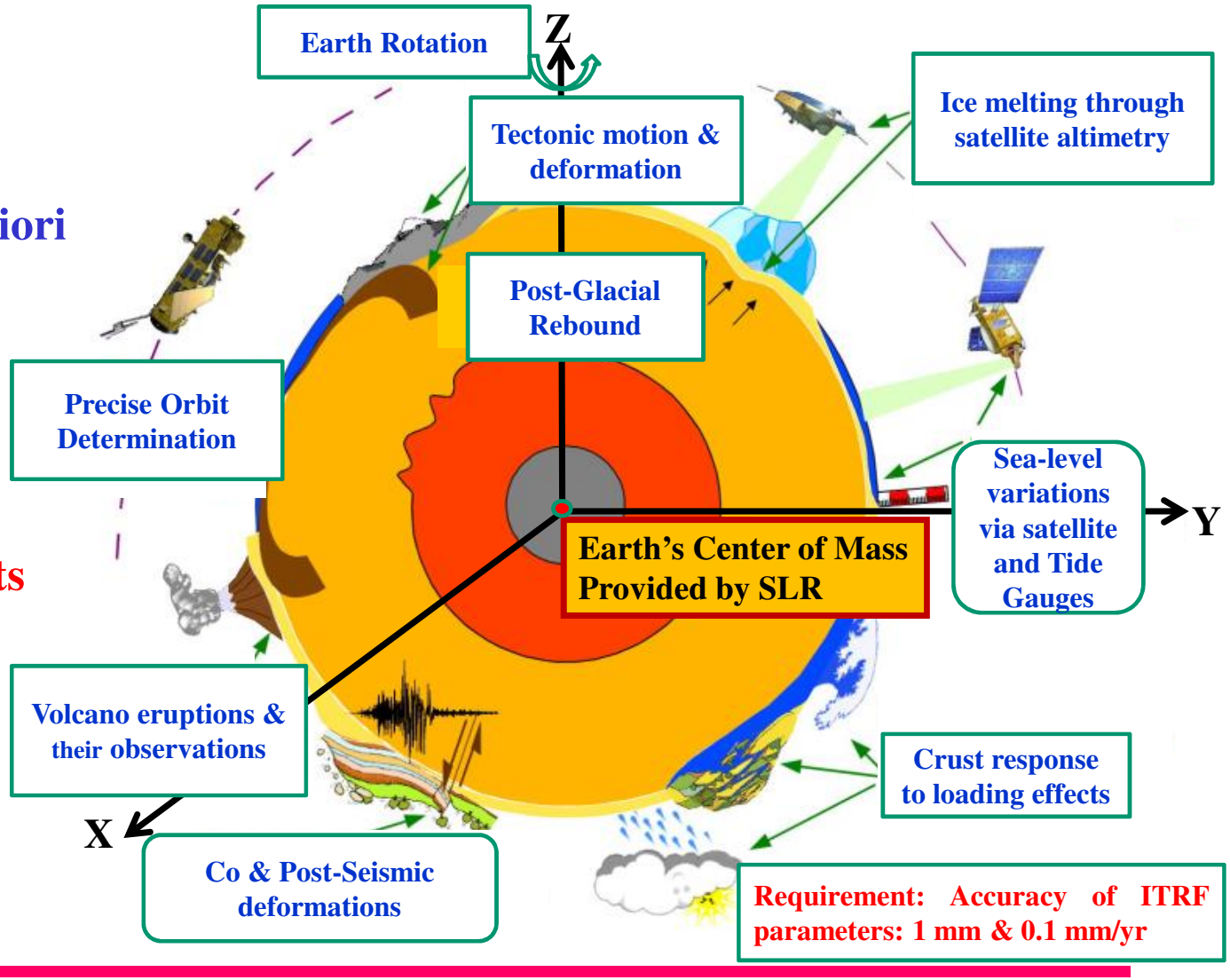
- ITRF2020:
  - Combination strategy & model
  - Network & colocations
  - An augmented parametric reference frame
    - Nonlinear station motions: Periodic signals and Post-Seismic Deformation
  - Scale of ITRF2020?
  - Some preliminary results: preliminary solution: ITRF2020P
  - Conclusion

Why a Reference System/Frame is needed?

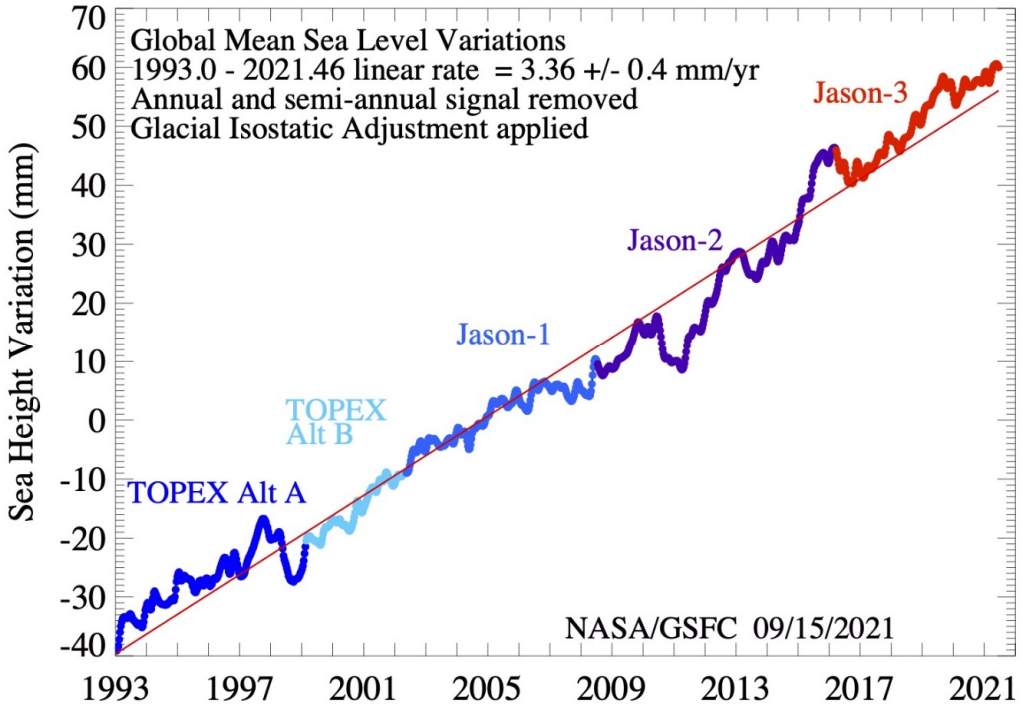
Operational geodesy applications:

- National geodetic systems/frames
- Positioning : Real Time or a posteriori
- Navigation: Aviation, Terrestrial, Maritime

- Today: via GNSS only!
- Require the availability of the orbits and the RF (ITRF)
- Many, many users…



Mean sea level change



A small drift of 1 mm/yr in the ITRF origin, translates into apparent 0.9 mm/yr in sea level rise at high latitudes

"Motions" of the deformable Earth & technique systematic errors

- **Nearly linear motion:**
  - **Tectonic motion: mainly horizontal (Plate Motion Model)**
  - **Post-Glacial Rebound: Vertical & Horizontal**

- **Nonlinear motion:**
  - **Loading deformation, including Annual, Semi & Inter-Annual, etc.**
  - **Co- & Post-seismic deformations,**
  - **Poro/thermo-elastic deformations**
  - **Transient deformations, Volcano Eruptions, local even**

- **Systematic errors, e.g. draconitics, monument instability, thermal deformation, gravitational deformation, …**

Reference Frame Representations

- **Long-Term Linear Frame: mean station positions at a reference epoch (t_0) and station velocities:**

$$X(t) = X(t_0) + \dot{X}(t - t_0)$$

<= Regularized Position
With piece-wise linear function

  - **The indispensable basis for science and operational geodesy applications**
- **Nonlinear Reference Frames:**
  - **Augmented Parametric RF: Secular Frame + nonlinear parametric functions (==> ITRF2020):**

$$X(t) = X(t_0) + \dot{X}.(t - t_0) + \delta X(t)_{PSD} + \delta X(t)_S$$

  - **Non-parametric RF: Time series of "Quasi-Instantaneous" reference frames**
    - **Daily or weekly representations**
    - **Nonlinear motion embedded in their time series**
    - **Still rely on the ITRF for at least the orientation definition**

All the above suffer from technique systematic errors

ITRF2020 Construction

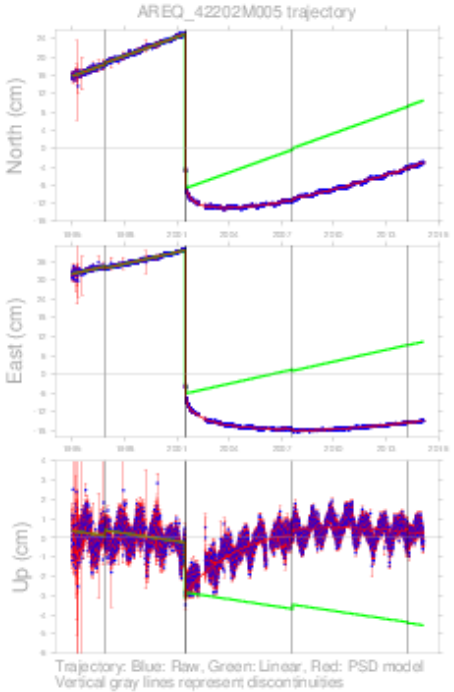
Input data: Time series:

- **DORIS/IDS weekly**
- **GNSS/IGS daily**
- **SLR/ILRS weekly**
- **VLBI/IVS: Session-wise**

- **Local ties**

Additional constraints at colocation sites: Equality constraints for

- **Station velocities**
- **Station seasonal signals**



Time series analysis & stacking of the 4 technique time series all together + Modeling of nonlinear station motions:

- **Periodic signals**
- **Post-Seismic Deformation**

ITRF2020 Specifications:
Origin: SLR
Scale: SLR & VLBI
Orientation: Alignment to ITRF2014

ITRF2020

$X, \dot{X}, \delta X_{PSD}$, *Seasonal Signals and EOPs*

ITRF Combination model

Station positions, velocities, transfo parameters & periodic terms

$$
\begin{cases}
\begin{pmatrix} x_s^i \\ y_s^i \\ z_s^i \end{pmatrix} = \begin{pmatrix} x^i \\ y^i \\ z^i \end{pmatrix} + (t_s^i - t_0) \begin{pmatrix} \dot{x}^i \\ \dot{y}^i \\ \dot{z}^i \end{pmatrix} + T_k + D_k \begin{pmatrix} x^i \\ y^i \\ z^i \end{pmatrix} + R_k \begin{pmatrix} x^i \\ y^i \\ z^i \end{pmatrix} \\
\qquad + (t_s^i - t_k) \left[\dot{T}_k + \dot{D}_k \begin{pmatrix} x^i \\ y^i \\ z^i \end{pmatrix} + \dot{R}_k \begin{pmatrix} x^i \\ y^i \\ z^i \end{pmatrix} \right] \\
\qquad + \sum_{j=1}^{n_f} \left[\begin{pmatrix} a_x^i \\ a_y^i \\ a_z^i \end{pmatrix} \cos[\omega_j (t_s^i - t_0)] + \begin{pmatrix} b_x^i \\ b_y^i \\ b_z^i \end{pmatrix} \sin[\omega_j (t_s^i - t_0)] \right] \\
\begin{pmatrix} \dot{x}_s^i \\ \dot{y}_s^i \\ \dot{z}_s^i \end{pmatrix} = \begin{pmatrix} \dot{x}^i \\ \dot{y}^i \\ \dot{z}^i \end{pmatrix} + \dot{T}_k + \dot{D}_k \begin{pmatrix} x^i \\ y^i \\ z^i \end{pmatrix} + \dot{R}_k \begin{pmatrix} x^i \\ y^i \\ z^i \end{pmatrix}
\end{cases}
$$

Earth Orientation Parameters

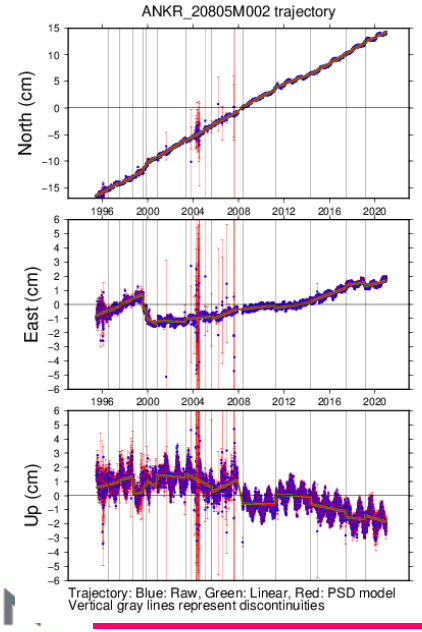
$$
\begin{cases}
x_s^p & = x_c^p + R2_k \\
y_s^p & = y_c^p + R1_k \\
UT_s & = UT_c - \frac{1}{f} R3_k \\
\dot{x}_s^p & = \dot{x}_c^p \\
\dot{y}_s^p & = \dot{y}_c^p \\
LOD_s & = LOD_c
\end{cases}
$$

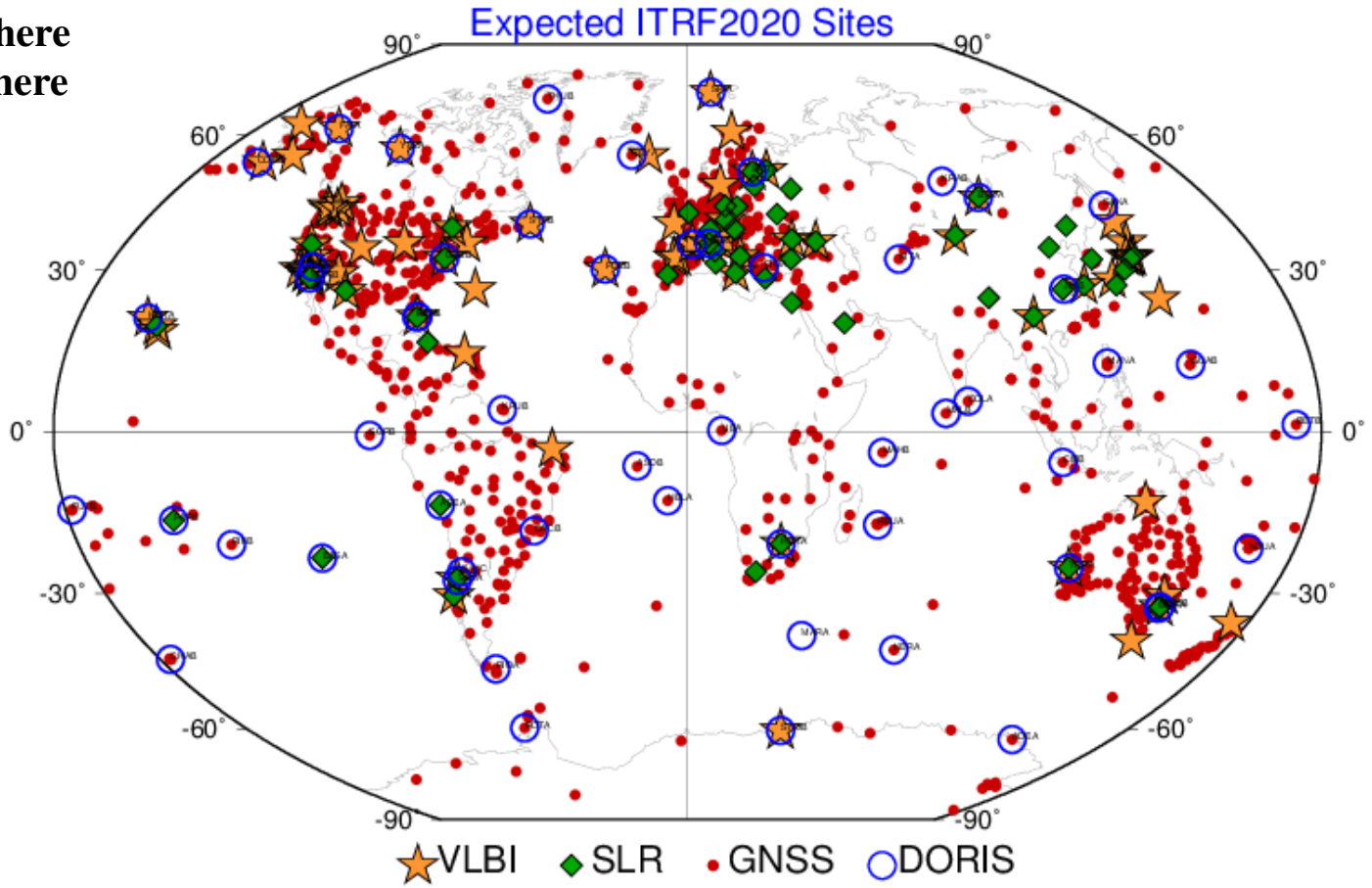
PSD: applied as a correction model before stacking

$$
\delta L(t) = \sum_{i=1}^{n^l} A_i^l \log(1 + \frac{t - t_i^l}{\tau_i^l}) + \sum_{i=1}^{n^e} A_i^e (1 - \mathrm{e}^{-\frac{t - t_i^e}{\tau_i^e}})
$$

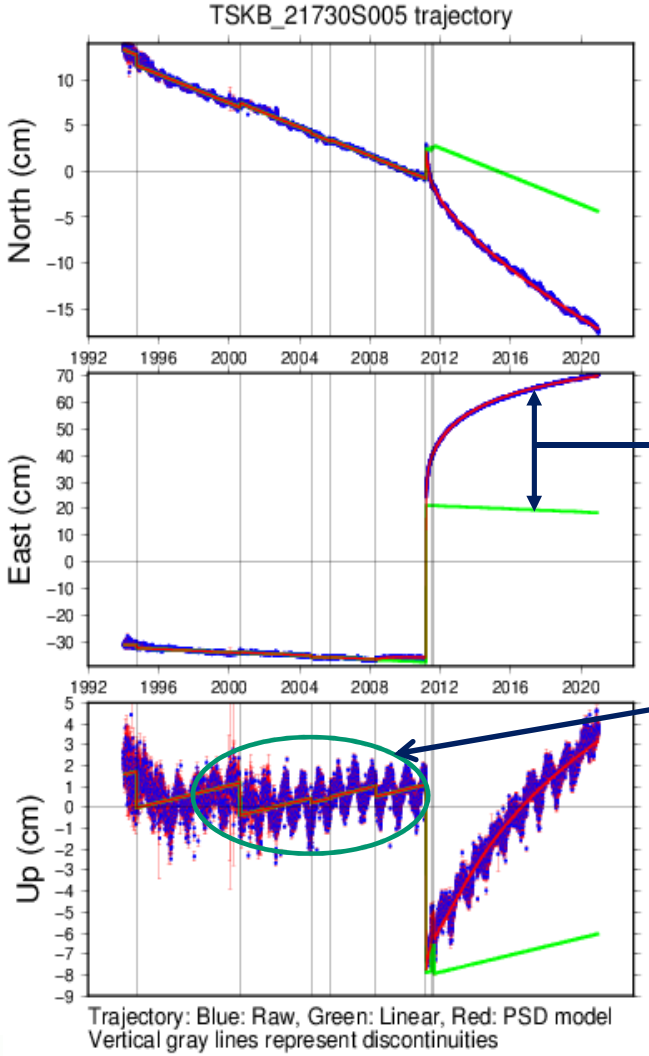
ITRF2020: Expected Sites

- 1223 sites
  - 878 Northern hemisphere
  - 355 Southern hemisphere
- 1800 stations
- 3106 discontinuities
- ~1159 GNSS sites
  - 1344 stations
  - 2938 discontinuities





ITRF2020: Augmented Parametric Reference Frame



Regularized position

$$X(t) = X(t_0) + \dot{X}.(t - t_0) + \delta X(t)_{PSD} + \delta X(t)_S$$

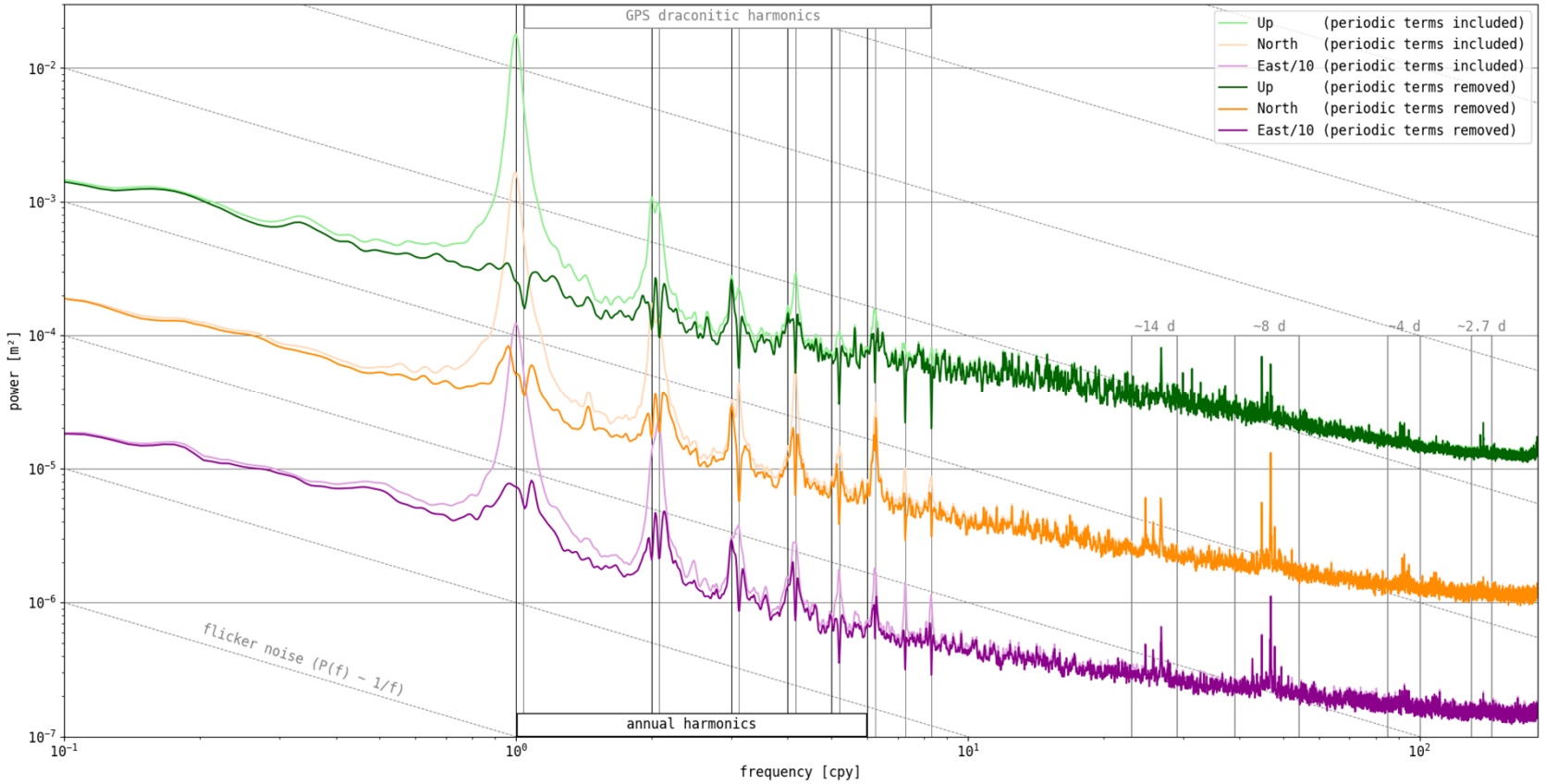
∑ Post-Seismic Deformations (PSD) Parametric models will be refined

∑ Seasonal Signals will be provided in the CM-SLR frame

But there are discrepancies in the annual signal between techniques at some colocation sites.

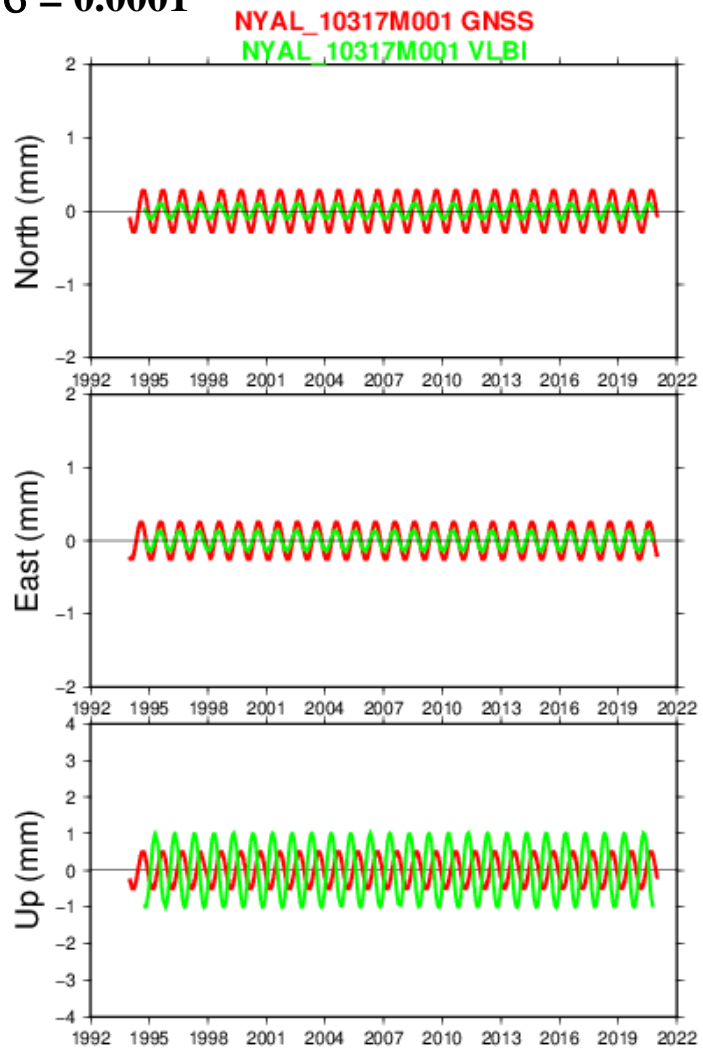
IGS Repro3 Residual Periodogram

10 Frequencies were estimated: Annual, semi-annual + 8 GPS draconitic harmonics

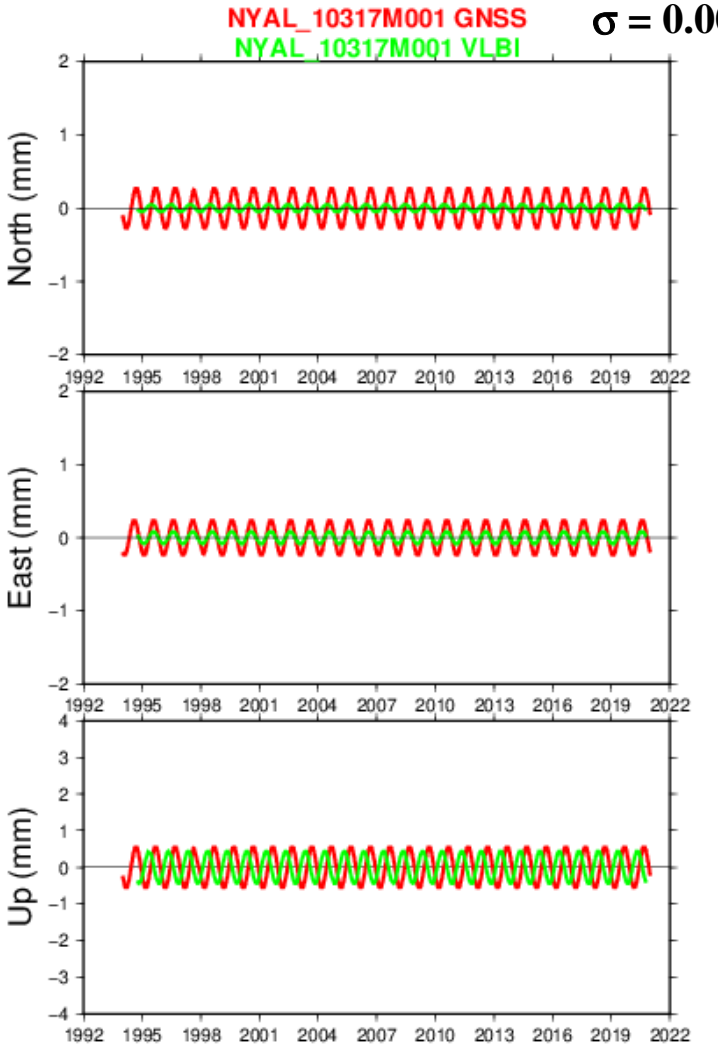


(Ny-Alesund): Annual frequency residual

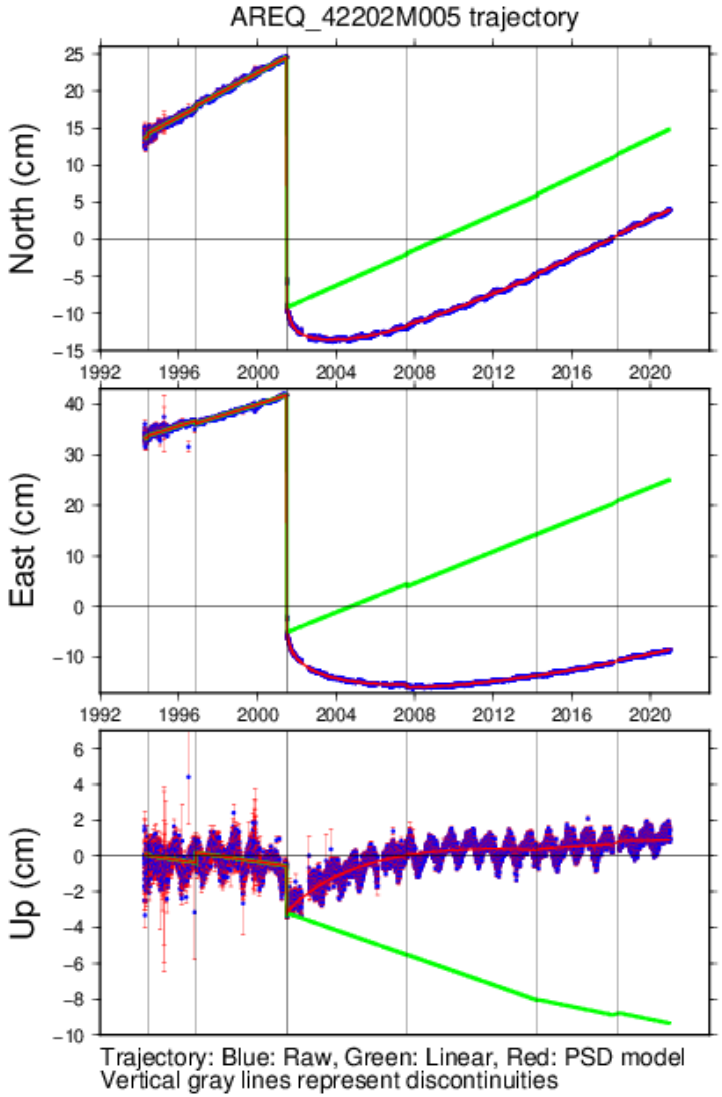
σ = 0.0001

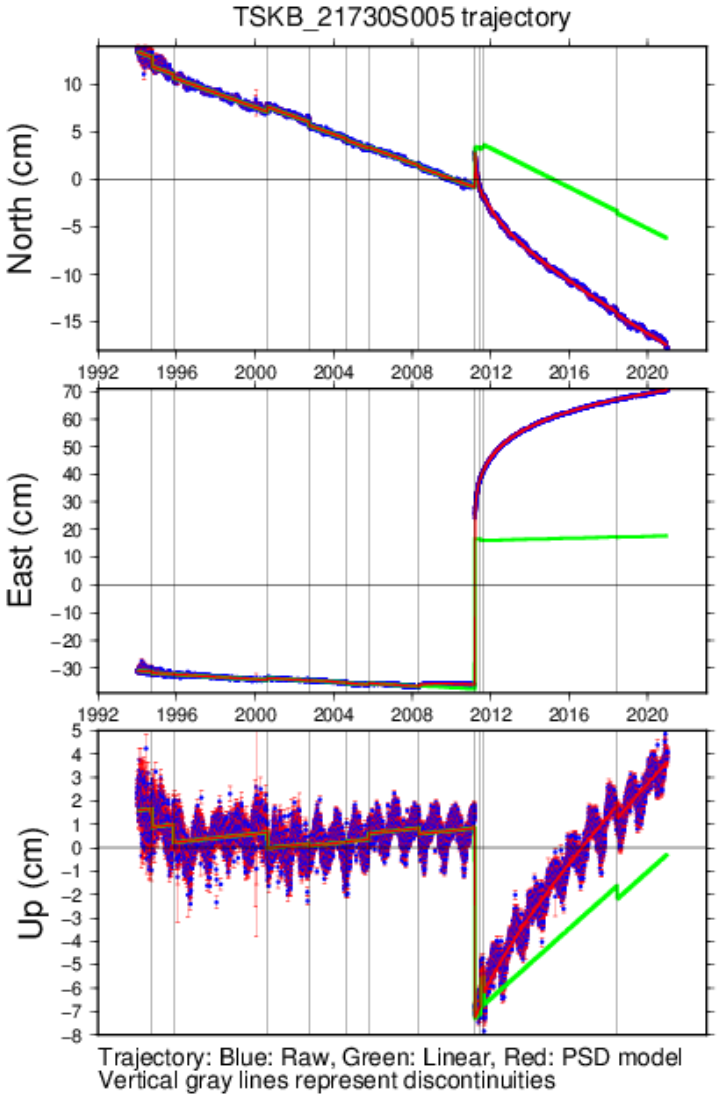


σ = 0.001



Arequipa & Tsukuba trajectories





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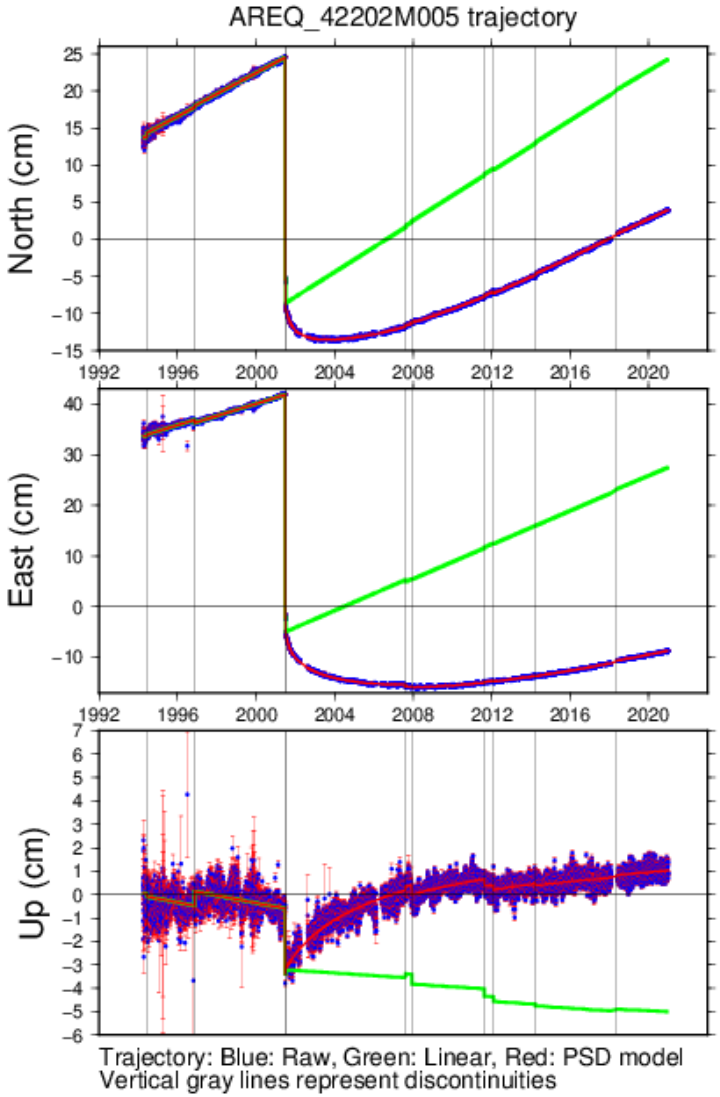
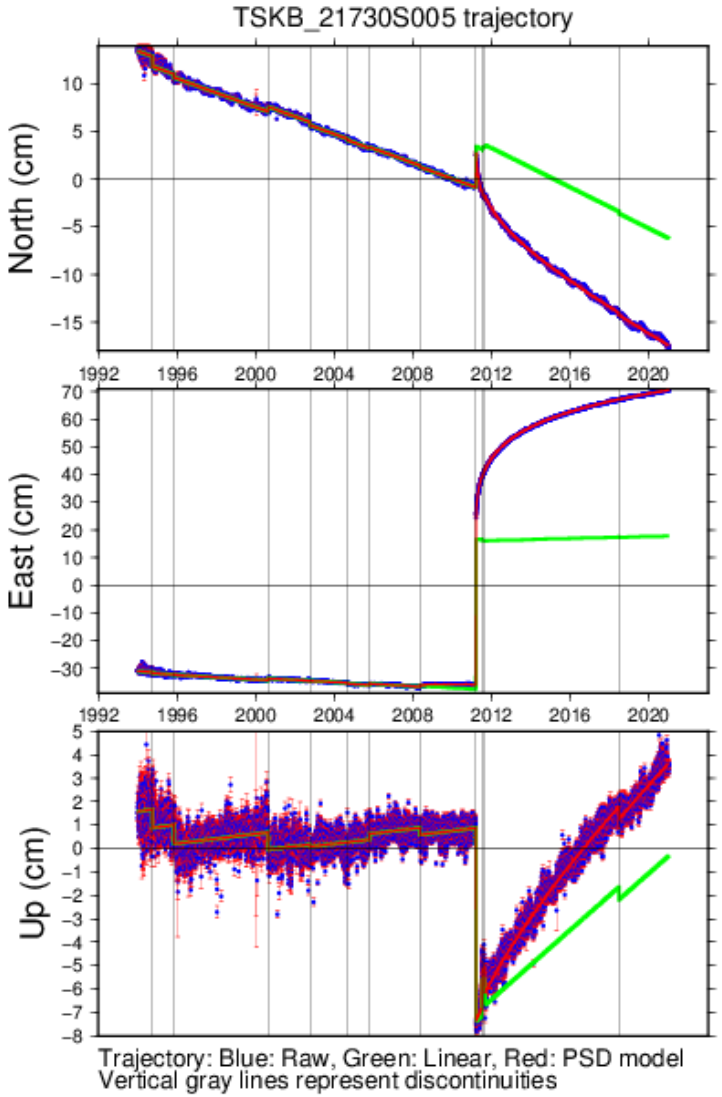
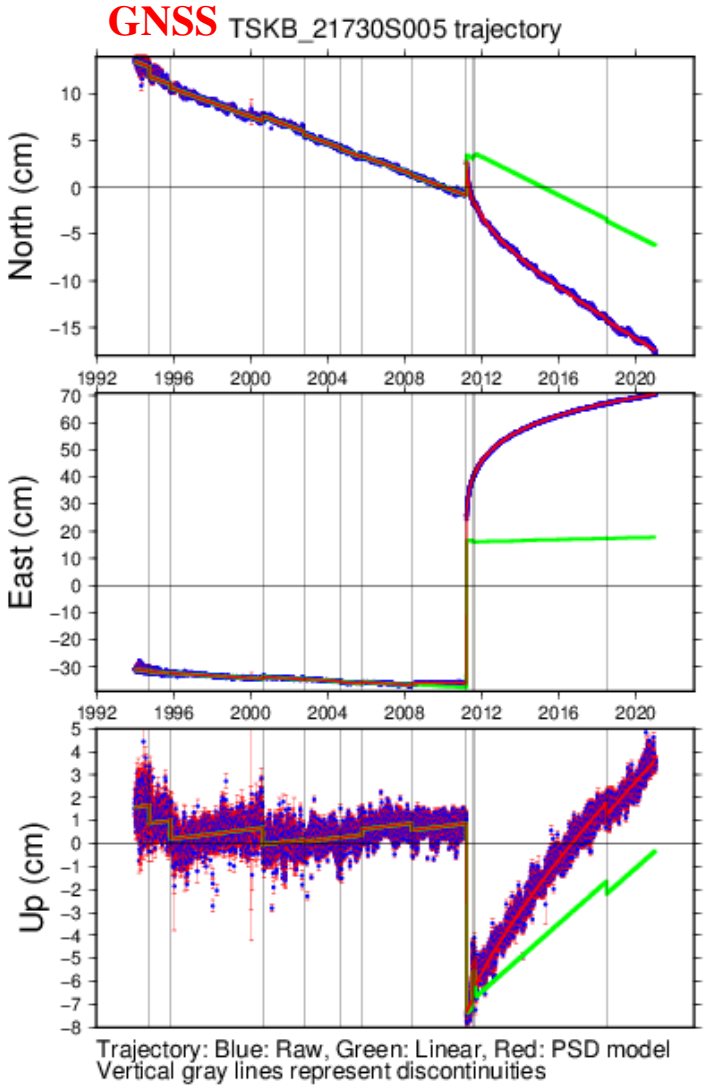
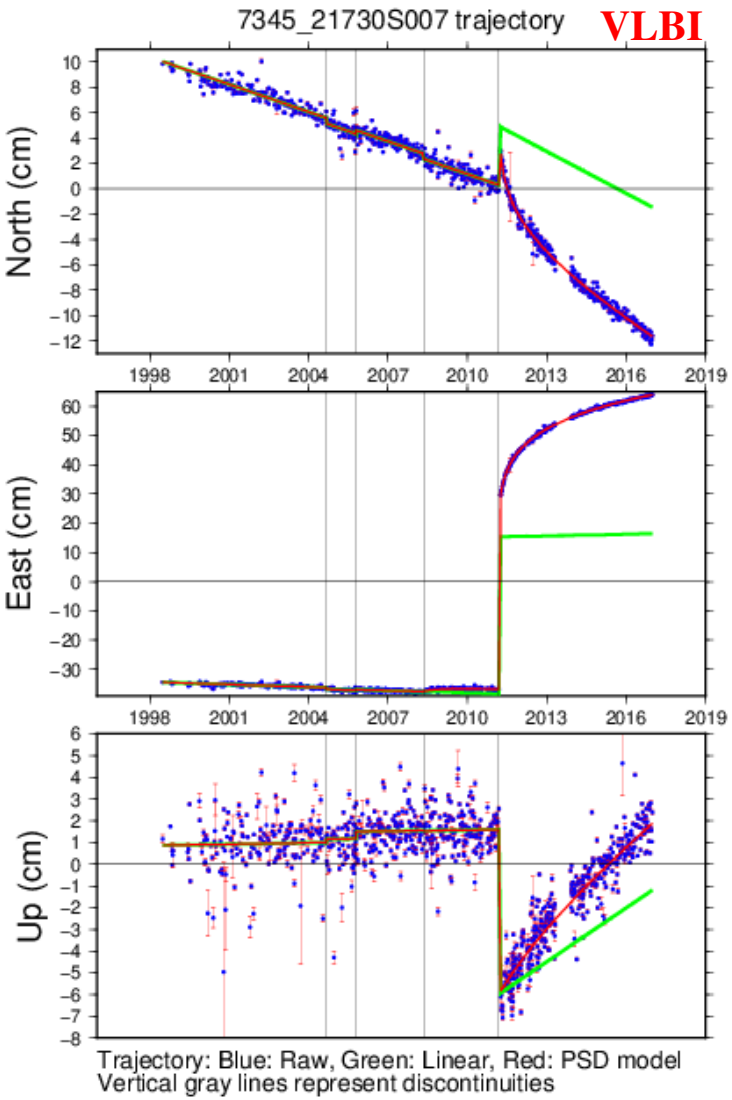


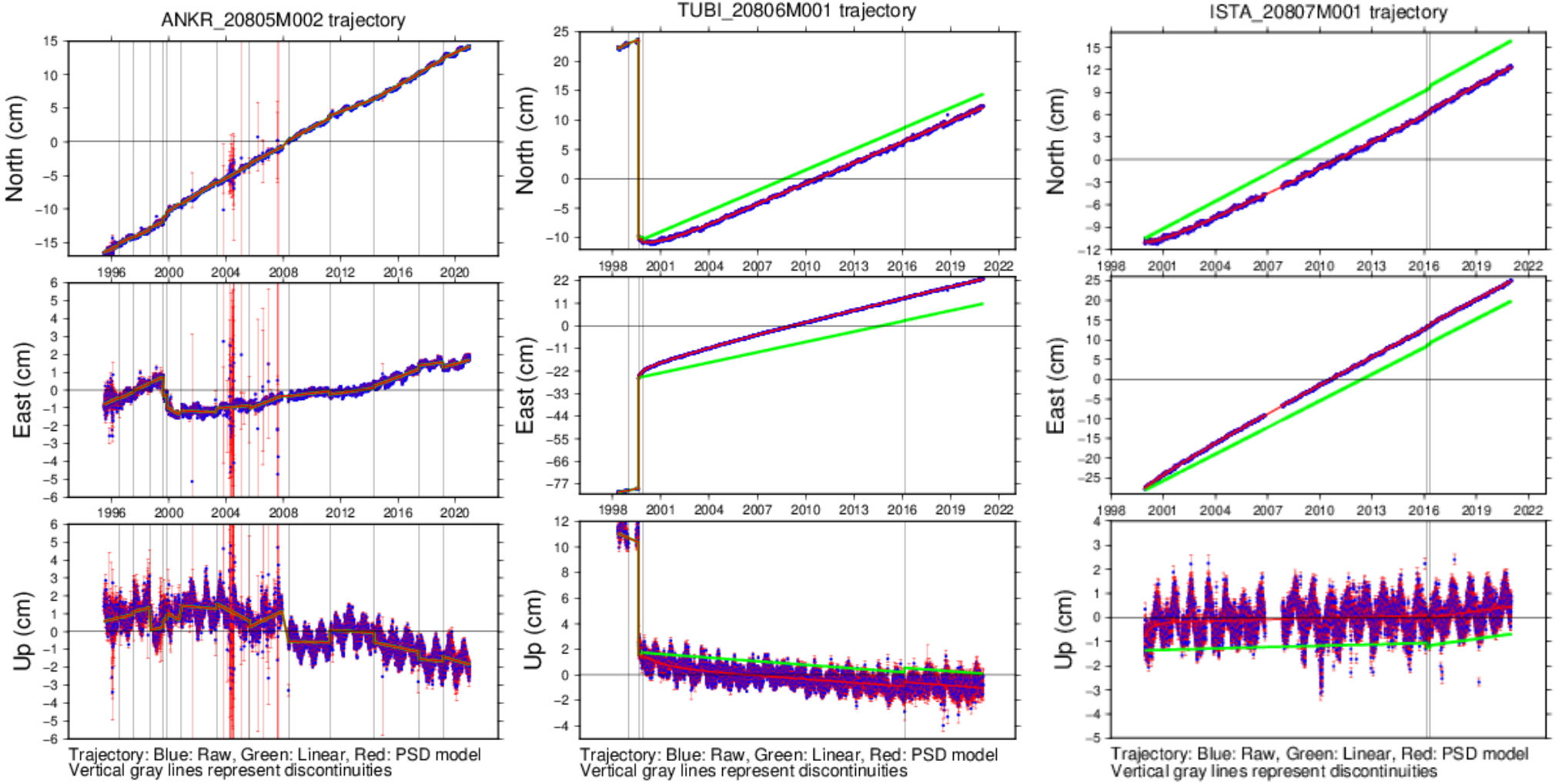


Tsukuba trajectories : GNSS & VLBI

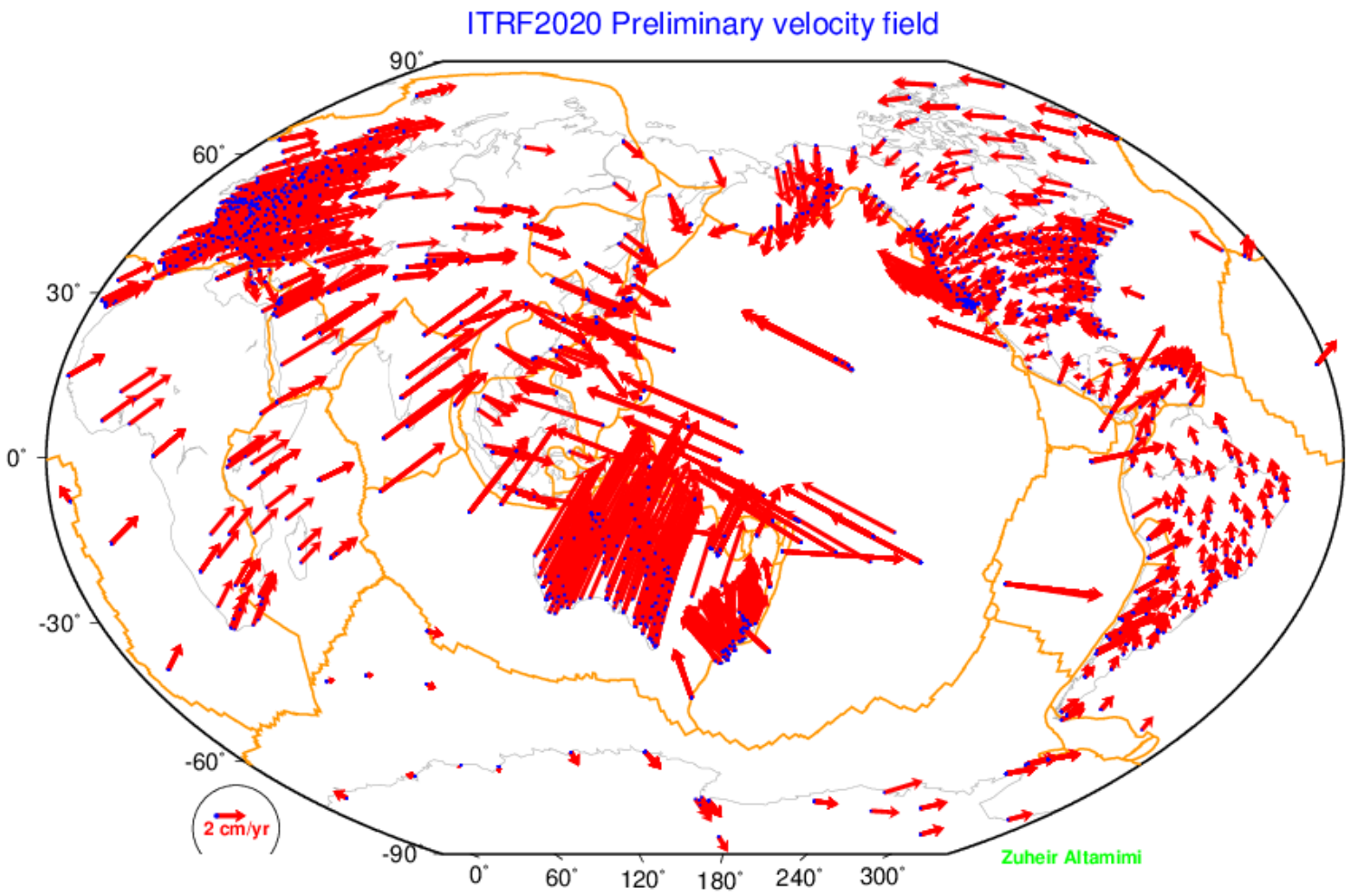




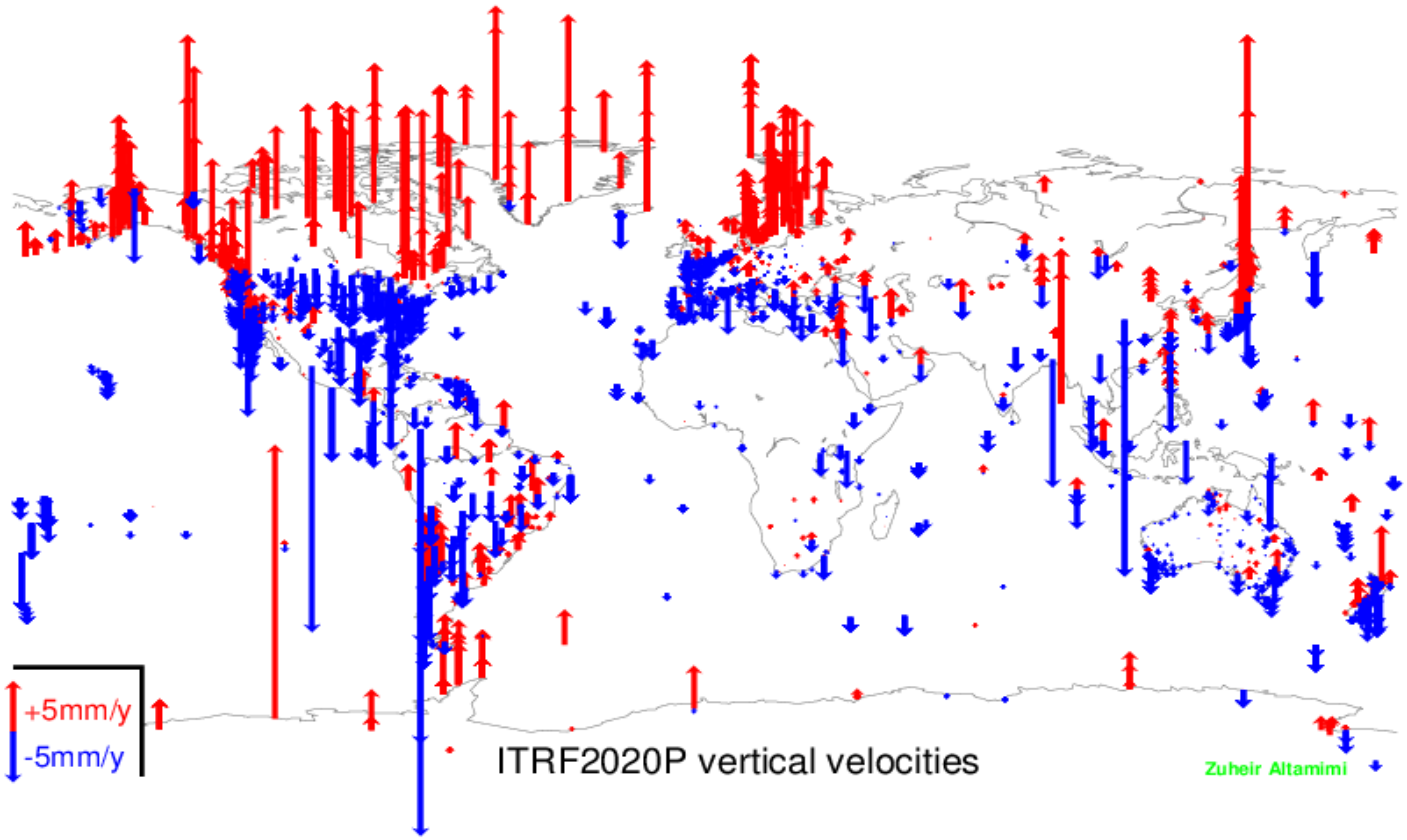
ANKR, TUBI & ISTA



ITRF2020: Preliminary horizontal velocity field



ITRF2020: Preliminary vertical velocity field



Scale of ITRF2020?

- **This is the first time of ITRF history where we have 4 independent and competitive scales stemming from the 4 techniques (DORIS, GNSS, SLR and VLBI)**

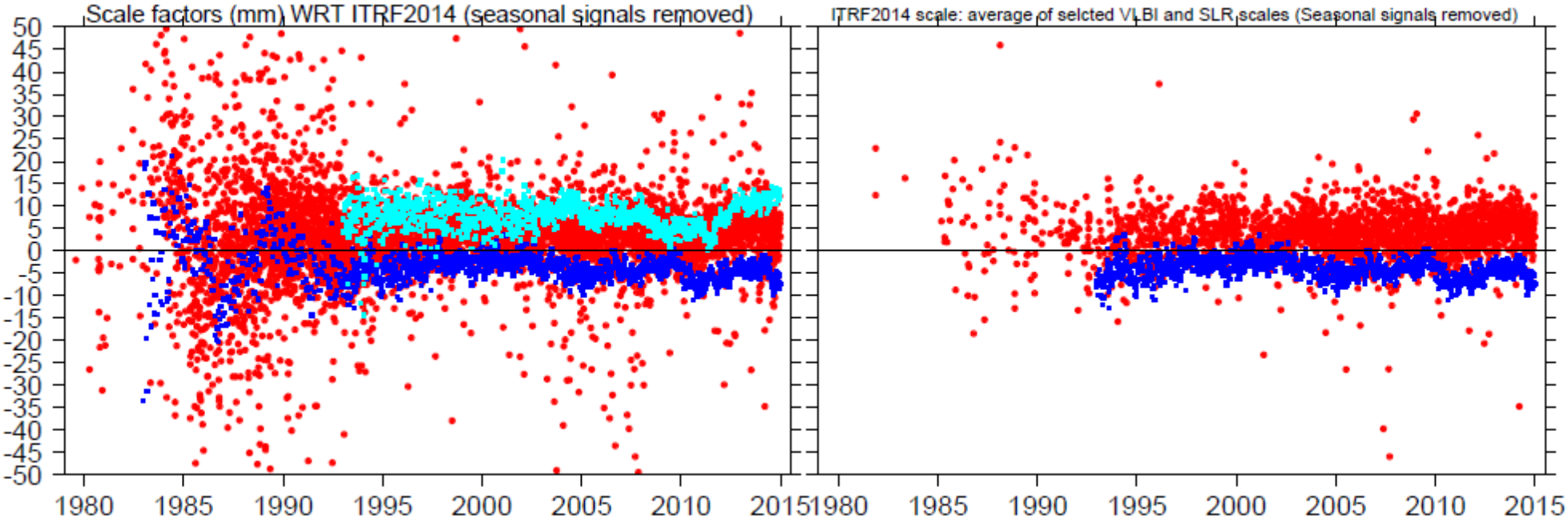
- **IGS / GNSS scale is based on z-PCOs for Galileo Satellites, using 3.7 yrs of Galileo data**

- **Improved ILRS / SLR scale determination with enhanced handling of range biases**

DORIS, SLR & VLBI scales wrt ITRF2014

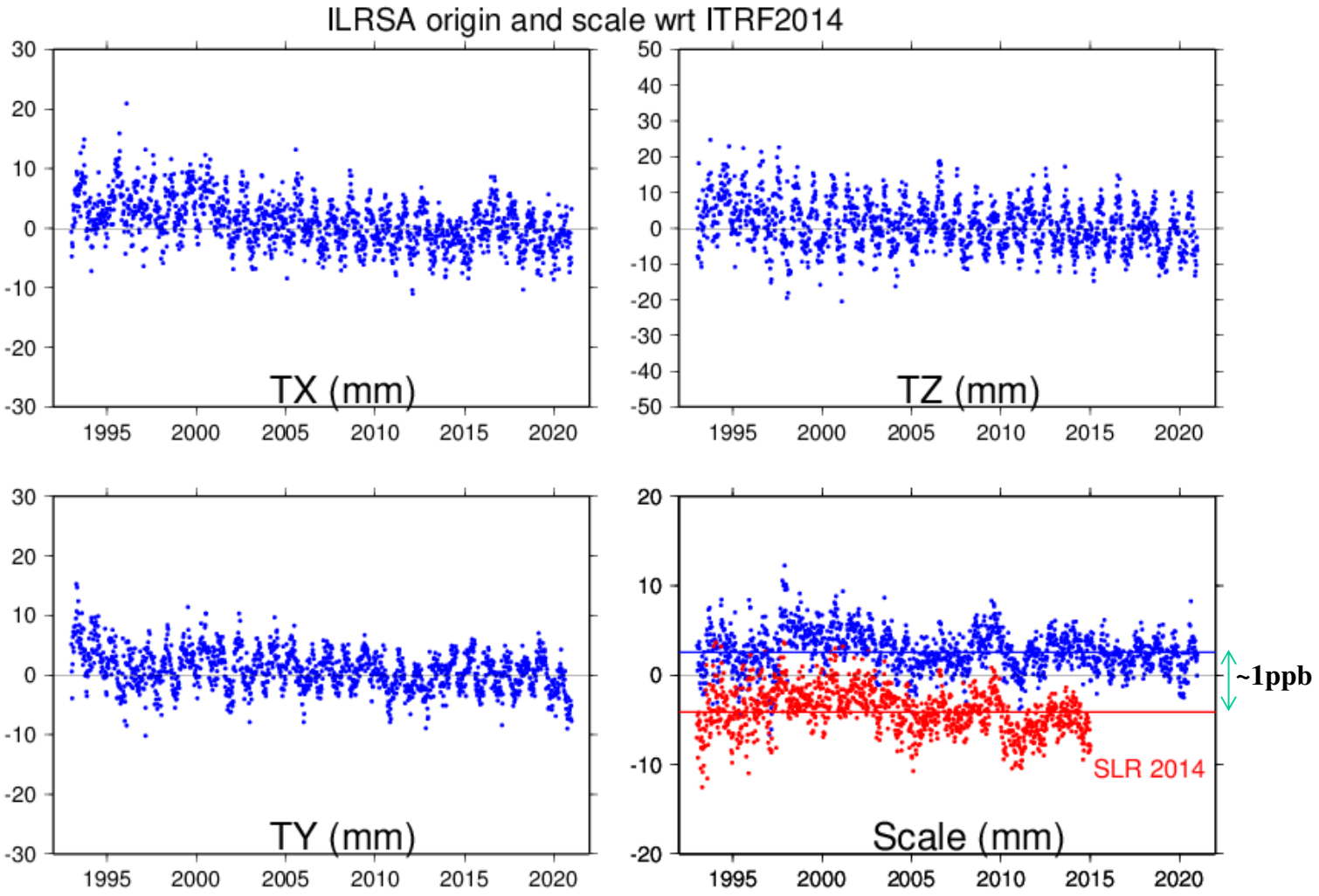
Full time series of scale factors

Scale factors of SLR and VLBI solutions selected to define ITRF2014 scale



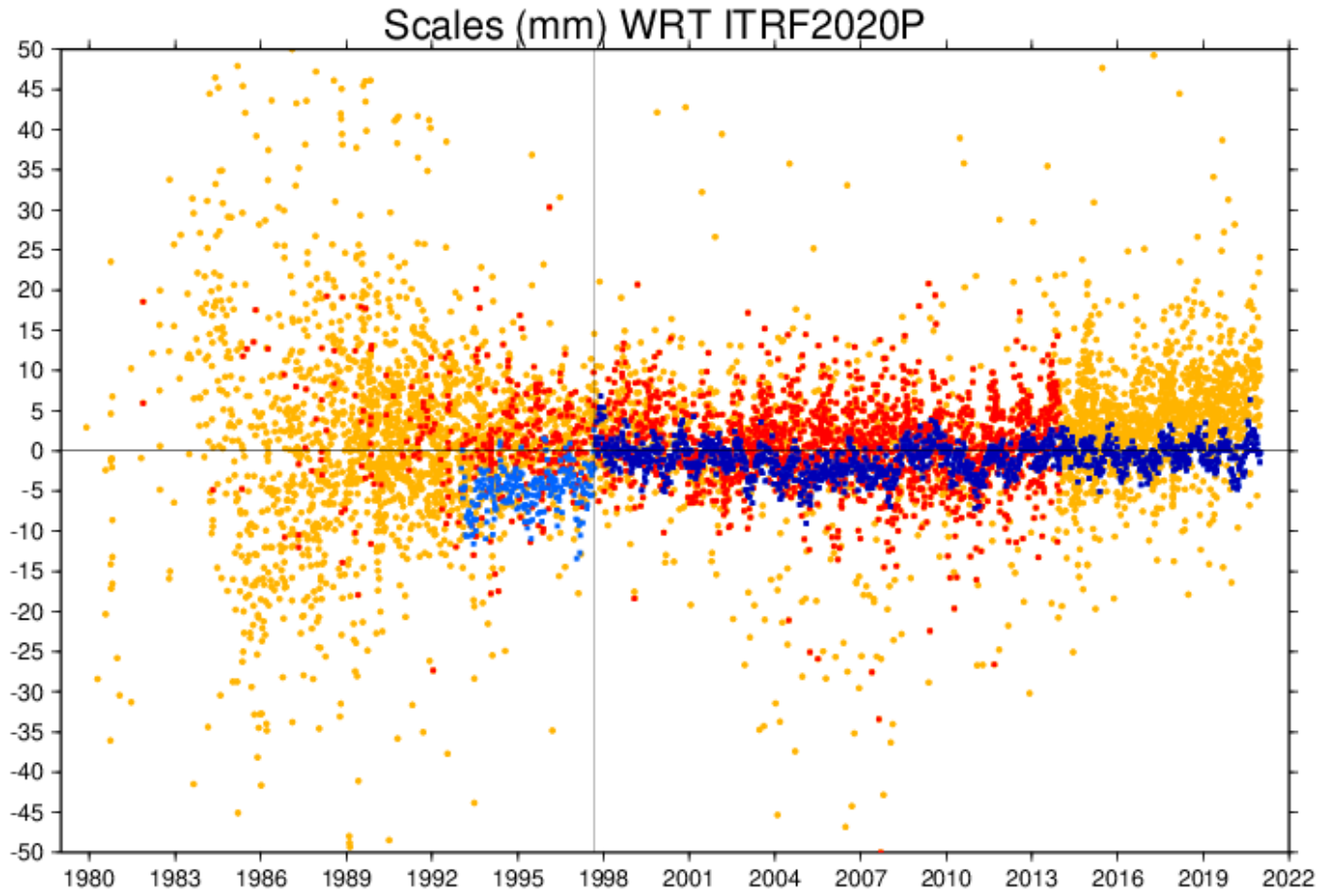
DORIS **SLR** **VLBI**

ILRSA 2020 origin & Scale wrt ITRF2014



ITRF2020 Preliminary: Relative scales

- Orange: all VLBI Sessions
- Red: Selected VLBI Sessions
- Light blue: all SLR time series
- Dark blue: Selected SLR time series

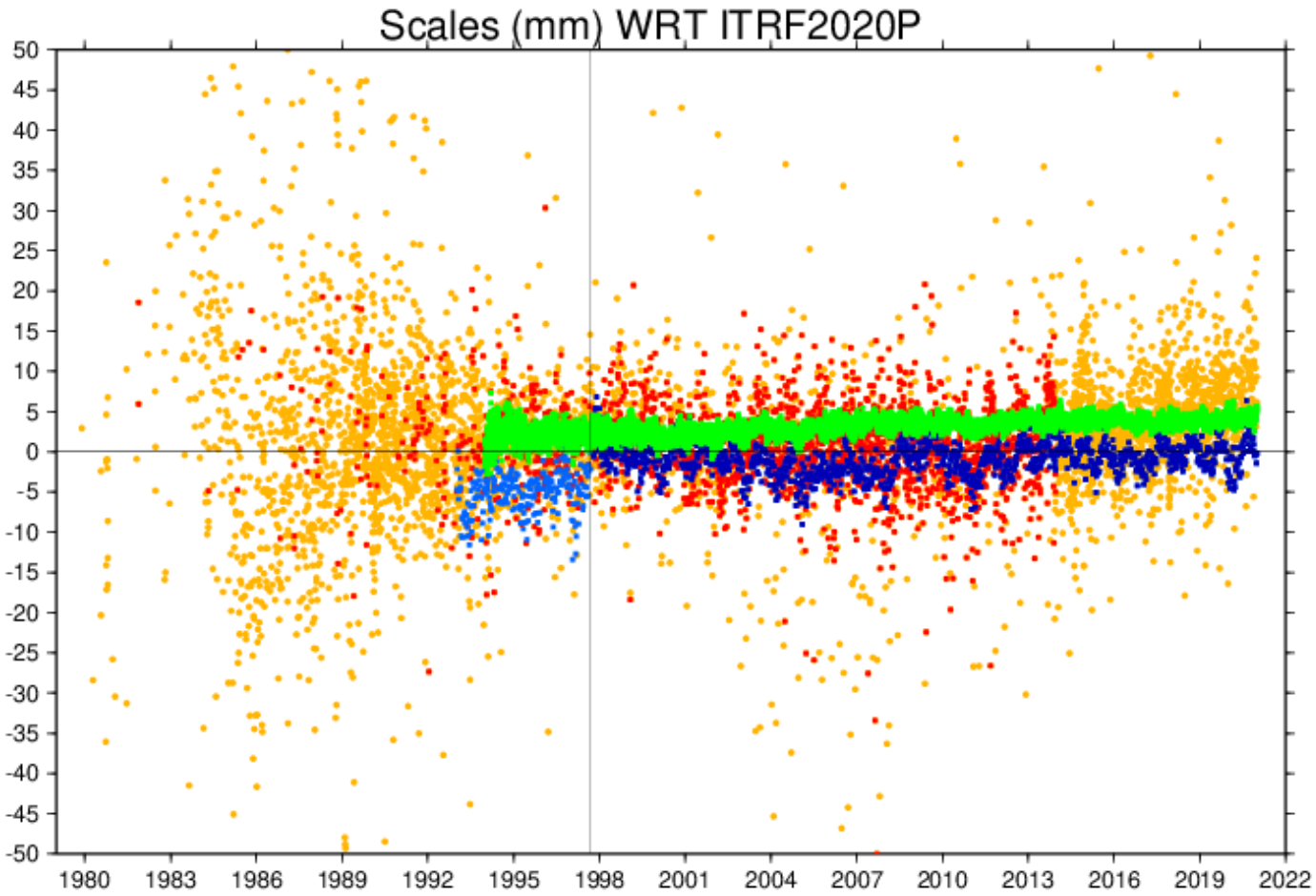


Scale offset SLR to VLBI (at 2015.0) = ~0.22 ppb (~1.4 mm)

ITRF2020P scale definition: VLBI red + SLR dark blue = 0

ITRF2020 Preliminary: Relative scales

- Orange: all VLBI Sessions
- Red: Selected VLBI Sessions
- Light blue: all SLR time series
- Dark blue: Selected SLR time series
- Green: IGS/Repro3

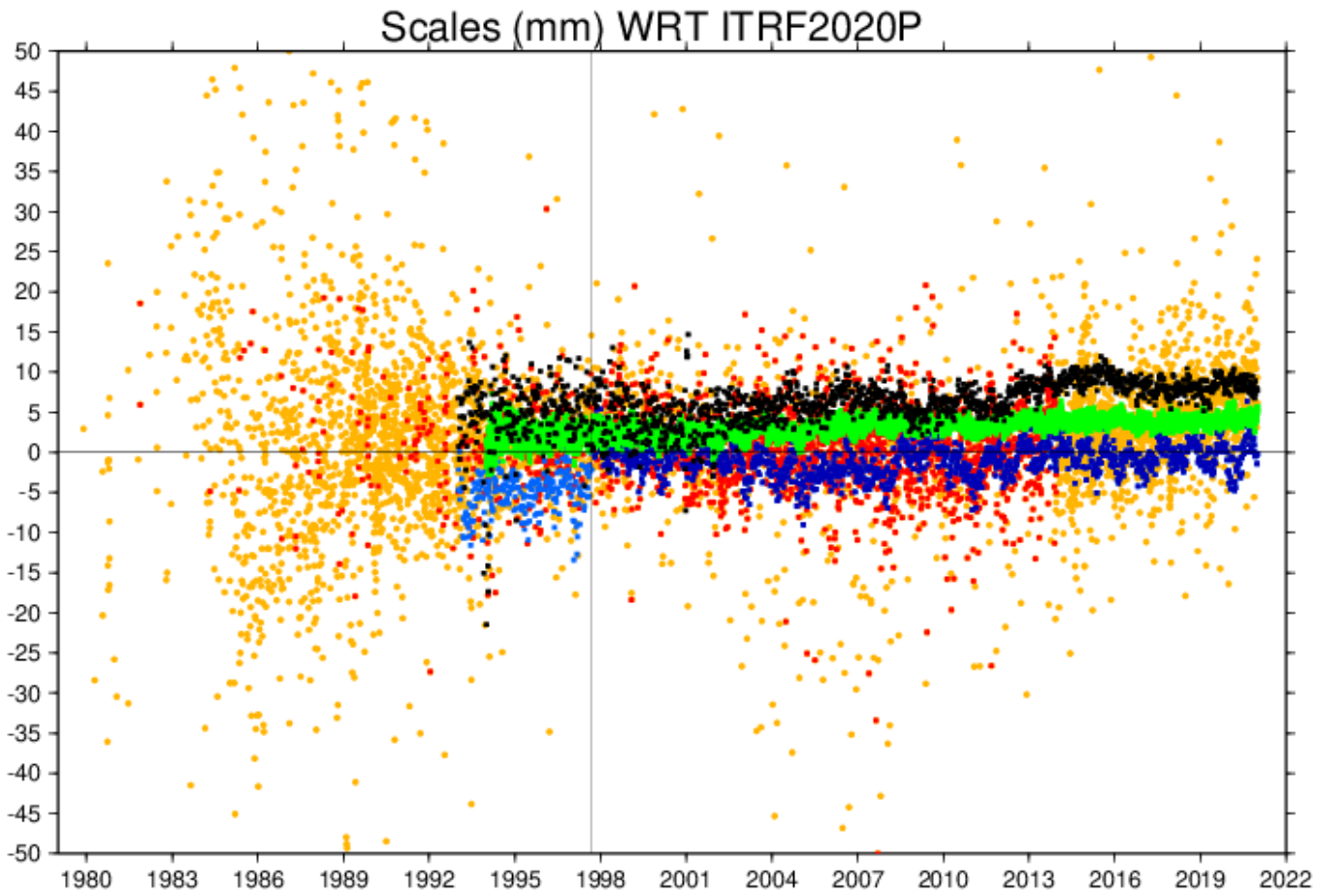


ITRF2020P scale definition: VLBI red + SLR dark blue = 0

ITRF2020 Preliminary: Relative scales

- Orange: all VLBI Sessions
- Red: Selected VLBI Sessions
- Light blue: all SLR time series
- Dark blue: Selected SLR time series
- Green: IGS/Repro3
- Black: DORIS

Solution	Scale at 2015 (ppb)	Scale rate ppb/yr
IGS	0.646 *±0.058*	0.016 *±0.004*
IVS	0.111 *±0.052*	0.001 *±0.004*
ILRS	-0.111 *±0.052*	-0.001 *±0.004*
IDS	1.347 *±0.090*	0.025 *±0.010*



ITRF2020P scale definition: VLBI red + SLR dark blue = 0

Conclusion

- **ITRF2020: an augmented parametric frame**

- **ITRF2020 Scale:**
  - **Expected scale difference between SLR & VLBI:**

    ~ 0.22 ppb (~1.4 mm), versus 1.37 ppb (~8.2 mm) in ITRF2014
  - **The ITRF2020 scale will be determined using inner/internal constraints**
  - **Average of SLR (1997.7 – 2021.0) and VLBI (selected session up to 2014.0)**

- **ITRF2020P (Preliminary) Solution expected to be ready soon, will be submitted to the techniques for evaluation**