The International Terrestrial Reference Frame (ITRF): An update
A new release: ITRF2020

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Outline

- **Key points of GNSS/IGS contribution to the ITRF**

- **ITRF2020:**
  - **Input data**
  - **GNSS contribution**
  - **An augmented parametric frame modeling nonlinear station motions**
  - **Scale**

- **Conclusion**

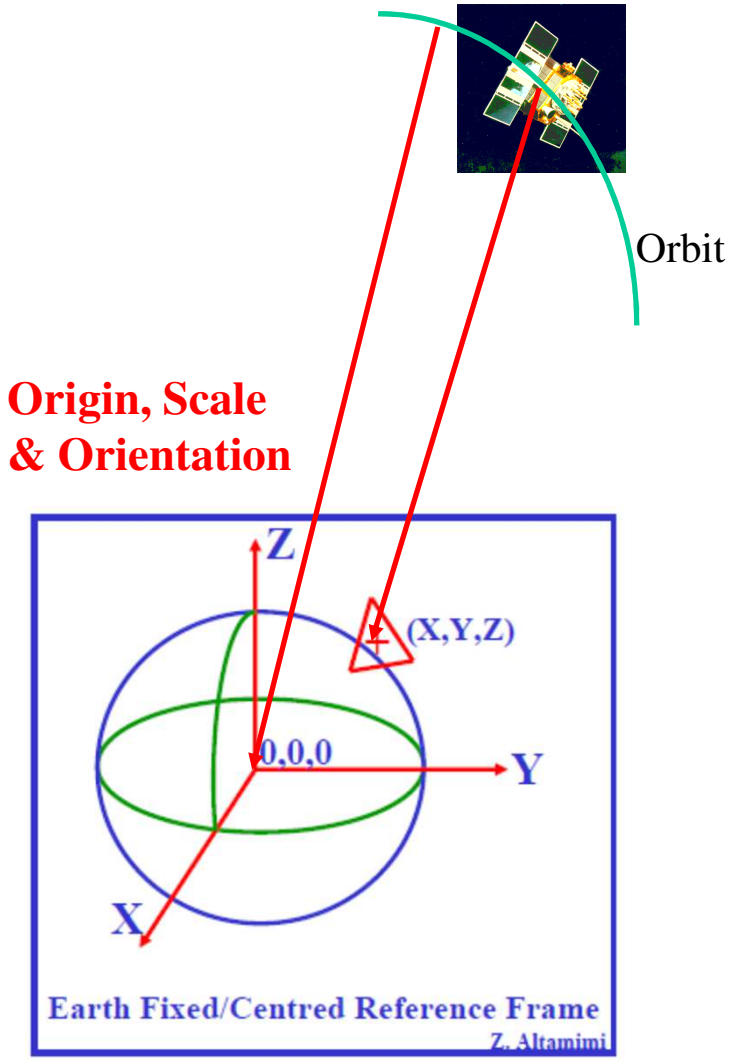
What is a Reference Frame in practice?

- **Earth fixed/centered Reference Frame: allows determination of point positions and satellite orbits as a function of time**

- **When analyzing space geodesy data, we have to take into account:**
  - **Relativity theory**
  - **Forces acting on the satellite**
  - **The atmosphere**
  - **Earth rotation**
  - **Solid Earth and ocean tides**
  - **…**
- **Linear and nonlinear variations/deformations**

==> Station coordinates are function of time

Accuracy: few mm and few 0.1 mm/yr for the best stations



Key Points of the GNSS/IGS Contribution to the ITRF

1. **Inter-Technique link : reinforcing the ITRF definition (origin, scale & orientation)**

2. **Determination of Post-Seismic Deformation Models**

3. **ITRF Plate Motion Models**

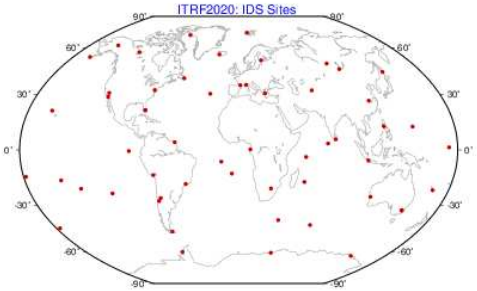
4. **Polar Motion**

5. **ITRF Access & densification through the IGS Products:**
   - **Using IGS Products provides Universal access to and densification of the ITRF**
   - **More than 80% of National RFs are aligned to the ITRF**

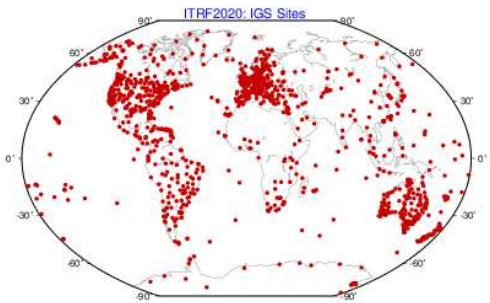
ITRF2020 Input Data

TC	# of solutions	Time-span	# of sites	Theoretical Frame Origin
IDS/DORIS	1456 weekly	1993.0 – 2021.0 (28 yrs)	87	CM
IGS/GNSS/GPS	9861 daily	1994.0 – 2021.0 (27 yrs)	1159	CN
ILRS/SLR	243 fortnightly 1460 weekly	1983.0 – 1993.0 1993.0 – 2021.0 (38 yrs)	100	CM
IVS/VLBI	6178 session-wise	1980.0 – 2021.0 (41 yrs)	117	CN

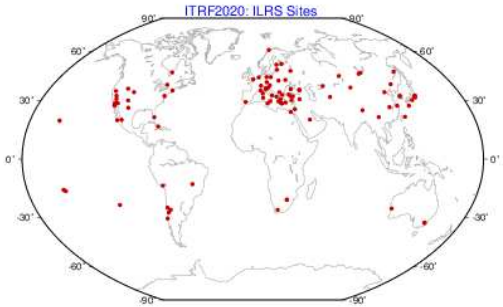
IDS/DORIS



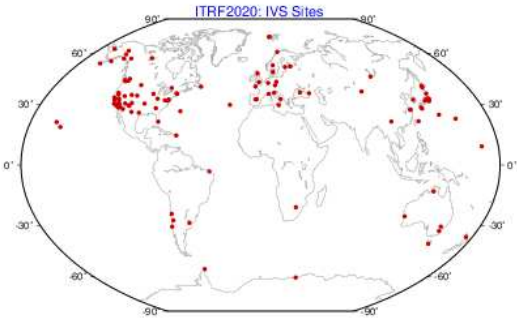
IGS/GNSS



ILRS/SLR

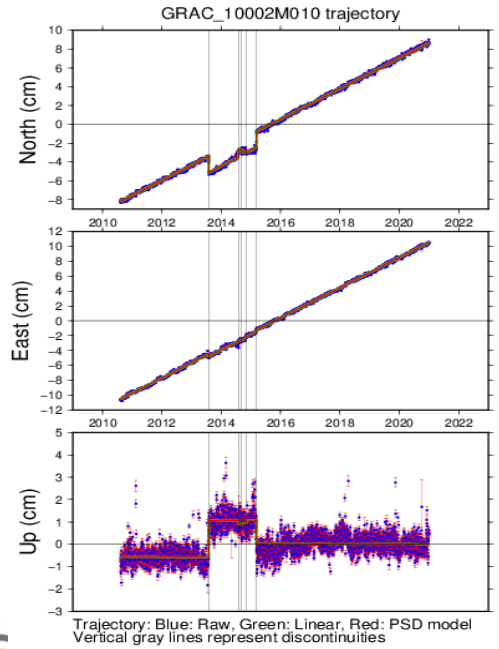


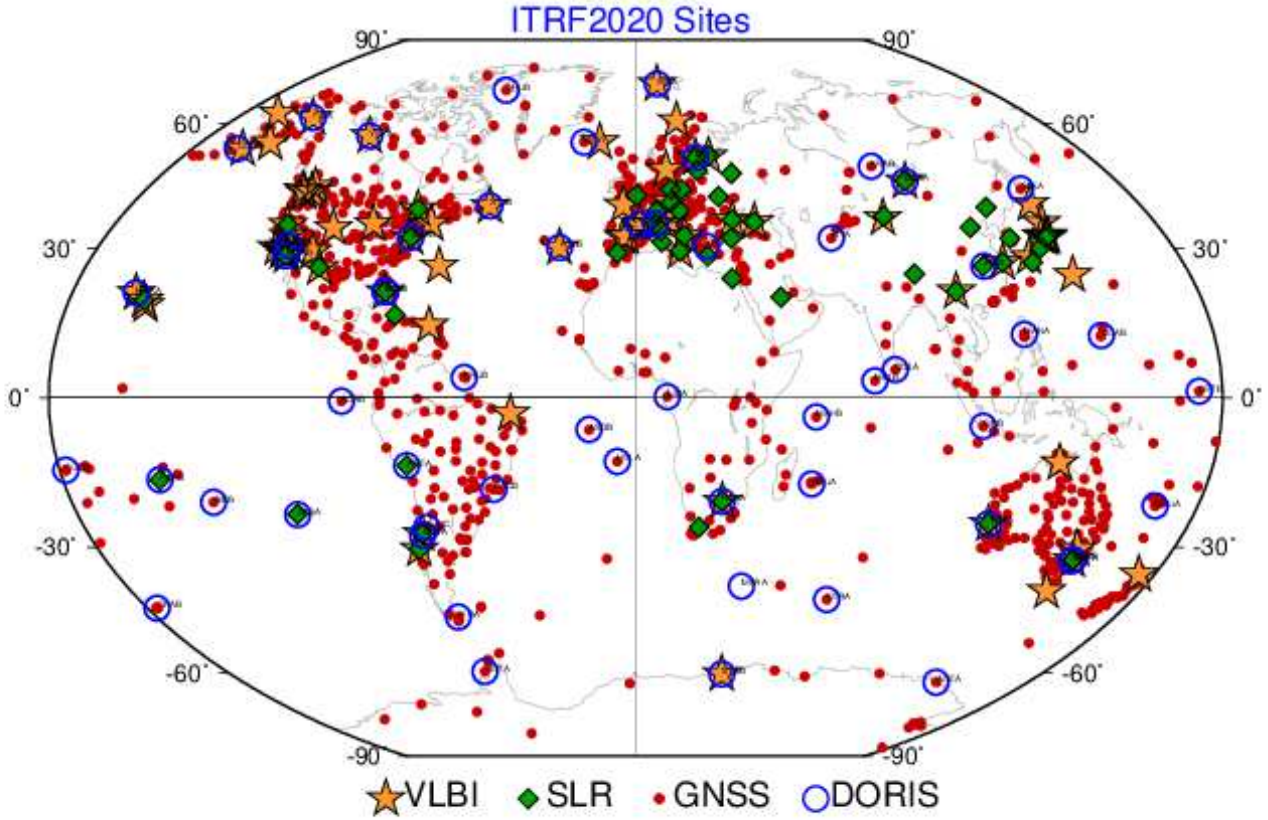
IVS/VLBI



ITRF2020 Network

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





DORIS

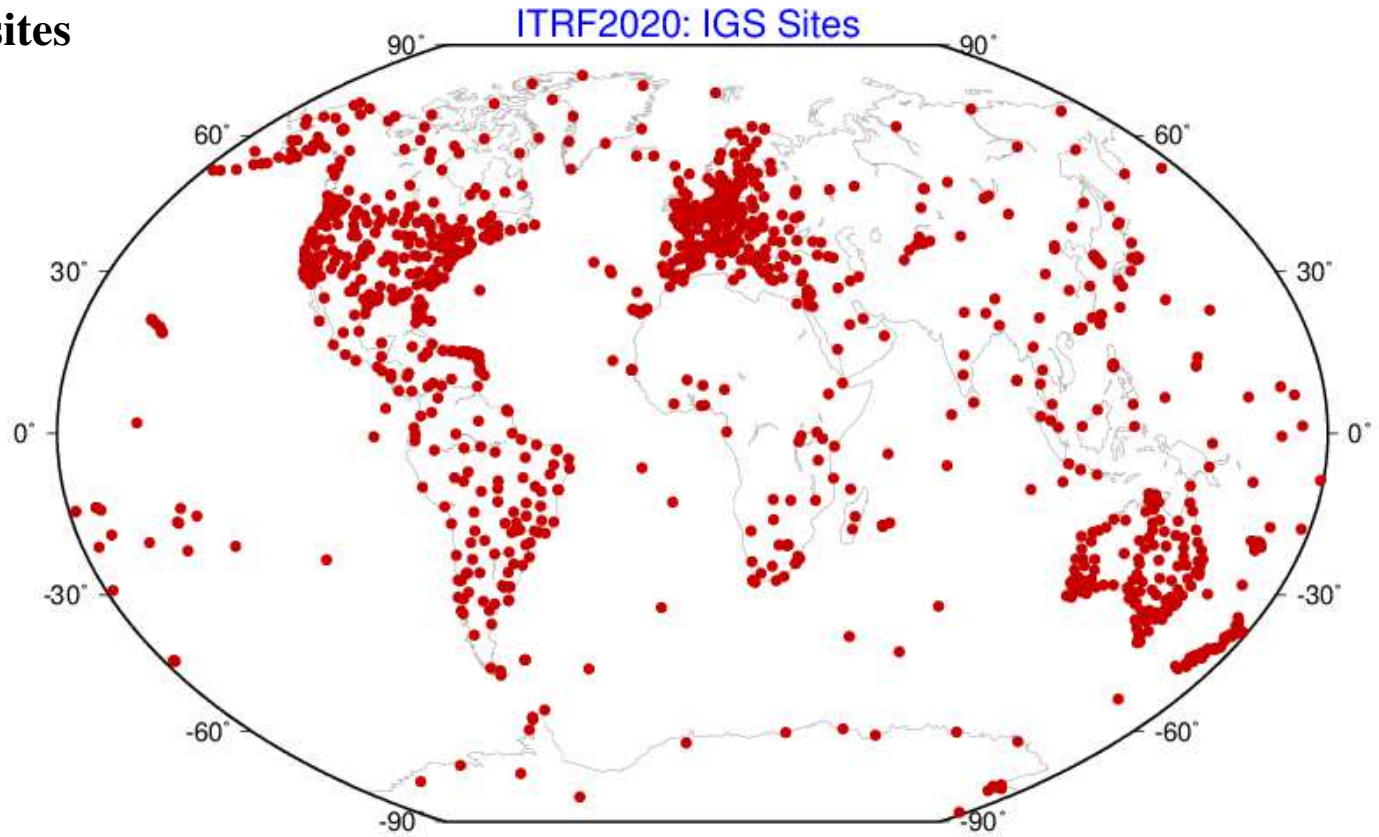
GNSS

SLR

VLBI

ITRF2020: GNSS Sites

- ~1100 GNSS/IGS sites
- 93 co-location sites

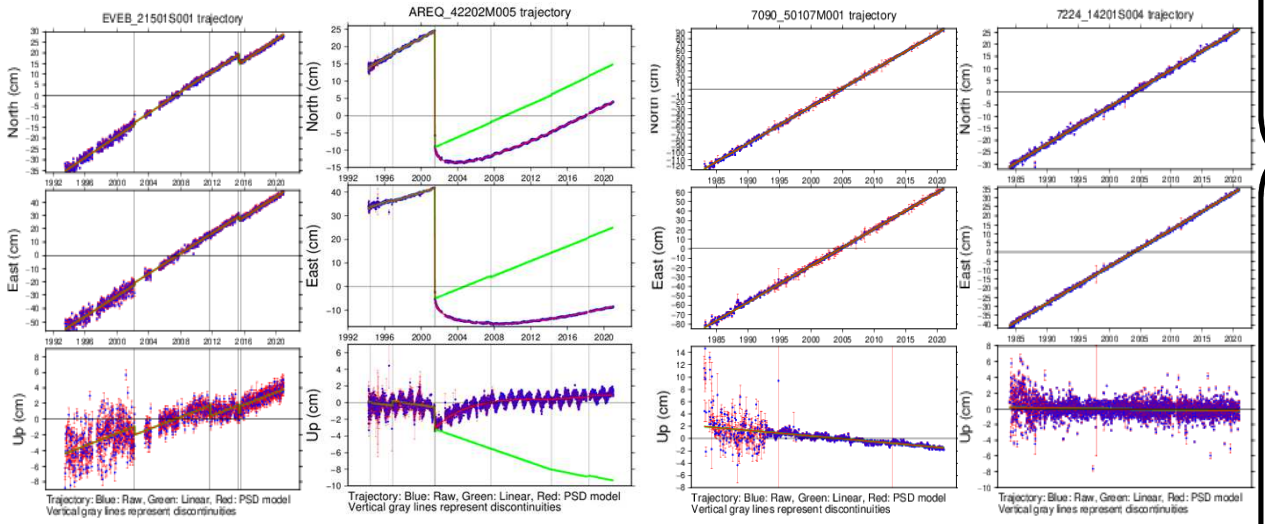


The International Terrestrial Reference Frame (ITRF):

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

Input

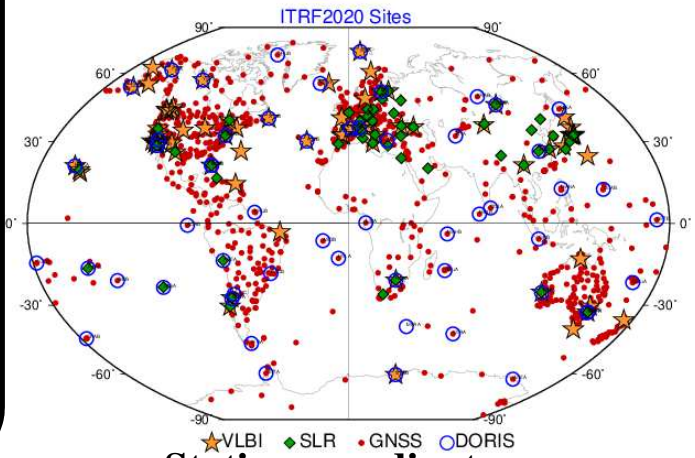
DORIS Weekly
GNSS Daily
SLR Weekly
VLBI Session-wise



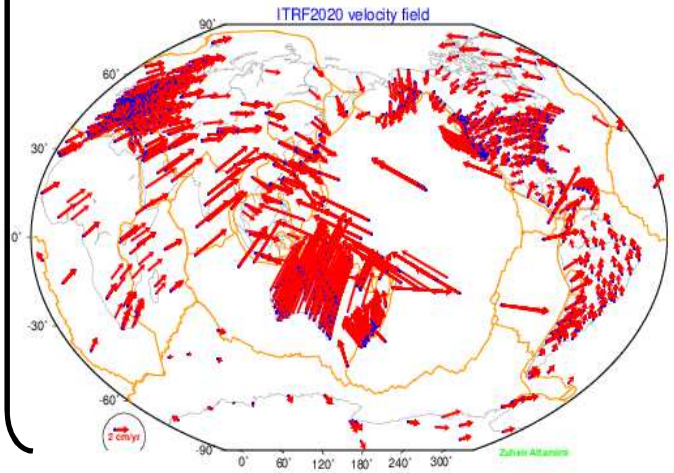
Fundamentally based on Co-location Sites

Time series analysis & stacking (CATREF Software)

Output

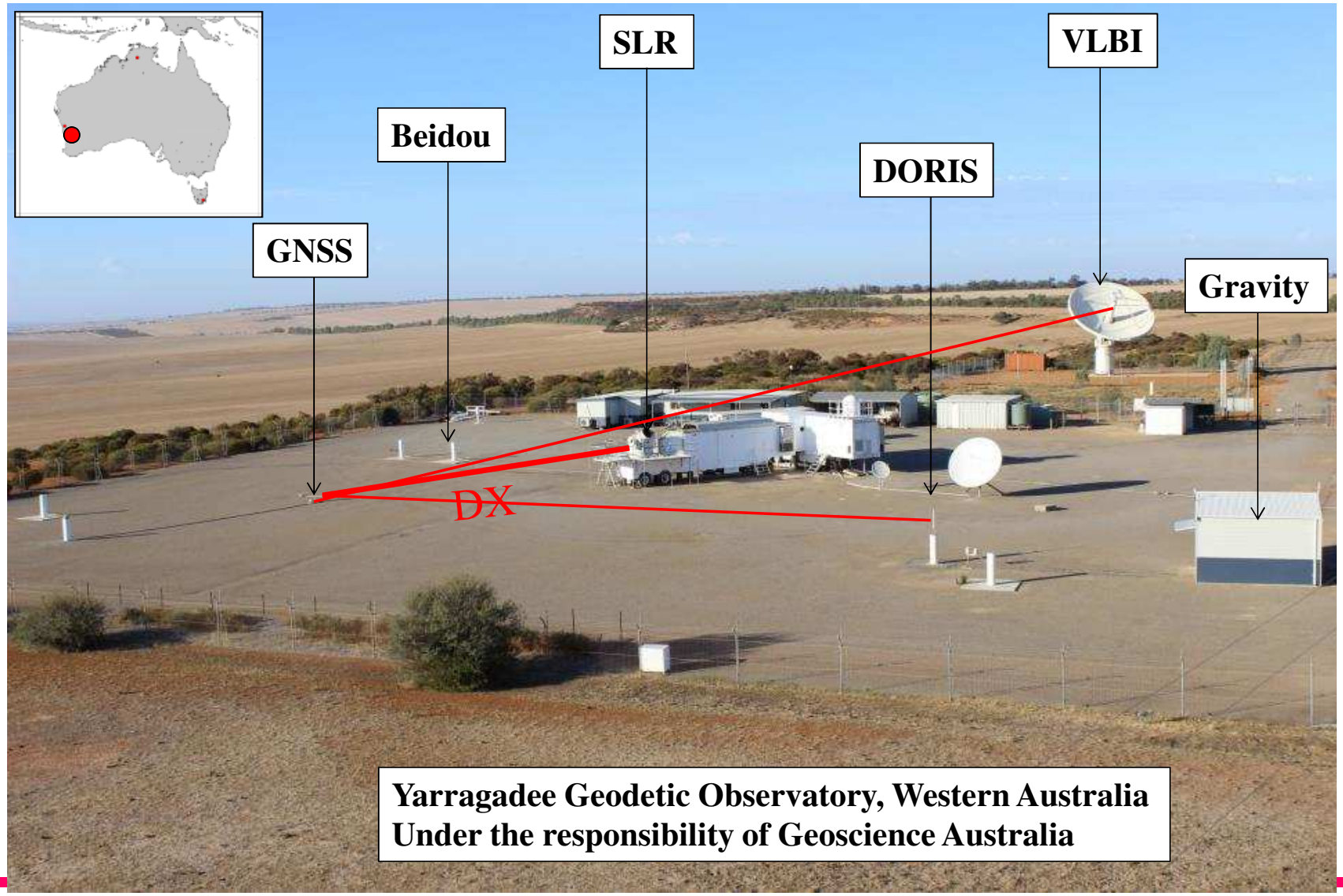


Station coordinates



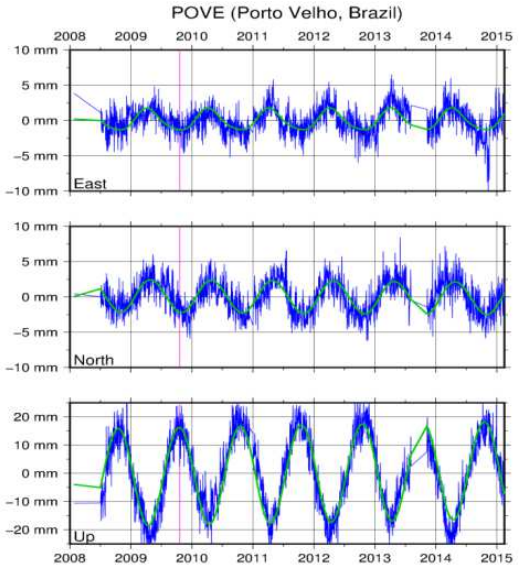
Station velocities

Colocation site



ITRF2020 Innovation: Precisely Modeling nonlinear station motions

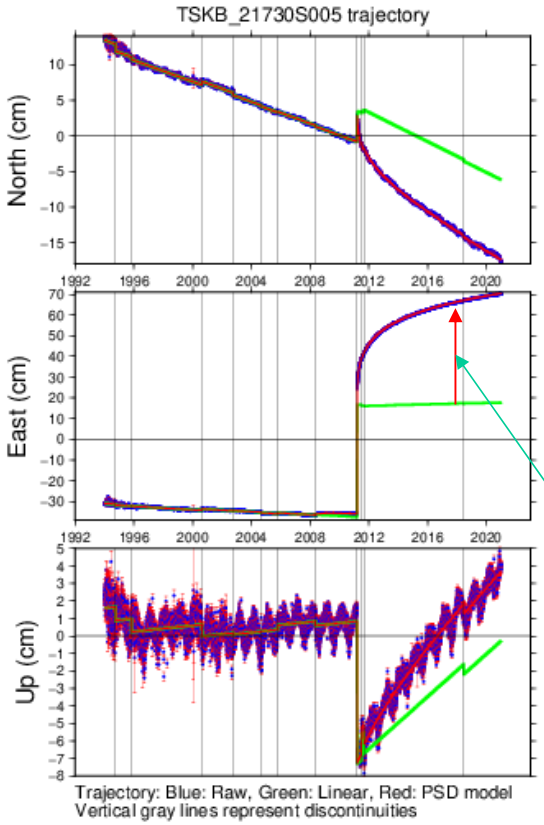
Impact of loading effects

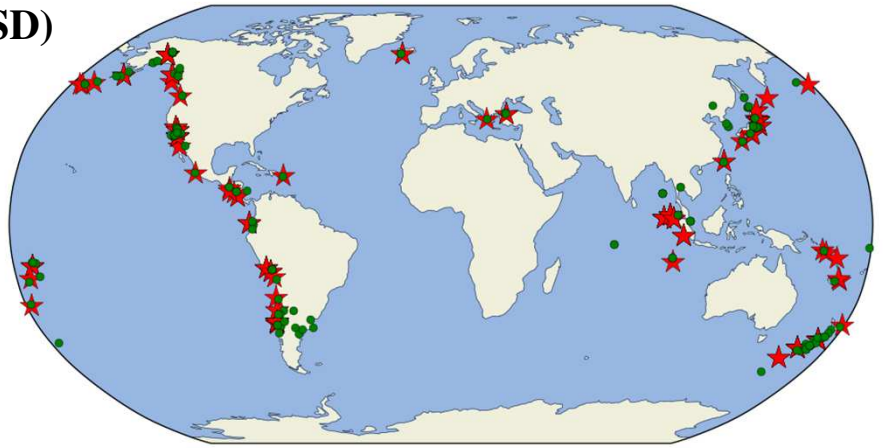


Sine wave function

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

Post-Seismic Deformation (PSD)
Impact of major earthquakes





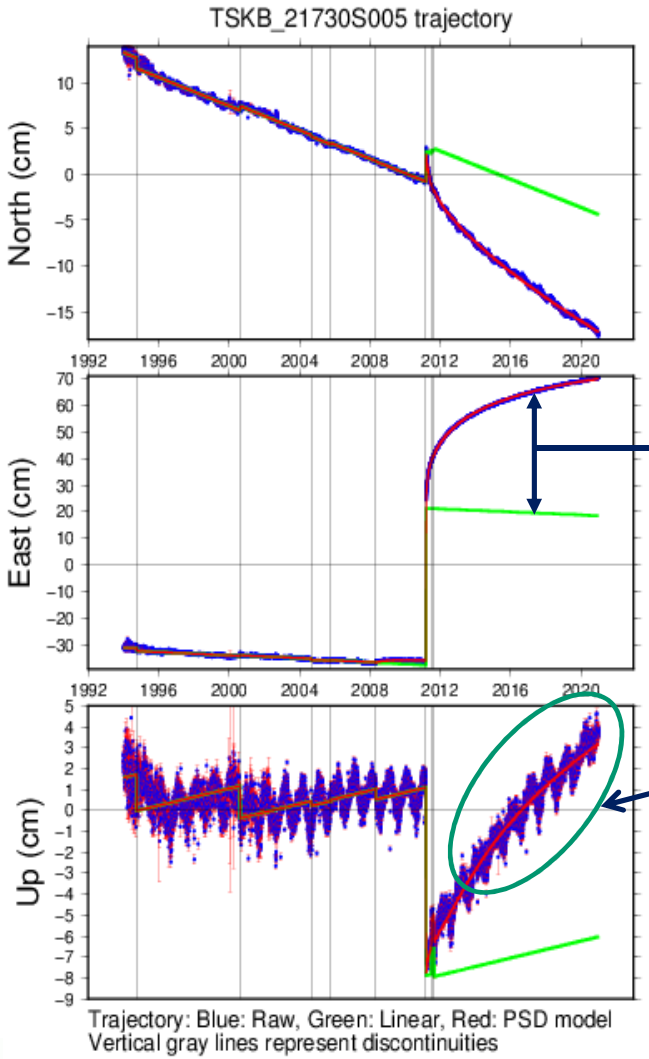
Red Stars: EQ Epicenters (65)
Green circles: ITRF2020 sites (118)

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

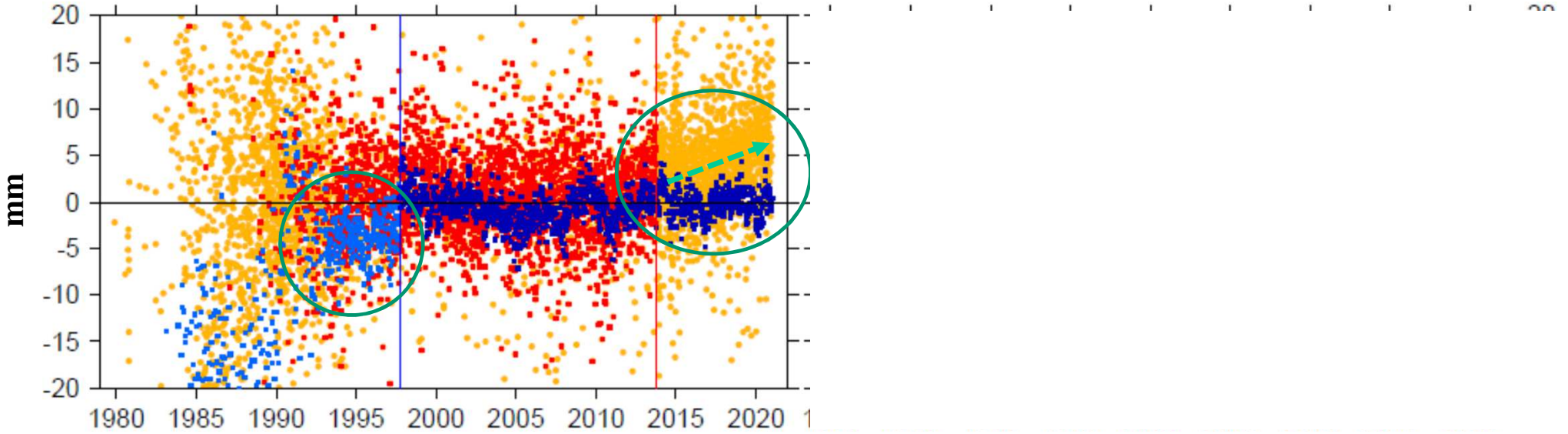
Scale of ITRF2020?

- 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:
  - GSC (2022) Galileo Satellite Metadata / European GNSS Service Centre

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

Scales with respect to ITRF2020

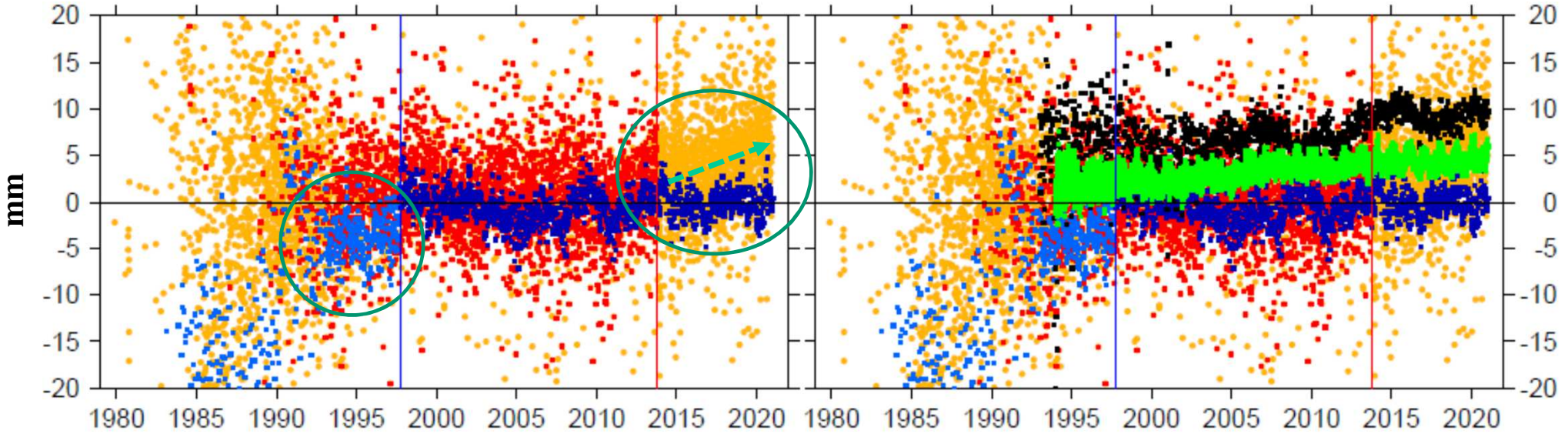


- Orange: all VLBI Sessions
- Red: Selected VLBI Sessions (convex hull volume $\geq 10^{19}$ m^3)
- Light blue: all SLR time series
- Dark blue: Selected SLR time series

ITRF2020 scale: Average of red (VLBI) and dark blue (SLR)

Scale offset between SLR & VLBI is 0.15 ppb
(1 mm at the equator)

Scales with respect to ITRF2020



- Orange: all VLBI Sessions
- Red: Selected VLBI Sessions (convex hull volume ≥ 10^{19} m^3)
- Light blue: all SLR time series
- Dark blue: Selected SLR time series
- Green: IGS/Repro3
- Black: DORIS

ITRF2020 scale: Average of red (VLBI) and dark blue (SLR)

Scale offset between SLR & VLBI is 0.15 ppb
(1 mm at the equator)

Solution	Scale at 2015.0 (ppb)	Scale rate ppb/yr
IGS/GNSS	0.682 ±0.018	0.018 ±0.001
IVS/VLBI	0.075 ±0.040	0.000 ±0.003
ILRS/SLR	-0.075 ±0.038	0.000 ±0.004
IDS/DORIS	1.386 ±0.037	0.028 ±0.003

Conclusion

- **GNSS/IGS Contribution is fundamental to the ITRF**

- **ITRF2020:**
  - **An augmented parametric frame: a step further in improving the ITRF:**
  - **PSD parametric models for stations impacted by major earthquakes**
  - **Seasonal signals in both CM and CF frames;**

- **ITRF2020 Scale:**
  - **IGS apparent scale offset/drift with respect to ITRF2020 needs to be understood: probably due to the assumption of constant z-PCOs**
  - **For the first time in ITRF history, the scale difference between SLR & VLBI is:**
  - **~ 0.15 ppb (~1 mm), versus 1.37 ppb (~8.2 mm) in ITRF2014**

- **The GNSS Providers are solicited to publish satellite metadata**