Challenges and achievements in combining terrestrial reference frames

- Introduction
- Current practice in time series combination
- Evaluation of DORIS solution IGN-JPL-D05
- Recent Multi-technique combination

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What is a Terrestrial Reference System ?

- A mathematical model with no physical existence
- Used to describe a deformable Earth
- An affine frame with an origin, scale and orientation
- Easily realized at a given epoch
- Its linear time evolution is also easily realized
- Combination based on 7-parameter similarity
- How to take into account non-linear variations: tidal, non-tidal « seasonal » variations… ?

Combination in the era of times series of station positions and EOP

- **Daily/Weekly/Monthly solutions of Station positions and Earth Orientation Parameters**
- **Allow to**
  - **Detect station non-linear and seasonal motions**
  - **Detect geocenter motion**
  - **Detect loading effects**
  - **Ensure TRF & EOP consistency in the combination**

- **But : how to ensure the TRF long-term stability (well defined time evolution) in presence of non-linear variations ?**
- **Basic question: real non-linear variations vs real geophysical motions ?**

Current practice for TRF realization

- **Use of the 7-transformation formula**

$$X_2 = X_1 + T + DX_1 + R.X_1$$

- **Assume linear variation:** $\dot{X}_2 = \dot{X}_1 + \dot{T} + \overbrace{\dot{D}\dot{X}_1}^{\approx 0} + \dot{D}X_1 + \overbrace{\dot{R}\dot{X}_1}^{\approx 0} + \dot{R}X_1$

- **Satisfactory for tectonic motions**

- **A secular (linear) frame (as ITRF2000) is needed for the expression of the results**

What to do for the (near) future ?

- **Assume there are accurate, fully validated geophysical models for these effects**
- **Corrections should be applied at the level of data analysis**

- **But this situation is not likely to happen soon**
- **So, leave all the « geophysical effects » in the geodetic data for a posteriori analysis!**

Current practice in TRF combination (1/2)

TRF & EOP time series Combination

CATREF Software

INPUT: $X(t)$, **EOP(t) in daily/weekly/monthly SINEX files**

OUTPUT: $X(t_0)$, $\dot{X}$, **EOP(t),** $\underbrace{(T_x, T_y, T_z}_{\text{Geocenter}}, D, R_x, R_y, R_z)$

$$\begin{cases} X_s^i = X_{itrf}^i + (t_s^i - t_0)\dot{X}_{itrf}^i + T_k + D_k X_{itrf}^i + R_k X_{itrf}^i \\ \quad + (t_s^i - t_k)\left[\dot{T}_k + \dot{D}_k X_{itrf}^i + \dot{R}_k X_{itrf}^i\right] \\ \dot{X}_s^i = \dot{X}_{itrf}^i + \dot{T}_k + \dot{D}_k X_{itrf}^i + \dot{R}_k X_{itrf}^i \end{cases}$$

$$\begin{cases} x_s^p = x^p + R2_k \\ y_s^p = y^p + R1_k \\ UT_s = UT - \frac{1}{f} R3_k \\ \dot{x}_s^p = \dot{x}^p + \dot{R}2_k \\ \dot{y}_s^p = \dot{y}^p + \dot{R}1_k \\ LOD_s = LOD + \frac{\Lambda_0}{f}\dot{R}3_k \end{cases}$$

- **Matching common EOP parameters at UT noon**
- **Propagate at UT noon if rates are available**

Current practice in TRF combination (2/2)

- **Use of reference set of stations, globally distributed & geophysically / geodetically monitored (???)**
- **Define the frame using minimum constraints approach**

$$(A^T A)^{-1} A^T (X_{RS} - X_c) = 0$$

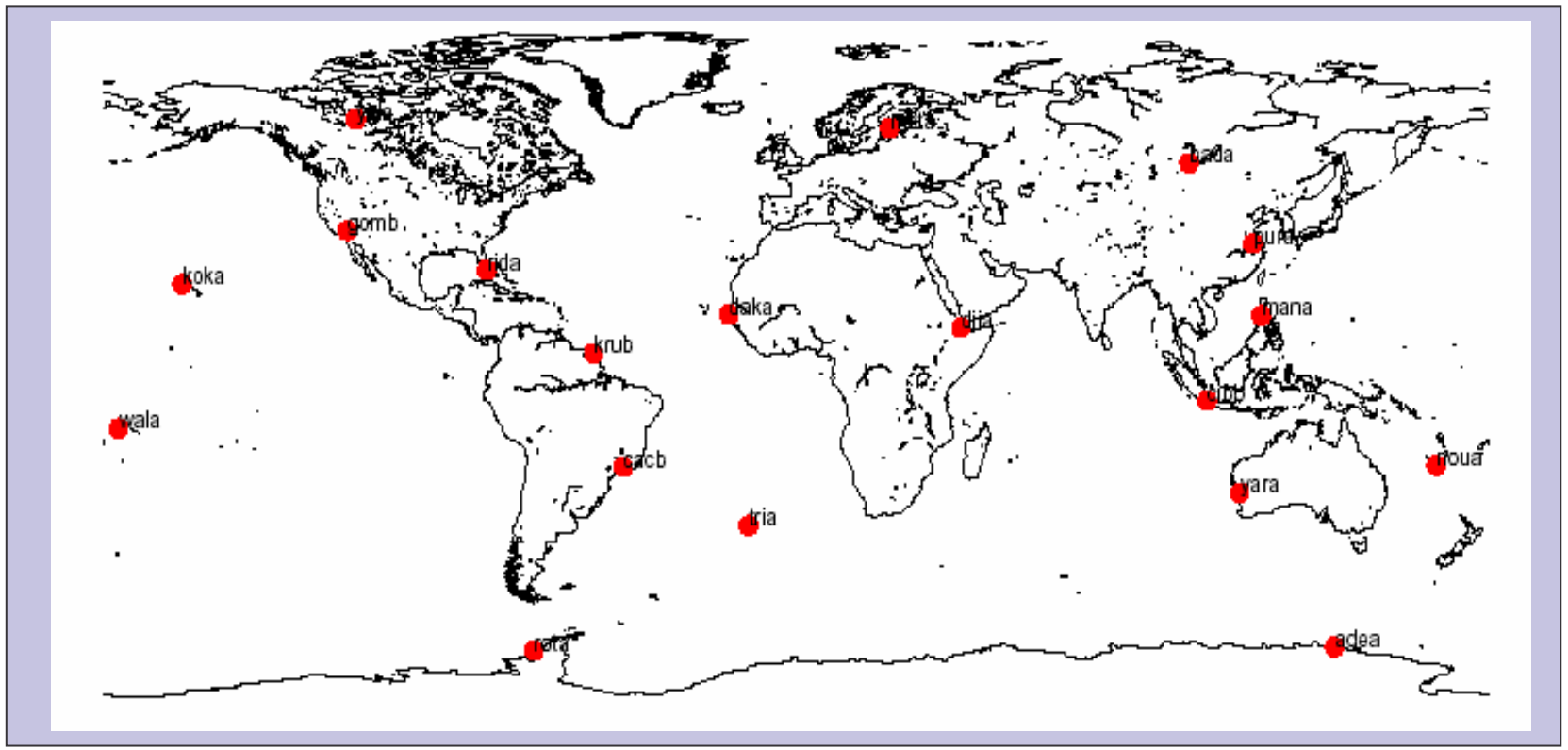
where A is a design matrix given by:

$$A = \begin{pmatrix} . & . & . & . & . & . & . \\ 1 & 0 & 0 & x_0^i & 0 & z_0^i & -y_0^i \\ 0 & 1 & 0 & y_0^i & -z_0^i & 0 & x_0^i \\ 0 & 0 & 1 & z_0^i & y_0^i & -x_0^i & 0 \\ . & . & . & . & . & . & . \end{pmatrix}$$

and x_0^i, y_0^i,z_0^i are approximate station positions.

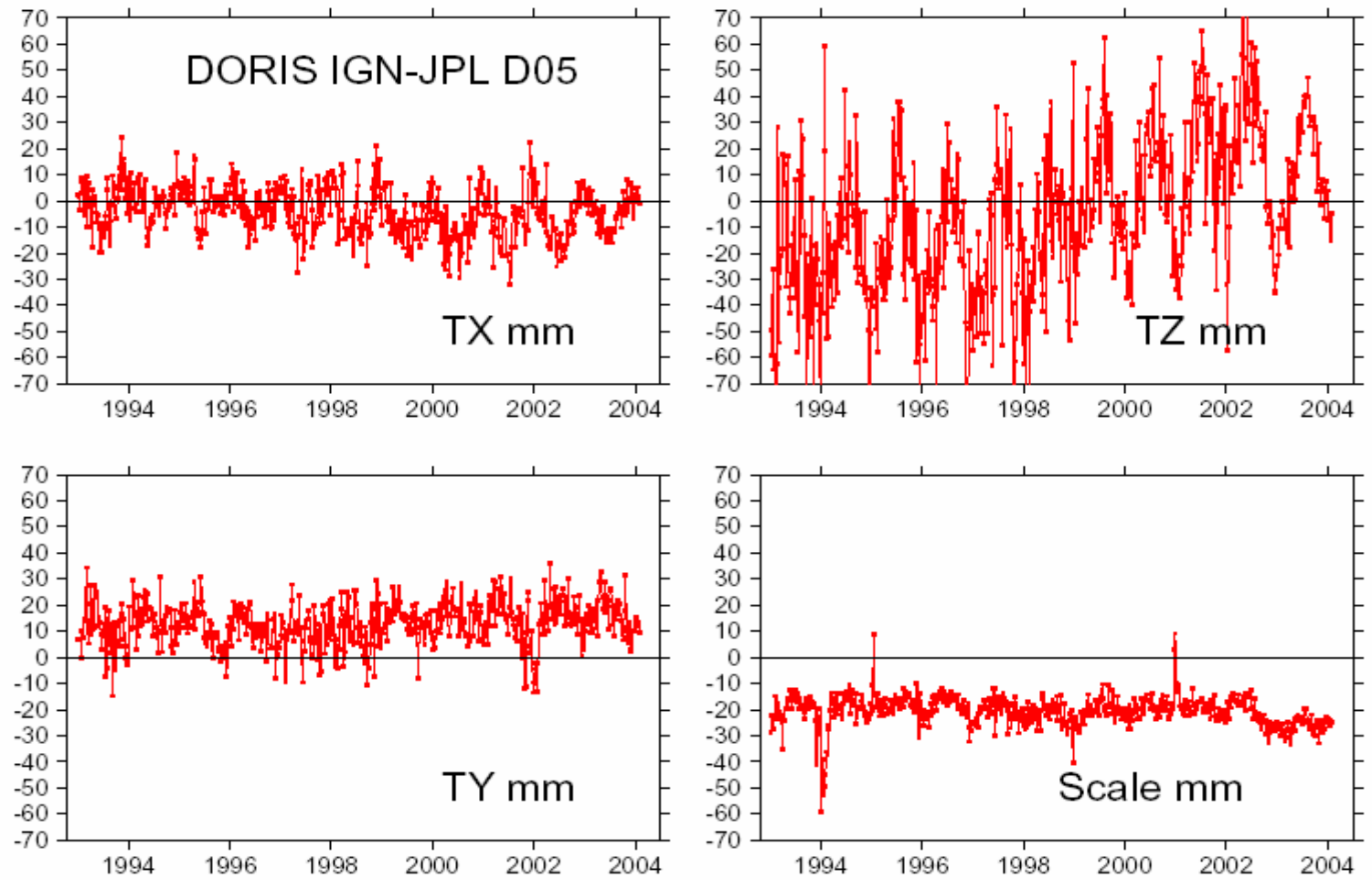
Example: IGN-JPL-D05 Time Series

Network of Reference Stations

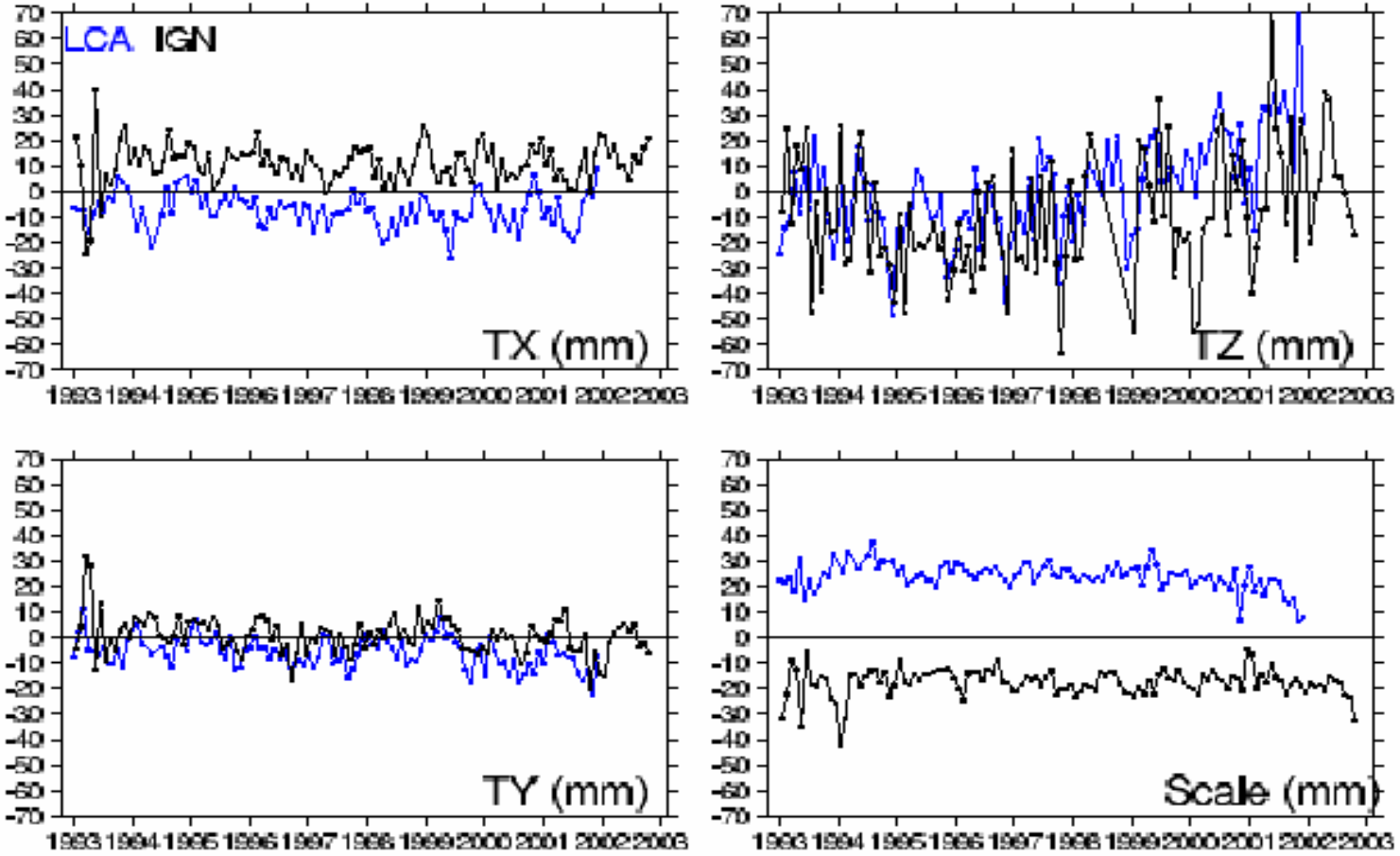


IGN-JPL-D05 Time Series

Translations and Scale time variation

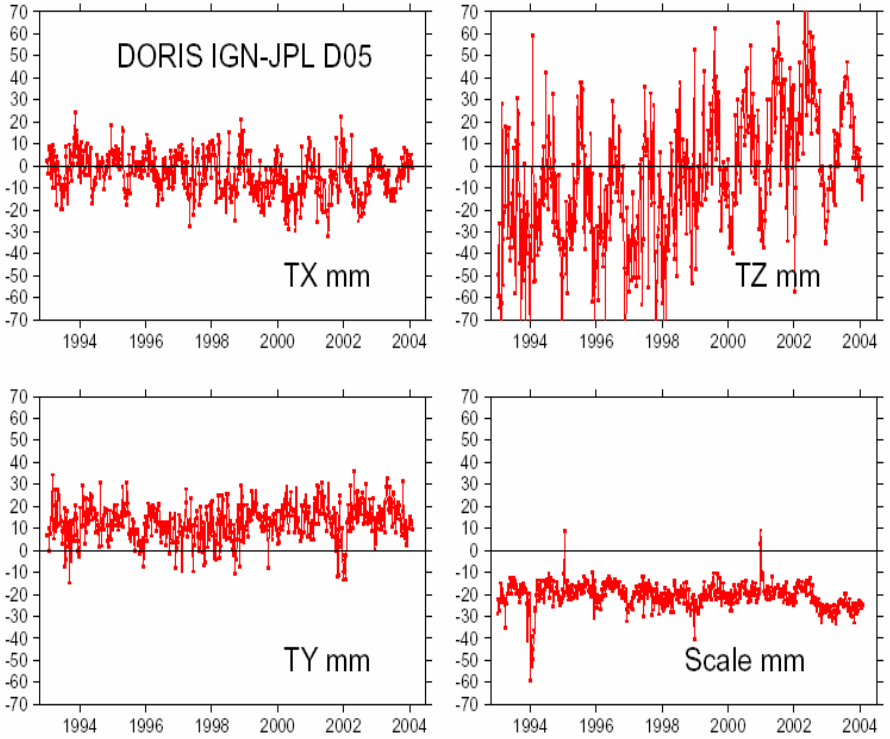


Geocenter and scale differences between LCA and IGN solutions

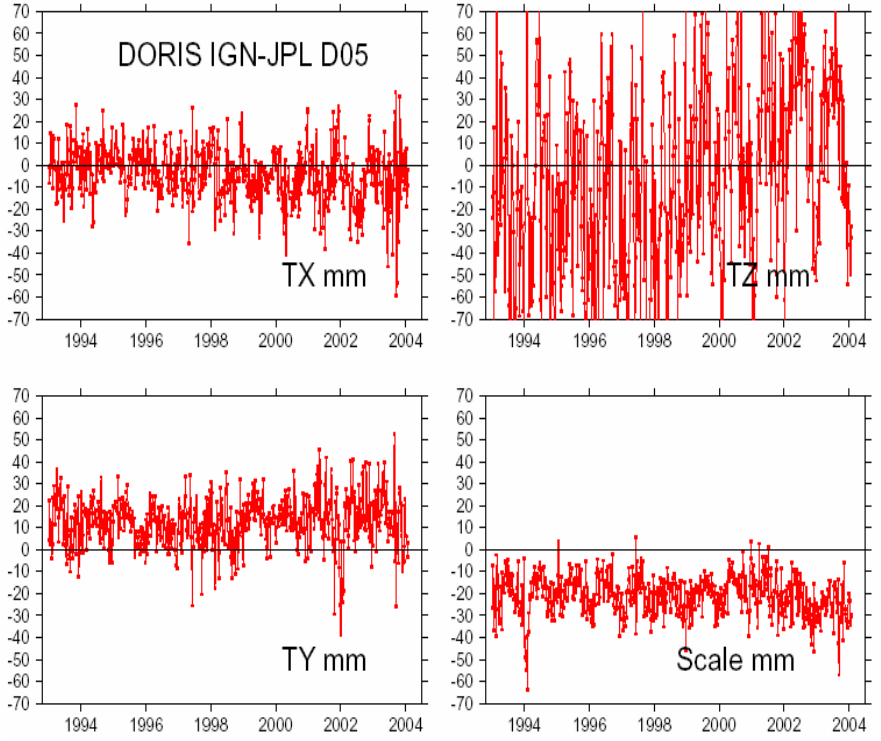


IGN-JPL-D05 Time Series
Translations and Scale time variation

Using MC equation

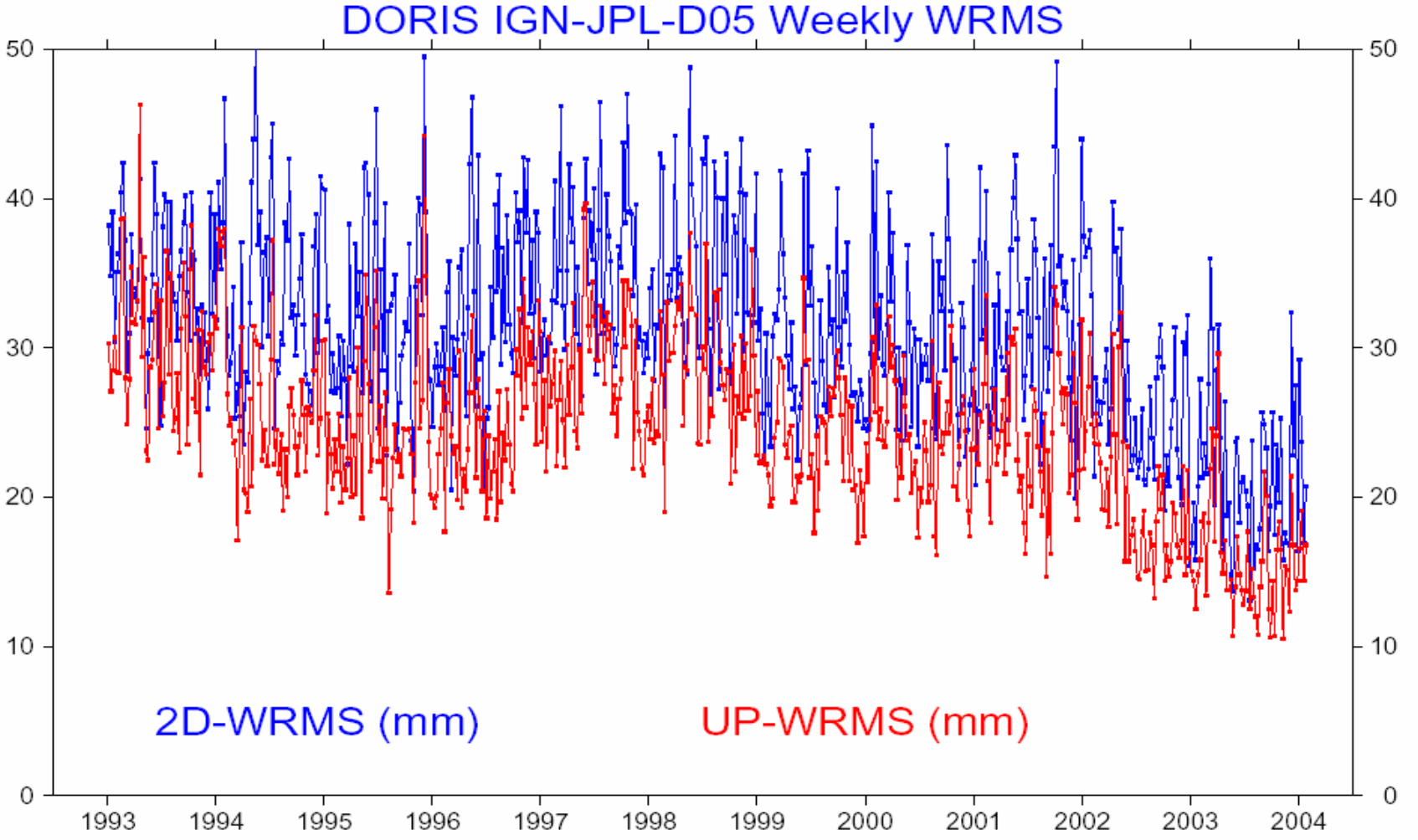


Using classical transfomation

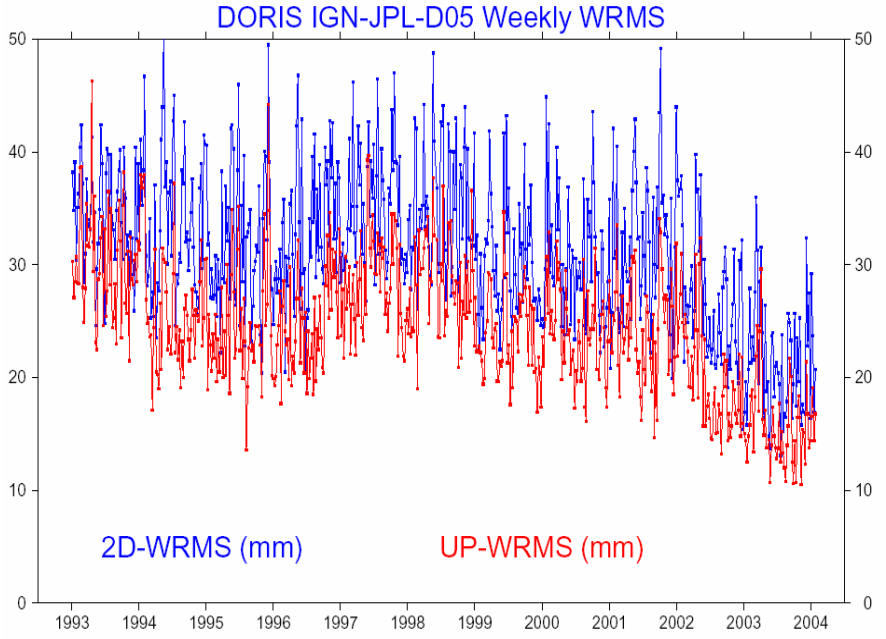


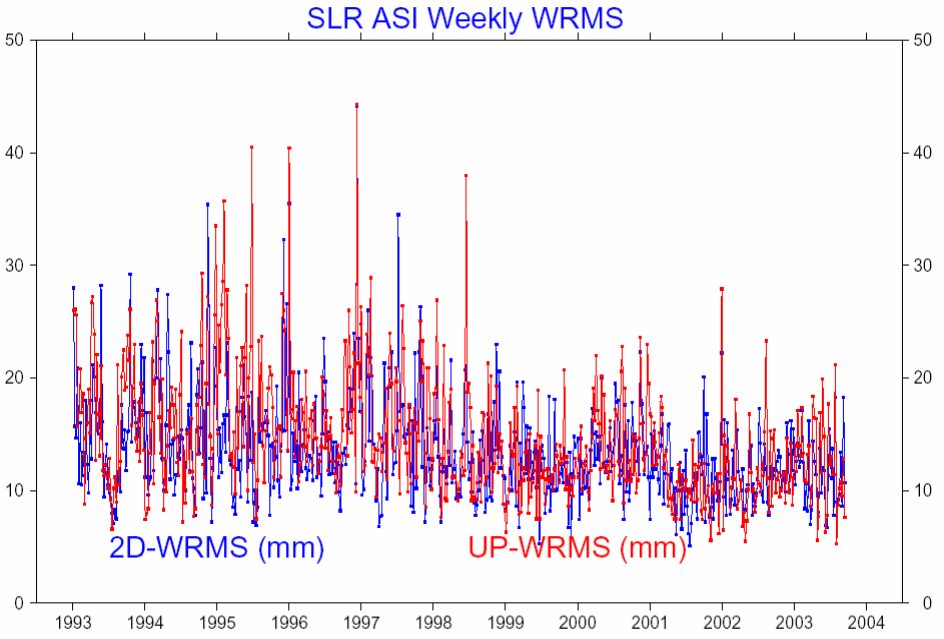
IGN-JPL-D05 Time Series

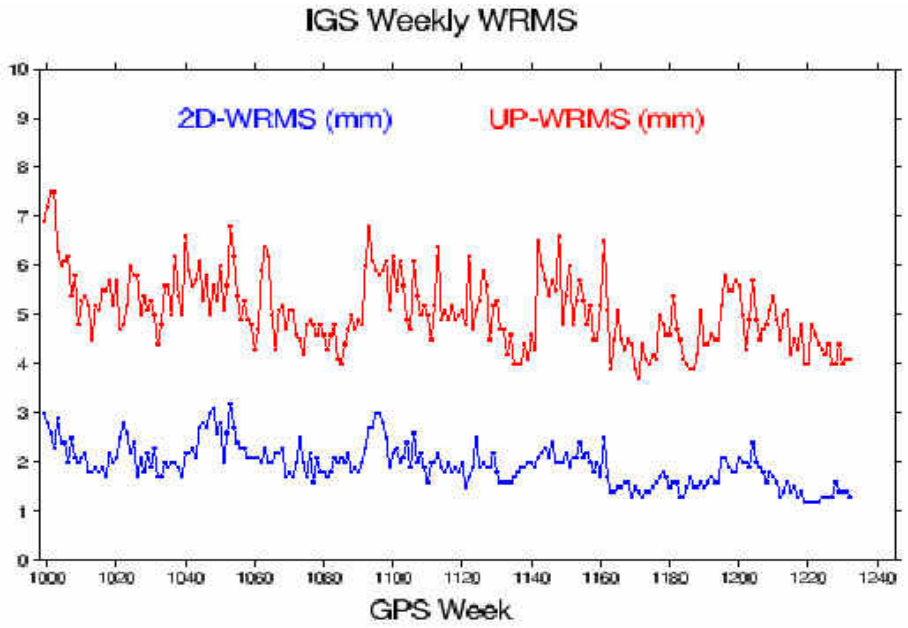
Weekly WRMS



DORIS, SLR and IGS Weekly WRMS







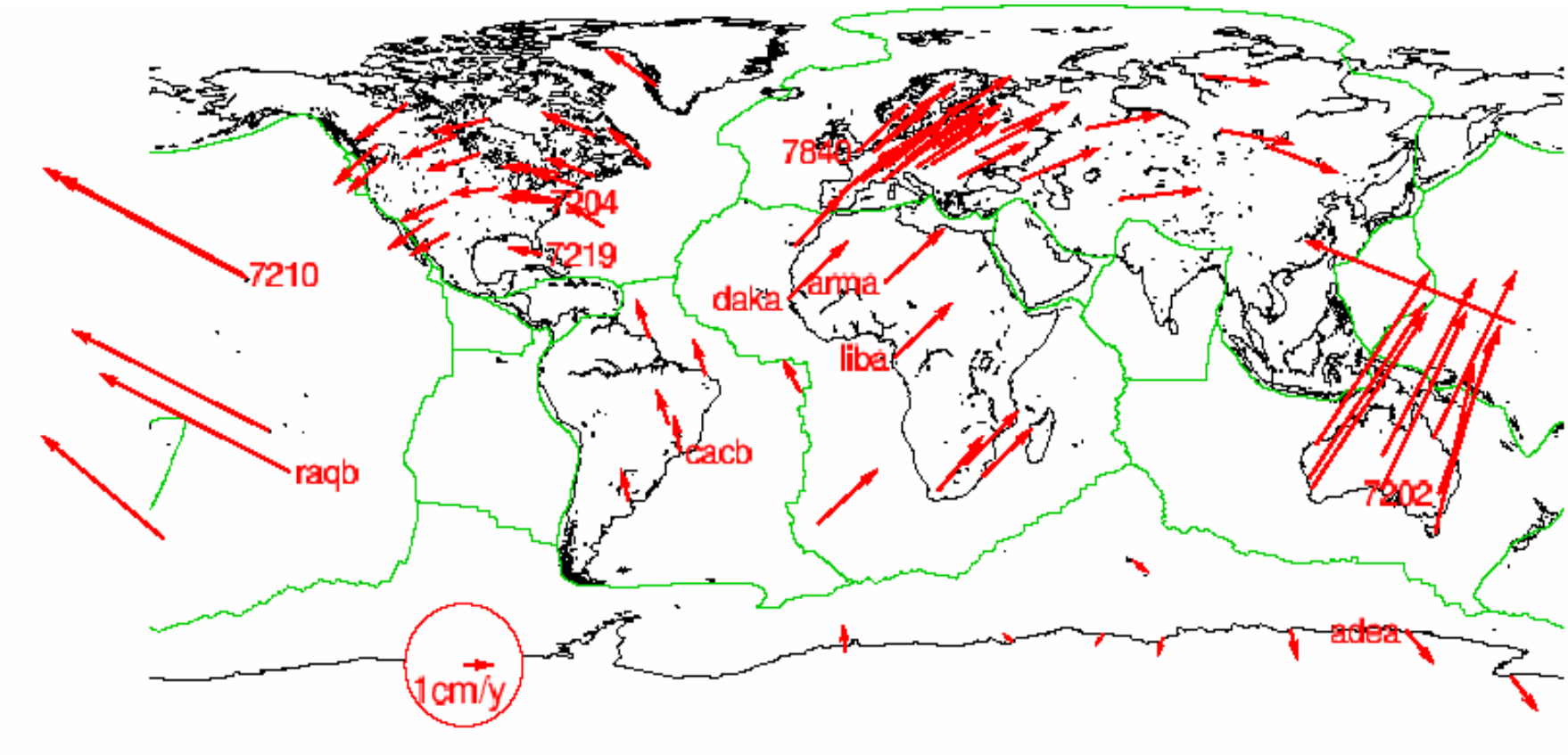
Recent Multi-technique combination

- **Data:**
  - VLBI: GSFC/IVS daily : 1990 – 2004
  - SLR : ASI weekly : 1993 – 2003
  - GPS: IGS combined weekly: 1999 – 2004
  - DORIS: IGN-JPL-D05 weekly: 1993 – 2004
- **Strategy:**
  - Per technique combination → Pos. Vel. & EOP
  - Combination of the per-tech. combinations + Ties → Pos. Vel. & EOP

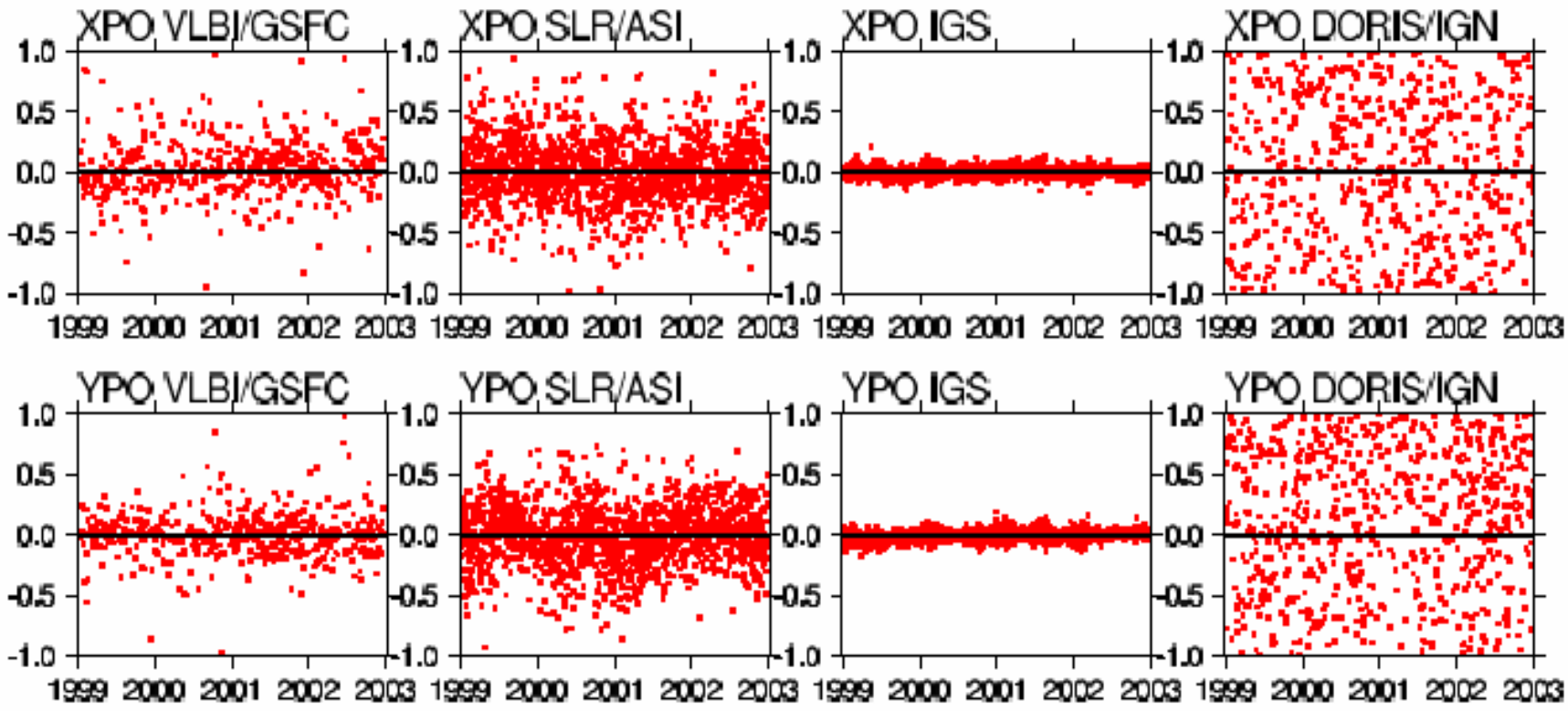
WRMS

Solution	Position		Velocity	
	2-D	Up	2-D	Up
	mm		mm/y	
VLBI/GSFC	2	3	1	2
SLR/ASI	4	5	1	2
GPS/IGS	2	5	1	2
DORIS/IGN-JPL	12	16	2.4	2.8

Plate Motion Estimate



(4-Years) multi-technique combination :
PM Residuals (mas)



Conclusions

- **Consult Position Paper of IGS Workshop for TRF issues, by J. Ray, D. Dong and Z. Altamimi**

- **DORIS Weekly WRMS :**
  - **2 cm horizontal**
  - **1.5 cm vertical**
- **DORIS cumulative WRMS:**
  - **15 mm in position**
  - **2.5 mm/y in velocity**

- **Could a DORIS weekly solution reaches 1 cm precision ?**

- **DORIS EOP still far from the other techniques**

- **IDS should select a set of reference stations**