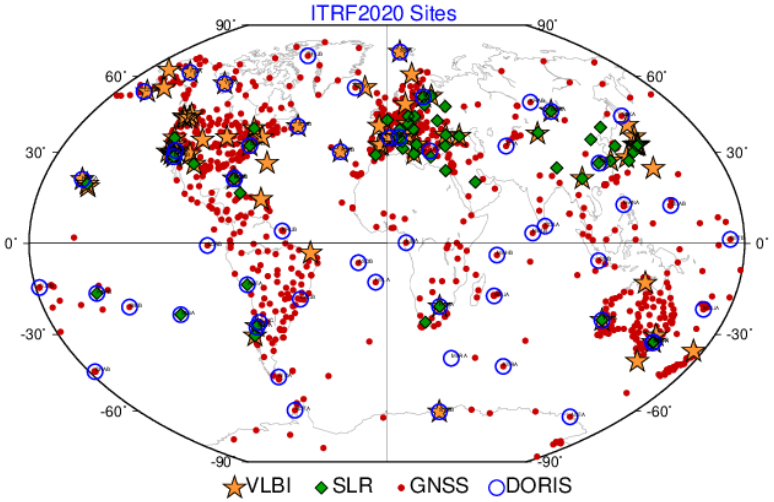
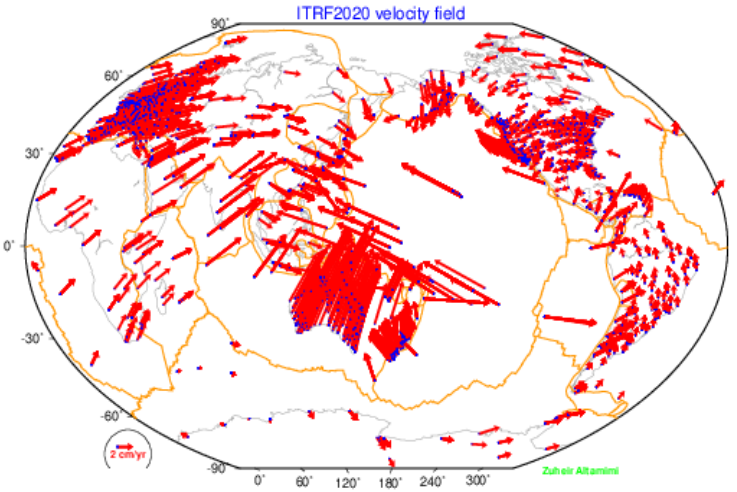
ITRF2020, son usage et perspectives



Zuheir Altamimi
Paul Rebischung
Maylis de La Serve
Xavier Collilieux
Laurent Métivier
Kristel Chanard

IGN-IPGP, France



Outline

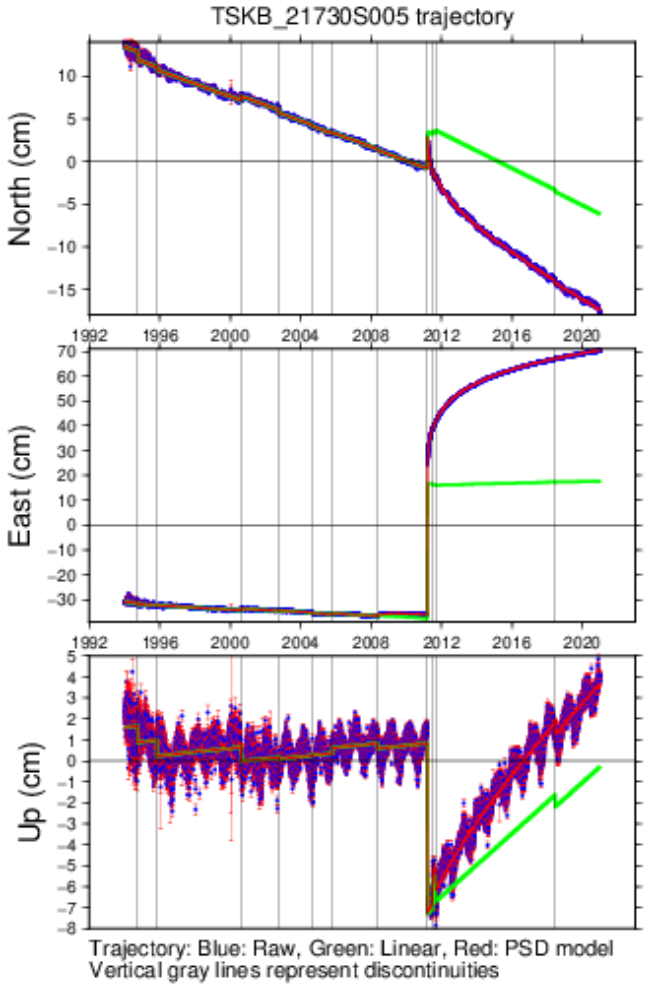
- Introduction
- Reference frame representations and:
  - The reality of a deformable Earth
  - Technique systematic errors
  - User needs

- ITRF2020:
  - Innovation: modeling of nonlinear station motions : seasonal signals & post-seismic deformation
  - ITRF2020 kinematic model and its usage

- Perspectives

“Motions” of the deformable Earth

- **Nearly linear motion:**
  - Tectonic motion
  - Post-Glacial Rebound
- **Nonlinear motion:**
  - Loading deformation, due to atmospheric pressure, hydrology and ocean circulation
  - Co- & Post-seismic deformations,
  - Transient deformations, Volcano Eruptions, local events…



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: Long-Term Frame + nonlinear parametric functions (==> ITRF2020):**

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

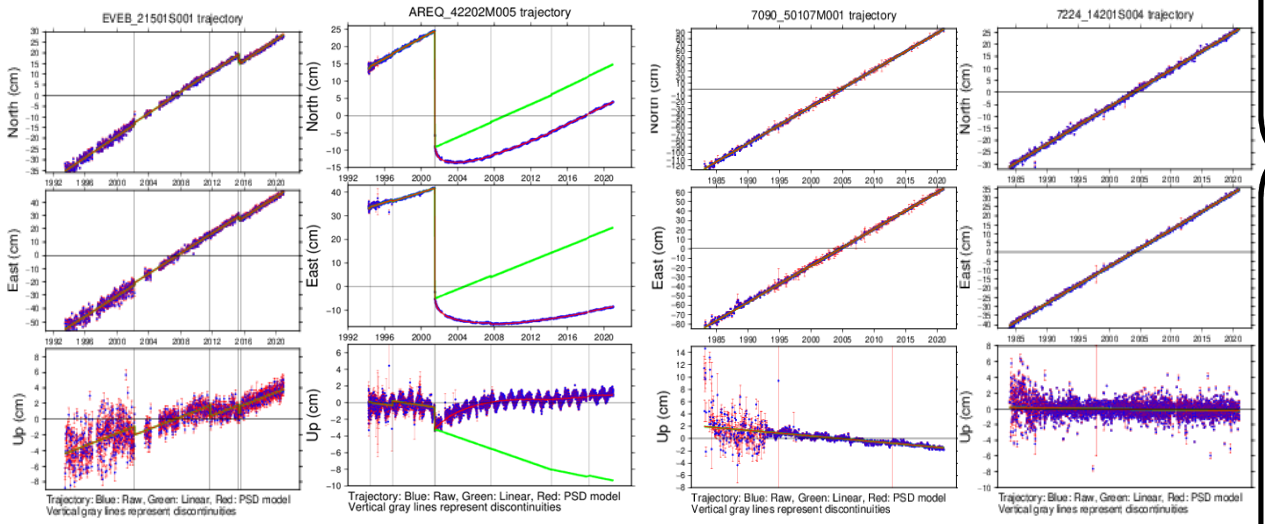
  - **Non-parametric RF: Time series of "Quasi-Instantaneous" reference frames**
    - **Daily or weekly representations**
    - **Nonlinear motion embedded in their time series**
    - **Still rely on the ITRF for at least the orientation definition**

The International Terrestrial Reference Frame (ITRF):

- **Realized and maintained by the ITRF Center hosted by IGN**
- **By combination of DORIS, GNSS, SLR and VLBI station position time series**

Input

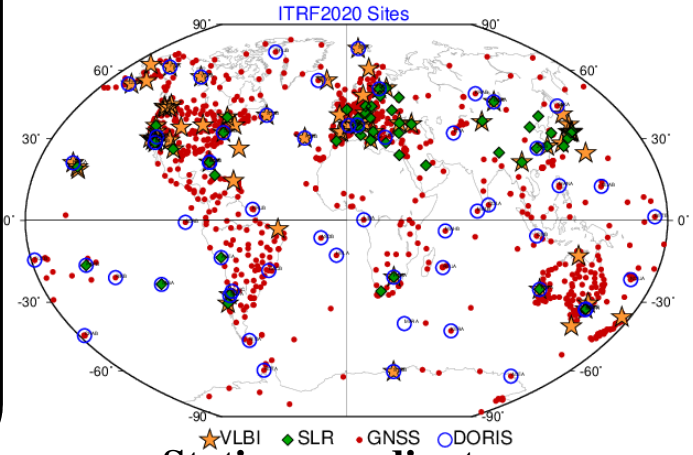
DORIS Weekly
GNSS Daily
SLR Weekly
VLBI Session-wise



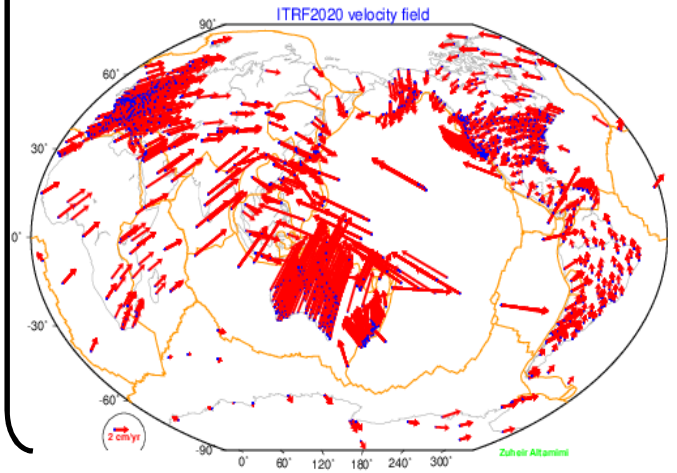
Fundamentally based on Co-location Sites

Time series analysis & stacking (CATREF Software)

Output



Station coordinates



Station velocities

++

Why is the ITRF needed?

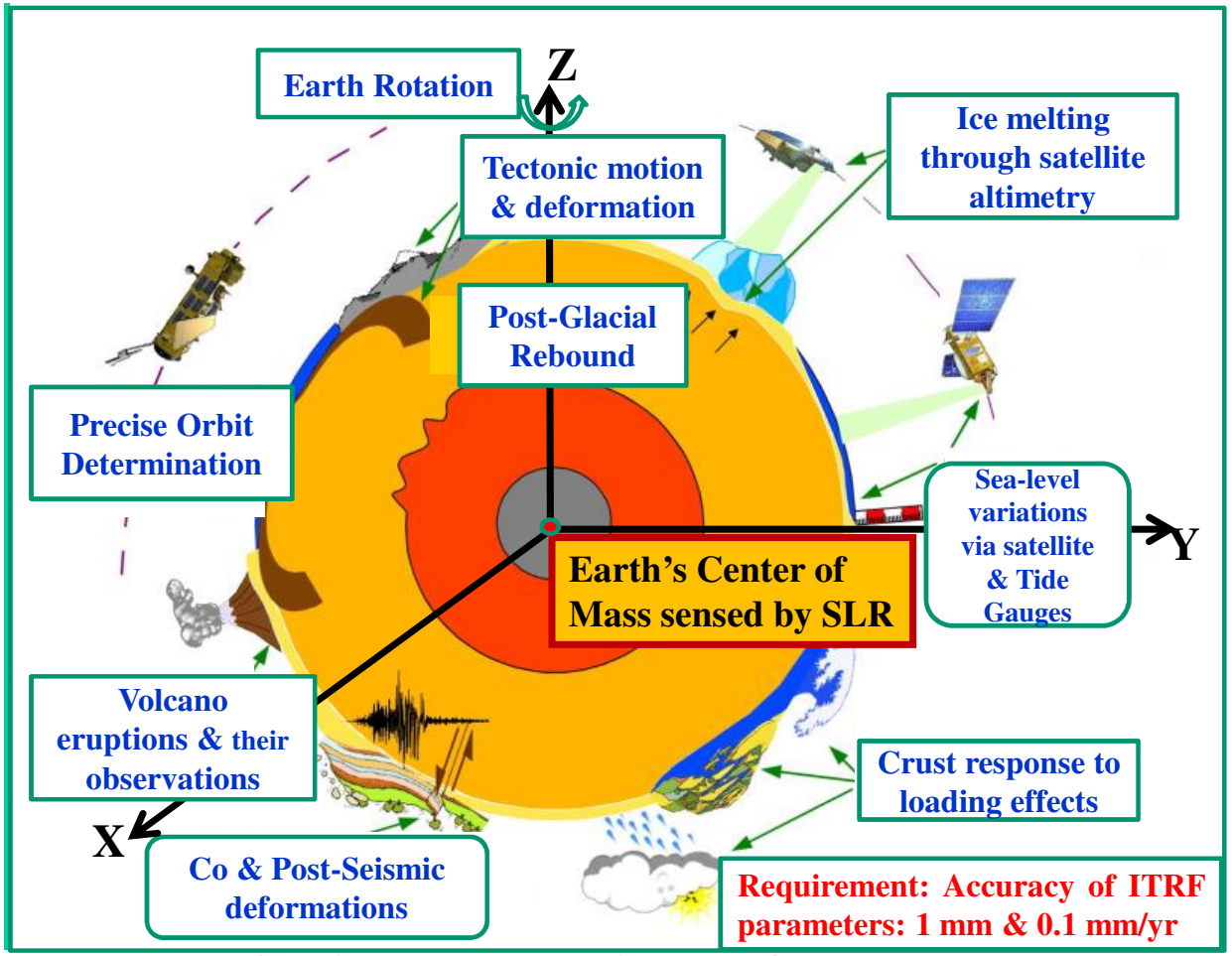
Operational geodesy applications:

- Positioning : Real Time or a posteriori
- Navigation: Aviation, Terrestrial, Maritime
- National geodetic systems/frames
- Today: via GNSS only!
- Require the availability of the orbits and the reference frame (ITRF)
- Many, many users…

GNSS-specific reference frames:

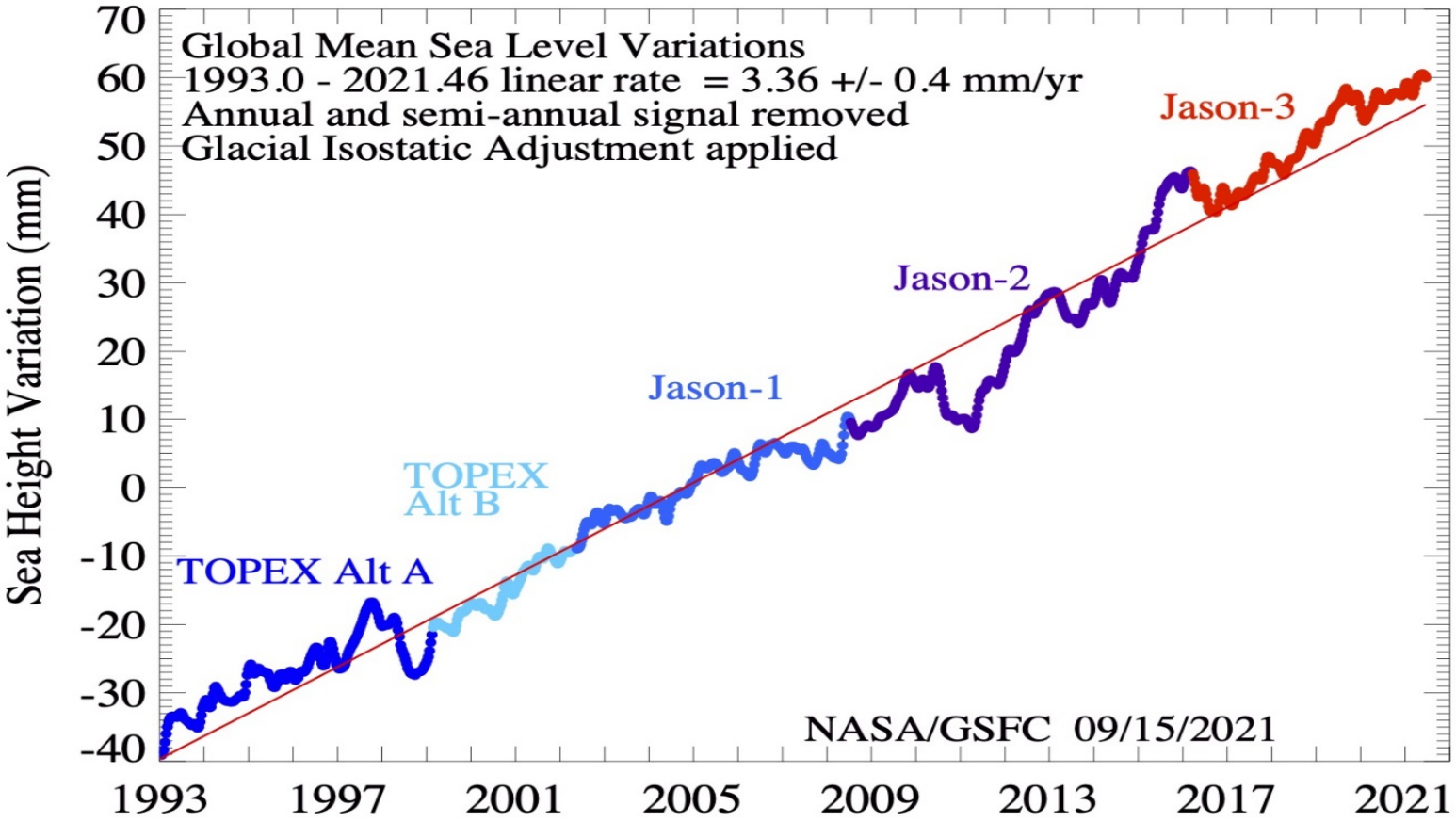
- GTRF/Galileo, WGS84/GPS, PZ-90/GLONASS, CGCS2000/Beidou, JGS/QZSS
- All are aligned to the ITRF

Scientific Applications:



Continuous observations are fundamental

Mean sea level change



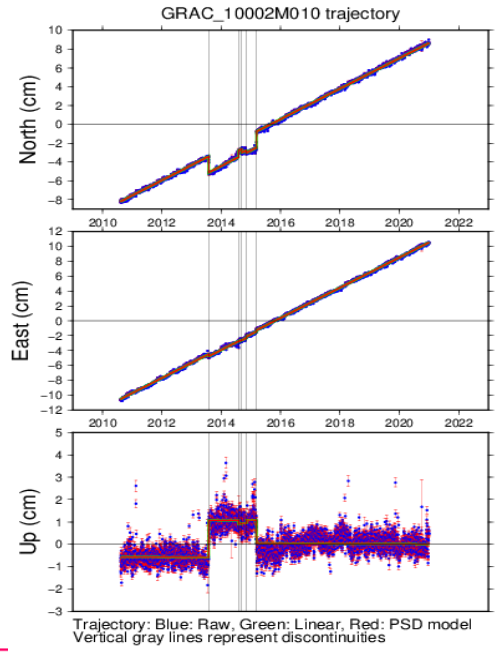
A small drift of 1 mm/yr in the ITRF origin, translates into an apparent 0.9 mm/yr sea level rise at high latitudes, via the POD

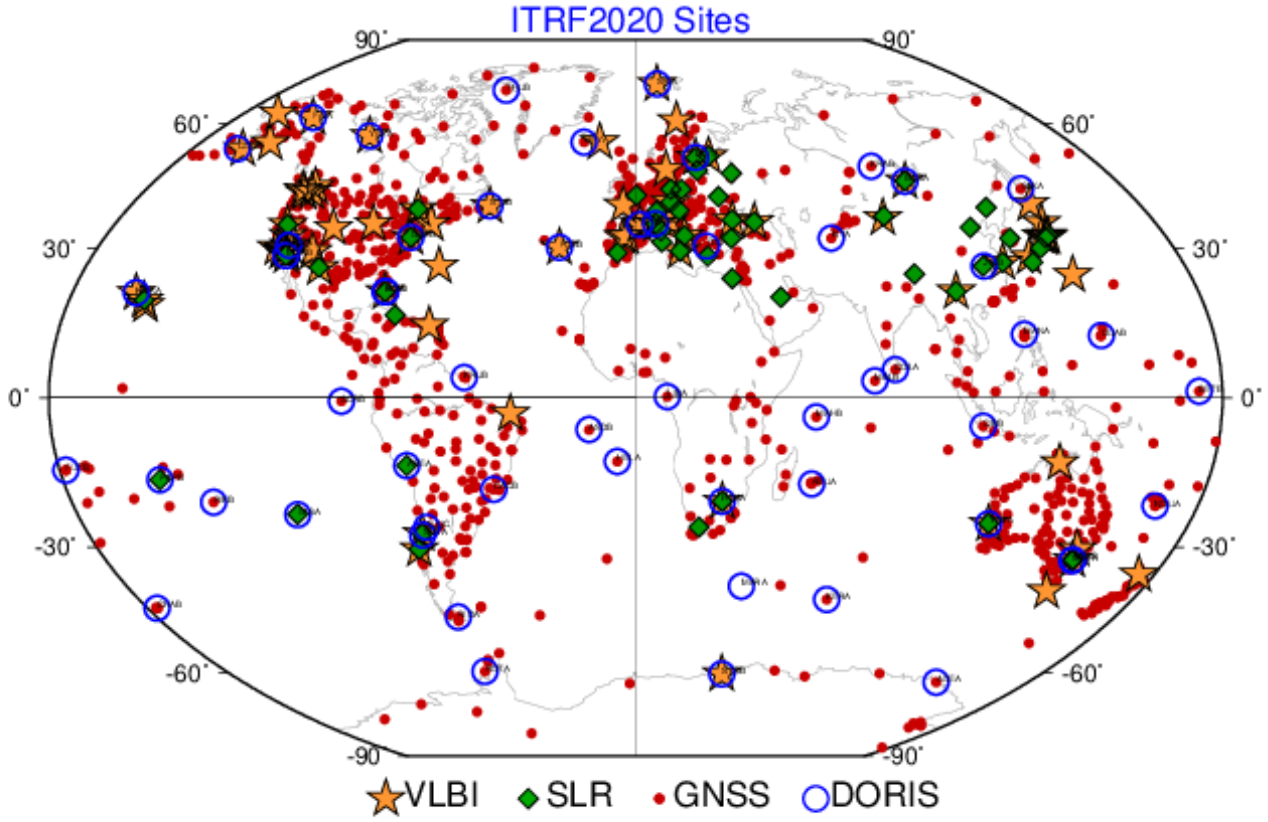
Resolutions on ITRS & ITRF

- **IUGG2007: adopted the ITRS as the preferred Geocentric Terrestrial Reference System (GTRS) for scientific and technical applications**
- **CGPM2011: recommends that the ITRS, as defined by the IUGG and realized by IERS, be adopted as the unique international reference system for terrestrial reference frames for all metrological applications**
- **ICG2012: recommendation to align GNSS-specific reference frames (WGS84, PZ90, GTRF, CGCS2000, JGS) to the ITRF**
- **IUGG2019: recommend to the user community that the ITRF be the standard for positioning, satellite navigation and Earth Science applications, …**
- **UN-GGIM-2019: adoption of the ITRS and the ITRF as the standard for scientific, geospatial and operational geodetic applications**
- **ISO Standard on ITRS/ITRF**

ITRF2020 Network

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

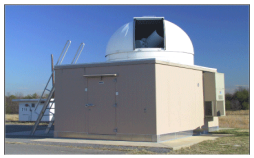




DORIS

GNSS

SLR



VLBI

ITRF2020 Analysis Strategy

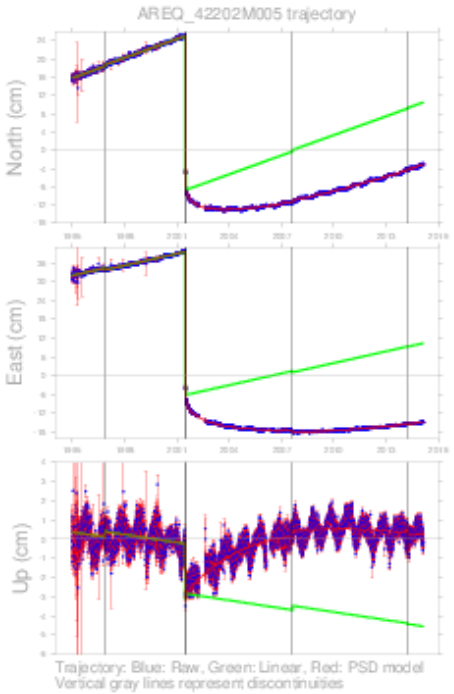
Input data: Time series:

- **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**

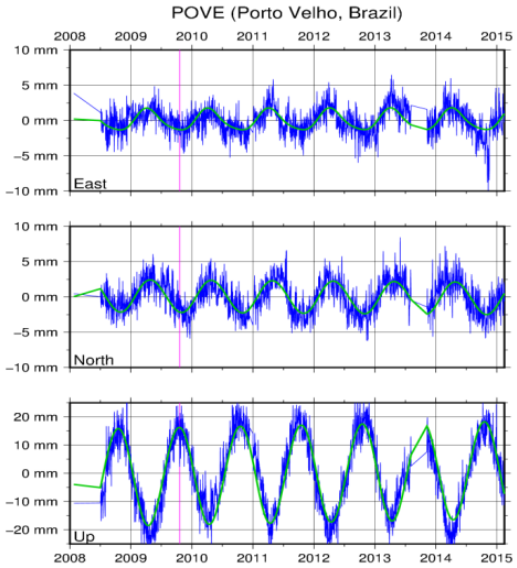
ITRF2020 Specifications:
Origin: SLR
Scale: SLR & VLBI
Orientation: Alignment to ITRF2014

ITRF2020

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

ITRF2020 Innovation: Precisely Modeling nonlinear station motions

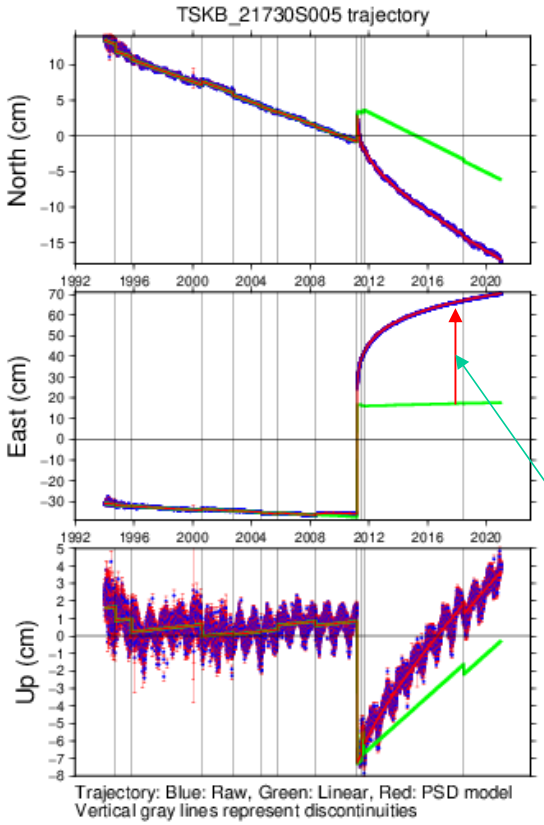
Impact of loading effects

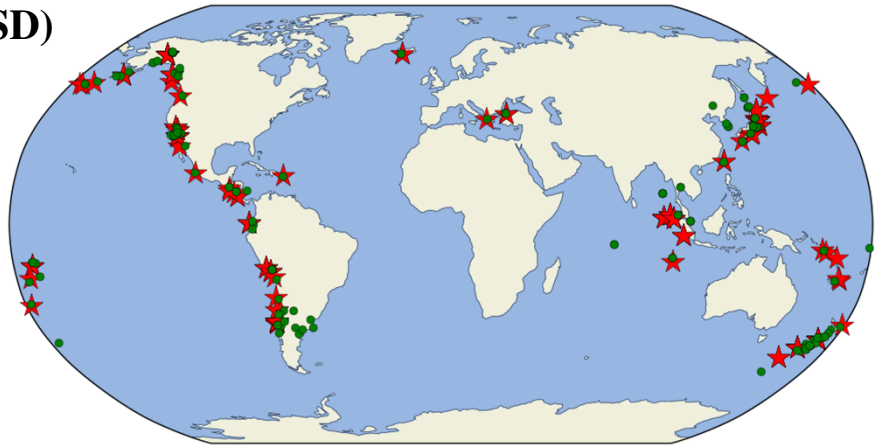


Sine wave function

$$\Delta X_f(t) = \sum_{j=1}^{n_f} a_j^i \cos(\omega_j t) + b_j^i \sin(\omega_j t)$$

Post-Seismic Deformation (PSD)
Impact of major earthquakes





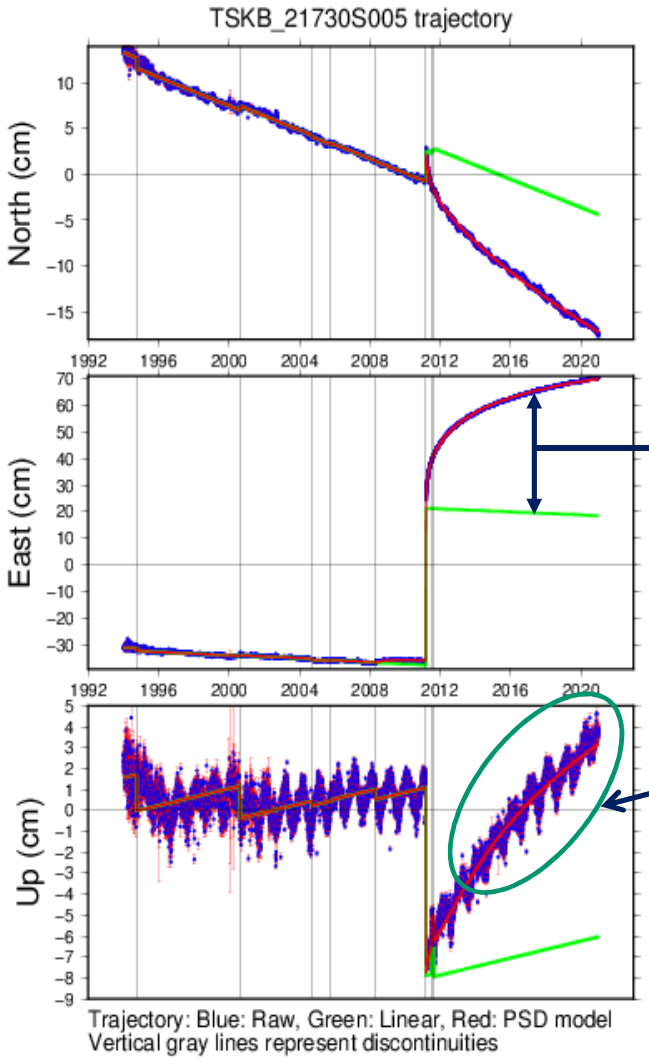
Red Stars: EQ Epicenters (65)
Green circles: ITRF2020 sites (118)

Refined PSD Parametric models:

1. Logarithmic Function
2. Exponential Function
3. Logarithmic + Exponential
4. Two Exponential Functions
5. Two Logarithmic Functions

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

ITRF2020: Augmented Parametric Reference Frame



ITRF2020 Kinematic Model:

Linear part | Nonlinear part

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

∑ Post-Seismic Deformations (PSD)
Refined Parametric models

∑ Seasonal Signals, expressed in the CM-SLR frame

Station seasonal signals, geocenter motion and the reference frame definition

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

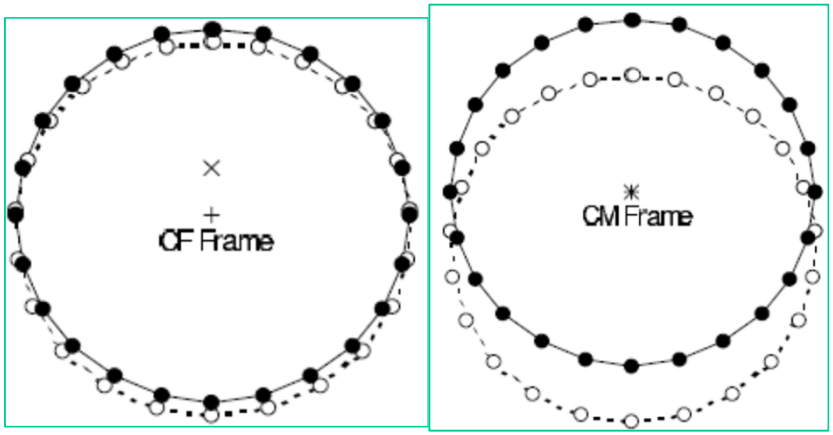
$$\delta X_f(t) = \sum_{i=1}^{2} \begin{pmatrix} a_x^i \\ a_y^i \\ a_z^i \end{pmatrix} \cos(2i\pi \cdot t) + \begin{pmatrix} b_x^i \\ b_y^i \\ b_z^i \end{pmatrix} \sin(2i\pi \cdot t)$$

- δX_f : *a* & *b* are estimated in SLR CM-frame

$X_{CM}(t) = X_{CF}(t) + \Delta X_G(t)$ (Geocenter motion)

CM : Center of Mass Frame

CF : Center of Figure Frame



(Blewitt, 2003)

		Amplitude (mm)	Phase (Degrees)
annual	X	1.23 +/- 0.16	-123.2 +/- 7.2
annual	Y	3.48 +/- 0.15	152.9 +/- 2.5
annual	Z	2.76 +/- 0.33	-139.5 +/- 6.8
Semi-annual	X	0.49 +/- 0.15	107.2 +/- 18.1
Semi-annual	Y	0.22 +/- 0.15	1.6 +/- 39.0
Semi-annual	Z	1.19 +/- 0.33	30.5 +/- 15.5

Usage of ITRF2020 Seasonal Signals

The ITRF2020 kinematic model: $X(t) = X(t_0) + \dot{X}.(t - t_0) + \delta X_{PSD}(t) + \delta X_f(t)$

Precise Orbit Determination : Use CM-based seasonal signals

Alignment of global solutions: Use either CM or CF seasonal signals

==> (1) Avoid aliasing the seasonal signals into the Helmert parameters &
(2) Seasonal signals will accurately be retained in the aligned solutions

1. **If CM: translational motion common to all stations (i.e., seasonal geocenter motion) will be transferred to the aligned solutions**
2. **If CF: the aligned solutions will be free from seasonal geocenter motion**

Alignment of local or regional solutions:

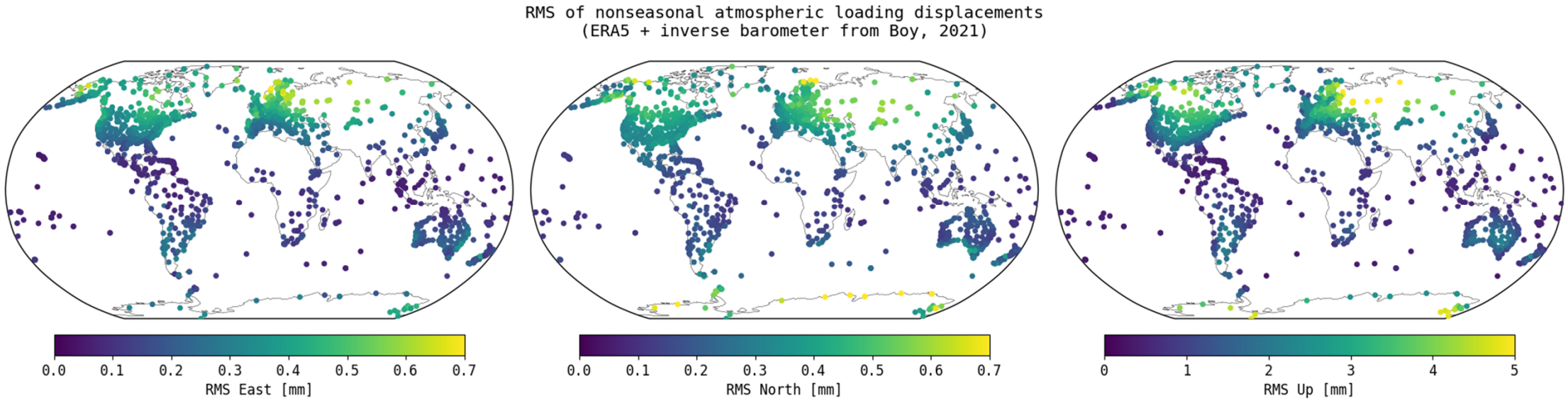
- **CM or CF seasonal signals can be used depending on the user's need**
- **Common mode will be retained in the aligned solutions**

ITRF Perspectives

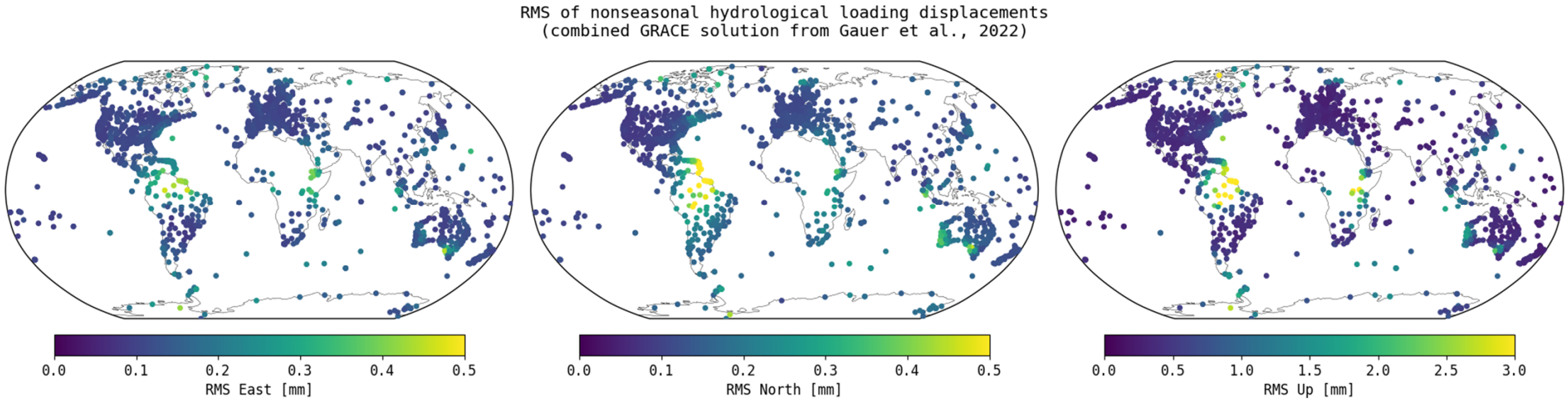
- Long-term solution (station positions and velocities) will always be needed
- How to best represent the shape of the constantly deforming Earth?
- ITRF2020 is an augmented TRF: linear part + nonlinear part (PSD & Seasonal signals)
- What is left to be modeled?
- Aperiodic signals/displacements ? Expected magnitude?
  - Nonseasonal loading effects ?
    - High frequency atmospheric loading : up to 5 mm RMS in Up
    - Inter-annual hydrological loading : up to 5 mm RMS in Up
    - Residual displacements due to current ice melting for some locations few mm ?

  ==> Geographically localized deformation (see illustrations next slides)
  - Other displacements?
    - Poro elastic, thermo elastic deformation, slow tectonic shifts?.. : few mm ?

RMS of nonseasonal atmospheric loading displacements (ERA5 + IB from Boy 2021)



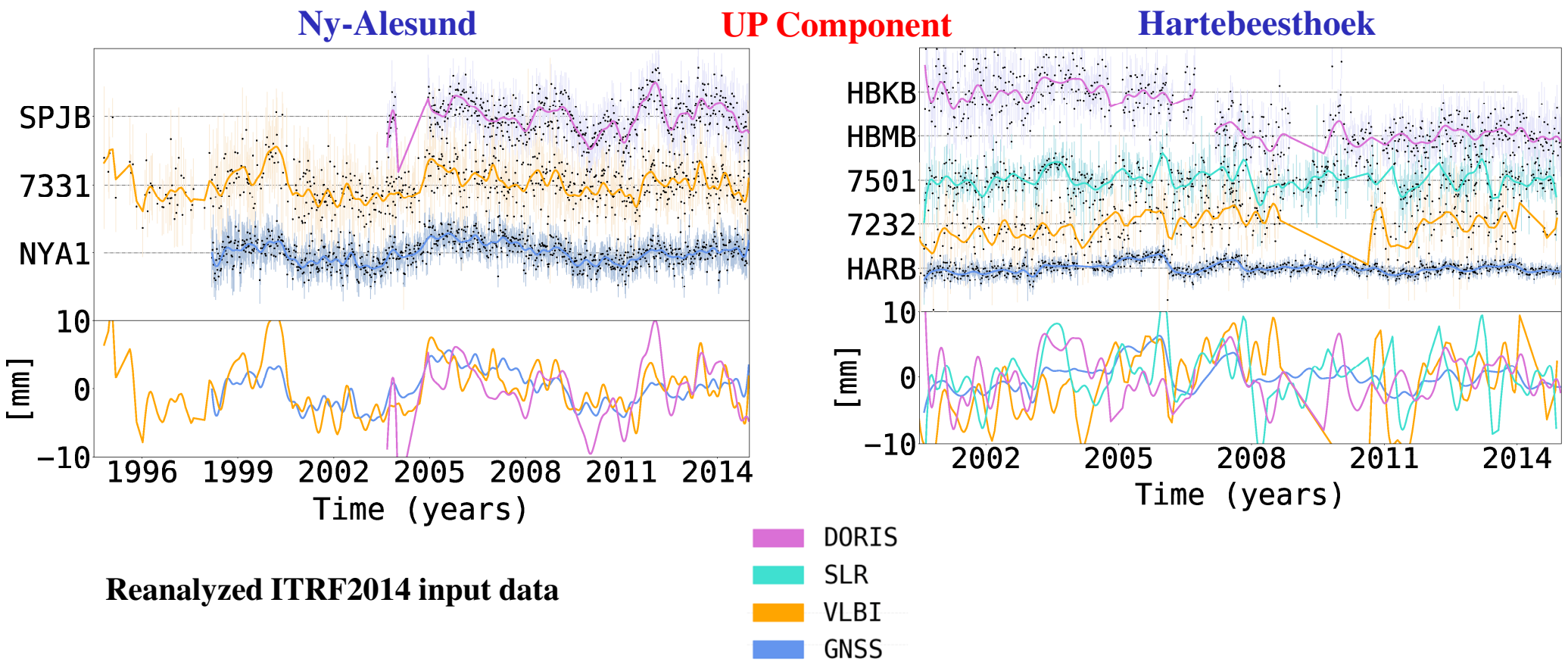
RMS of nonseasonal hydrological loading displacements (Combined GRACE solution, Gauer et al., 2022)



Are there common aperiodic displacements at ITRF co-location sites?

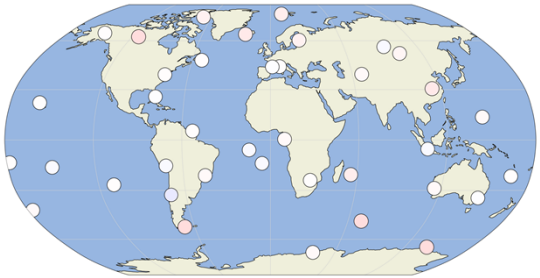
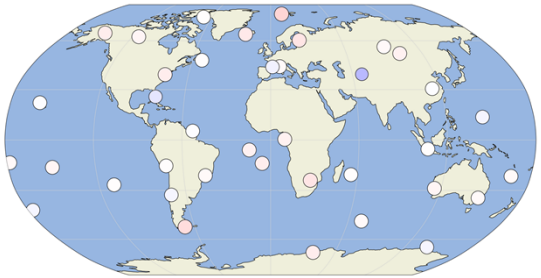
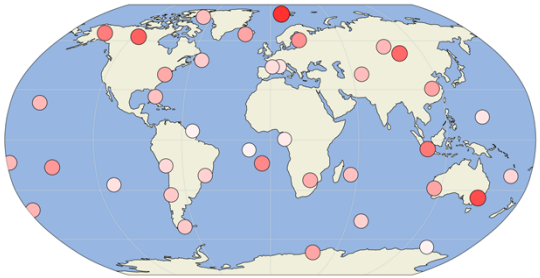
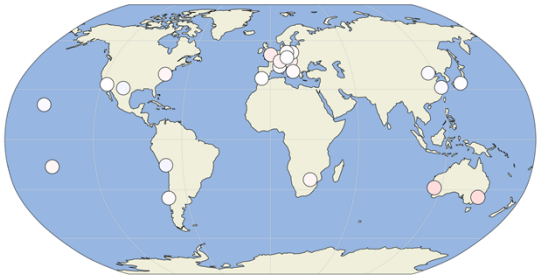
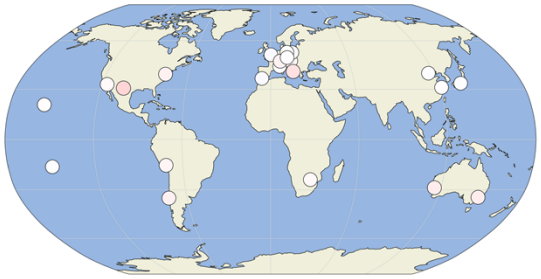
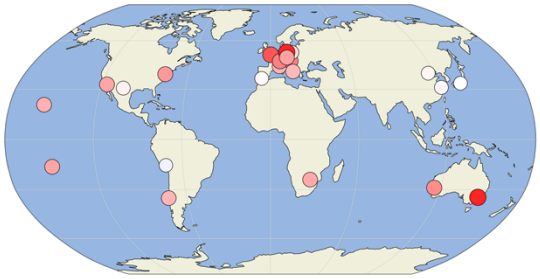
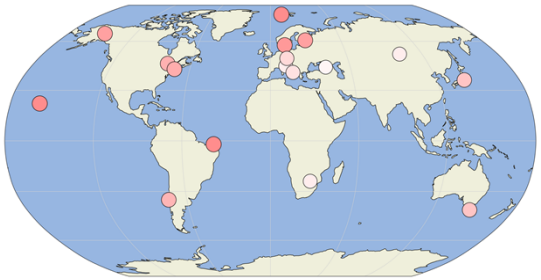
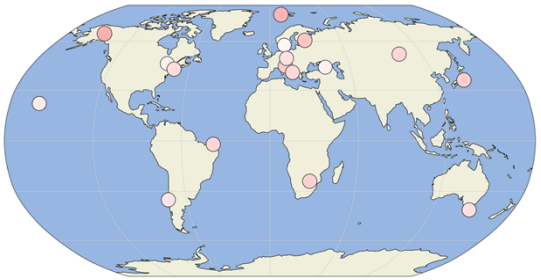
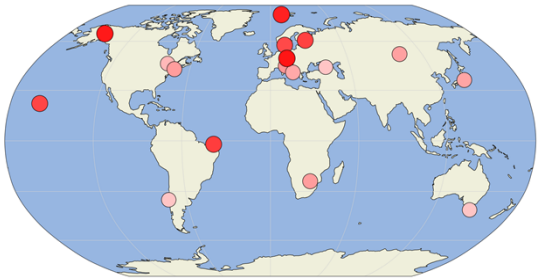
Are there common aperiodic displacements at ITRF co-location sites? (1/2)

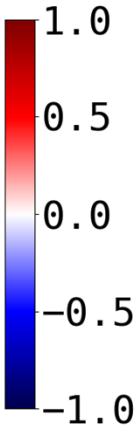
After modeling and removing linear and periodic signals, what is left at:



Reanalyzed ITRF2014 input data

Are there common aperiodic displacements at ITRF co-location sites? (2/2)

	East	North	Vertical
GNSS-DORIS 38 station pairs			
GNSS-SLR 22 station pairs			
GNSS-VLBI 17 station pairs			



Concordance correlation coefficients - Lin (1989)

Conclusion

- ITRF2020 is a step further in improving the ITRF determination;
- As an augmented TRF, ITRF2020 gives access to the quasi-instantaneous station positions, referred to the SLR CM, at the seasonal frequencies;
- Satisfies both operational geodesy and science applications, including Precise Orbit Determination;
- Some users are still reluctant to take full benefit of ITRF2020 seasonal signals
- ITRF2020 type of solution and its future updates will still be needed for a while!
- Limiting factors for detecting & combining "aperiodic signals" include:
  - Technique systematic errors;
  - Sparse networks;
  - limited observation density
  - Noise level;
  - …

  } especially VLBI & SLR
- Research on reference frames is still needed