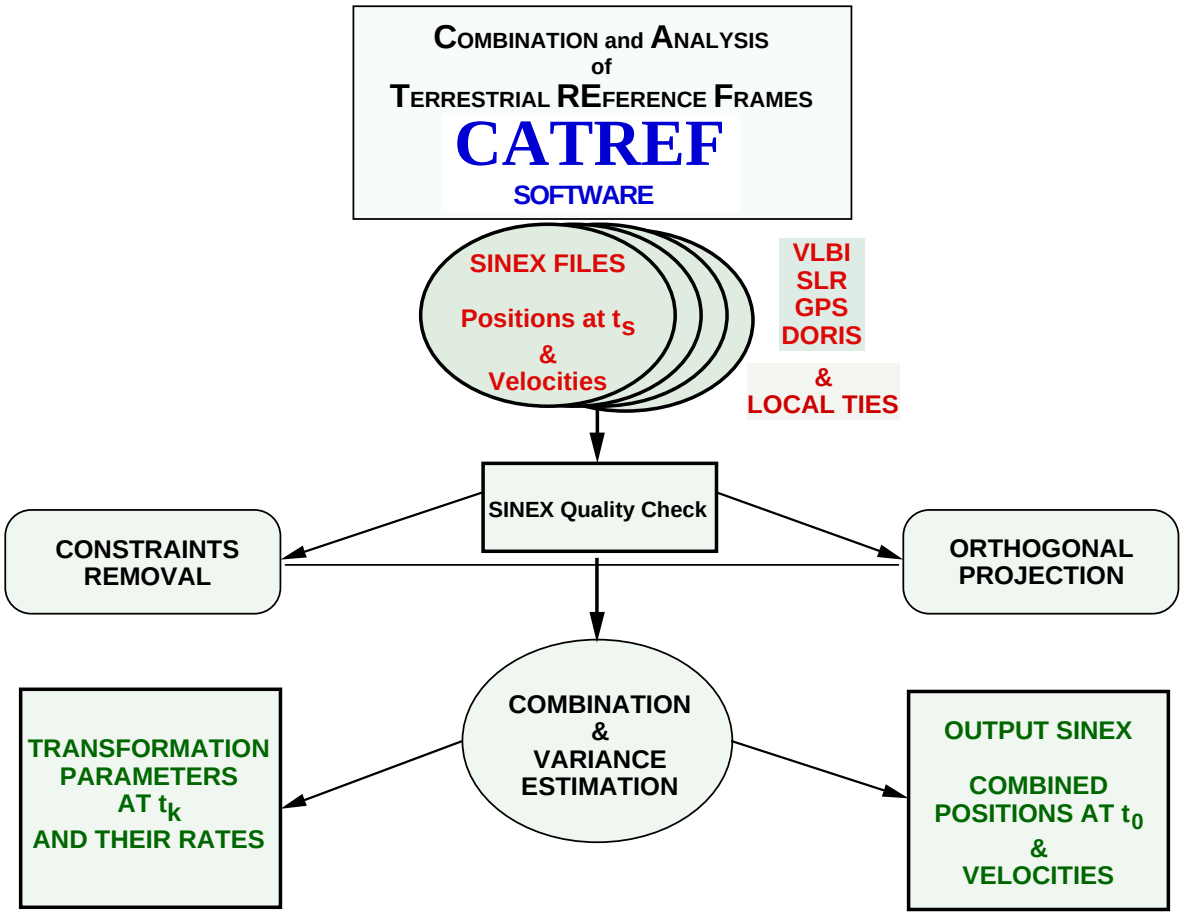
TRF and EOP comparative analysis between DORIS and other space geodesy techniques

- Consistency of DORIS Global TRF Solutions
- Evaluation of DORIS Local Ties in Collocation Sites
- Analysis of DORIS time series (TRF & EOP)
  - Geocenter (TRF Origin) and Scale Variation (DORIS,SLR,GPS)
  - EOP Consistency
  - Impact of local ties on the combined frame
- Conclusion

Zuheir Altamimi

Institut Géographique National, FRANCE

http ://lareg.ensg.ign.fr/ITRF/



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

TRF + EOP Simultaneous Combination

CATREF Software upgraded :

- **inclusion of EOP's**
- **Matching common EOP parameters at UT noon**
- **Propagate at UT noon if rates are available**

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

- **implementation of minimum constraint equations allowing to express the combined frame in any external frame (e.g. ITRF2000)**

Datum Definition / Minimum Constraints (1/4)

Application of Minimum Constraints (MC) approach based on theoretical works by many authors, since the 70's on, e.g. :

- **Free Network Adjustment**
- **S-transformation**
- **Minimum/Inner Constraints**

Main Goal : The "best" TRF datum definition preserving the actual quality of space geodesy observations.

Datum Definition / Minimum Constraints (2/4)

The starting point is the standard relation between two TRF's :

$$X_2 = X_1 + A\theta \qquad (1)$$

$$\theta = (T1, T2, T3, D, R1, R2, R3, \dot{T}1, \dot{T}2, \dot{T}3, \dot{D}, \dot{R}1, \dot{R}2, \dot{R}3)^T$$

$$A = \begin{pmatrix}
. & . & . & . & . & . & . & . & . & . & . & . & . & . \\
1 & 0 & 0 & x_i^0 & 0 & z_i^0 & -y_i^0 & & & & & & & \\
0 & 1 & 0 & y_i^0 & -z_i^0 & 0 & x_i^0 & & & & \approx 0 & & & \\
0 & 0 & 1 & z_i^0 & y_i^0 & -x_i^0 & 0 & & & & & & & \\
 & & & & & & & 1 & 0 & 0 & x_i^0 & 0 & z_i^0 & -y_i^0 \\
 & & & \approx 0 & & & & 0 & 1 & 0 & y_i^0 & -z_i^0 & 0 & x_i^0 \\
 & & & & & & & 0 & 0 & 1 & z_i^0 & y_i^0 & -x_i^0 & 0 \\
. & . & . & . & . & . & . & . & . & . & . & . & . & .
\end{pmatrix}$$

Datum Definition / Minimum Constraints (3/4)

L.S. of eq. (3) yields : $\theta = \overbrace{(A^T A)^{-1} A^T}^{\mathbf{B}} (X_2 - X_1)$

Using $B = (A^T A)^{-1} A^T$, **containing all the necessary info. to define a TRF, a "datum definition" equation at** Σ_θ **level could be written as :**

$$B(X_2 - X_1) = 0 \qquad (\Sigma_\theta) \tag{2}$$

and in terms of normal equation : $\boxed{B^T \Sigma_\theta^{-1} B(X_2 - X_1) = 0}$

Datum Definition / Minimum Constraints (4/4)

The initial NEQ system of space geodesy observations could be written as :

$$N_{unc}(\Delta X) = K \tag{3}$$

where $\Delta X = X - X_{apr}$ **(Linearized Unknowns)**

Selecting a Reference TRF (X_R), MC equation is :

$$B^T \Sigma_\theta^{-1} B(\Delta X) = B^T \Sigma_\theta^{-1} B(X_R - X_{apr}) \tag{4}$$

Cumulating (3) and (4) yields :

$$(N_{unc} + B^T \Sigma_\theta^{-1} B)(\Delta X) = K + B^T \Sigma_\theta^{-1} B(X_R - X_{apr})$$

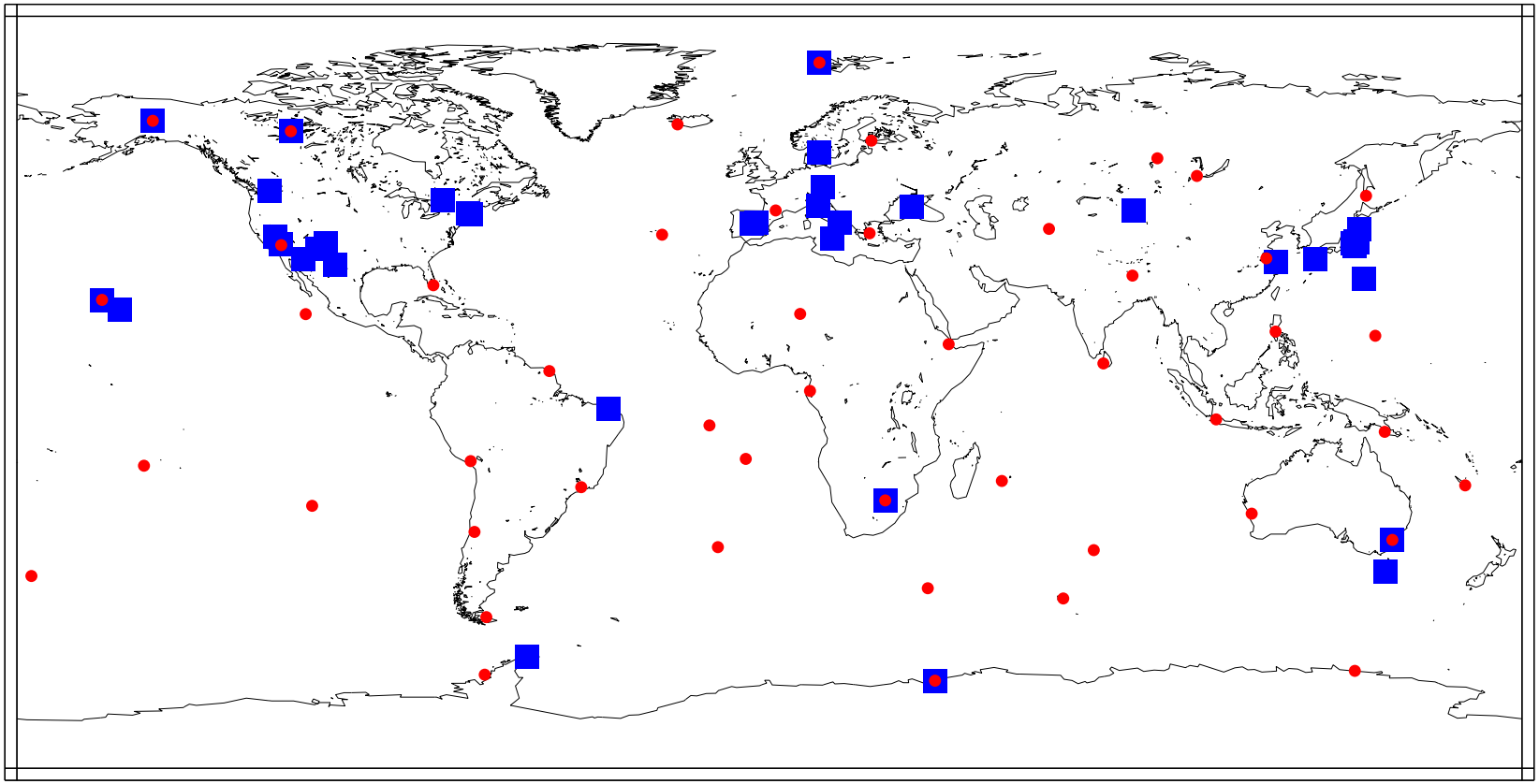
Some Analysis Tests

Data used :

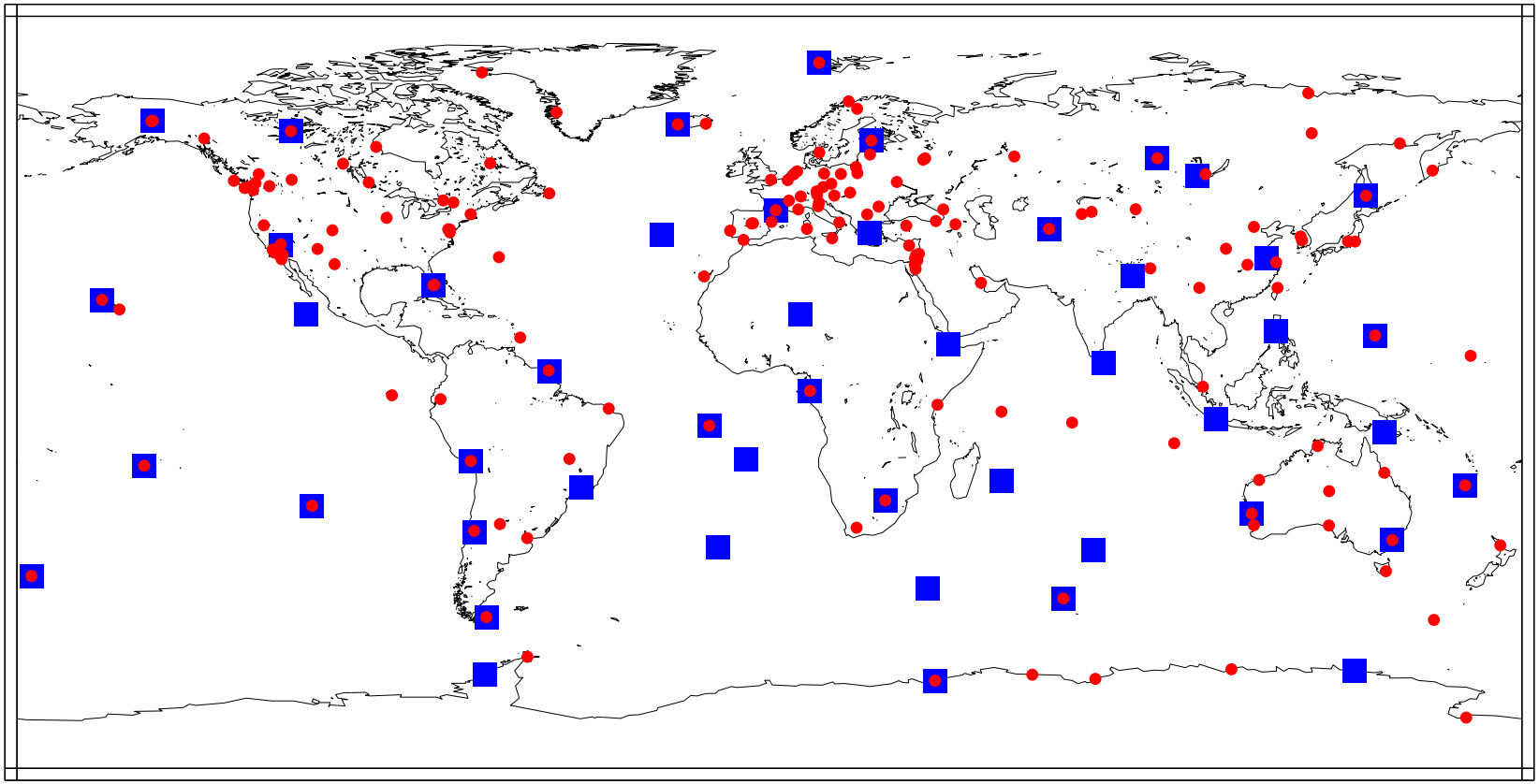
- **DORIS :**
  - **DORIS Global TRF Solutions : IGN/JPL D03, D04**
  - **Monthly solutions : (IGN/JPL D03), (LCA D02)**

- **SLR : CSR ILRS Pilot Project Monthly Solutions**
- **GPS : IGS weekly combined solutions**
- **VLBI : 24h-session sinex files from GSFC**
- **ITRF2000 data : VLBI, GPS, SLR + (DORIS Local Ties)**
- **IGS cumulative solution + (DORIS Local Ties)**

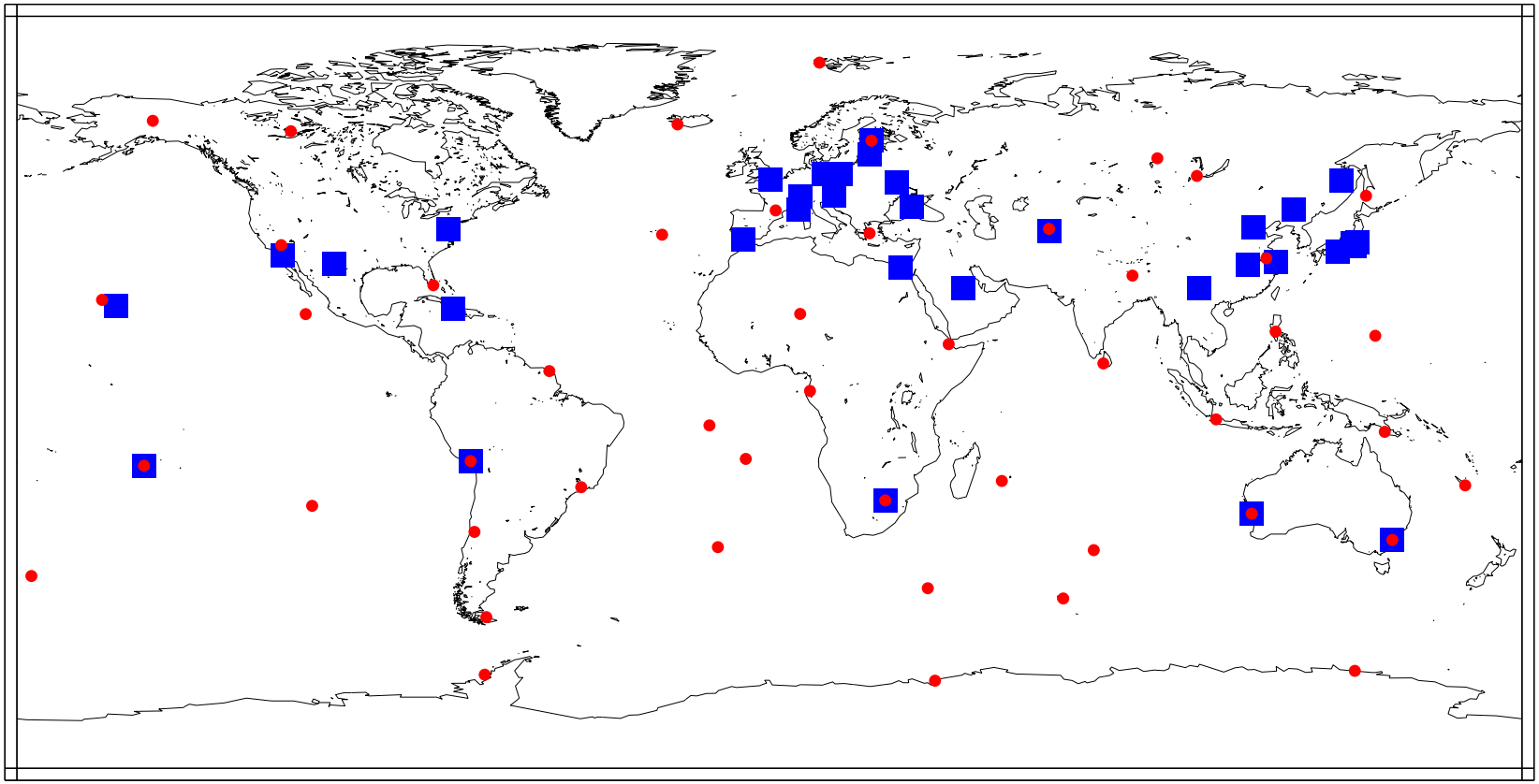
Current VLBI-DORIS Collocations



Current DORIS-GPS Collocations



Current SLR-DORIS Collocations



Analysis of DORIS Global TRF Solutions

Compared to VLBI+SLR+GPS + (DORIS Local Ties)

Solution	Sta. #	WRMS Pos (mm)	WRMS Vel (mm/y)
IGN D03	63	20	2.9
IGN D03 (*)	63	20	2.7
IGN D04	63	20	3.4
IGN Test	63	20	2.8
LCA D02 (*)	52	39	3.7
		$\pm$ 2	$\pm$ 0.2

(*) : Combination of monthly solutions

Analysis of DORIS Global TRF Solutions

Compared to IGS Cumulative Solution + (DORIS Local Ties)

Solution	Sta. #	WRMS Pos (mm)	WRMS Vel (mm/y)
IGN D03 (*)	53	19	3.6
LCA D02 (*)	45	37	3.9
		$\pm$ 2	$\pm$ 0.2

(*) : Combination of monthly solutions

Local Tie problems (?)

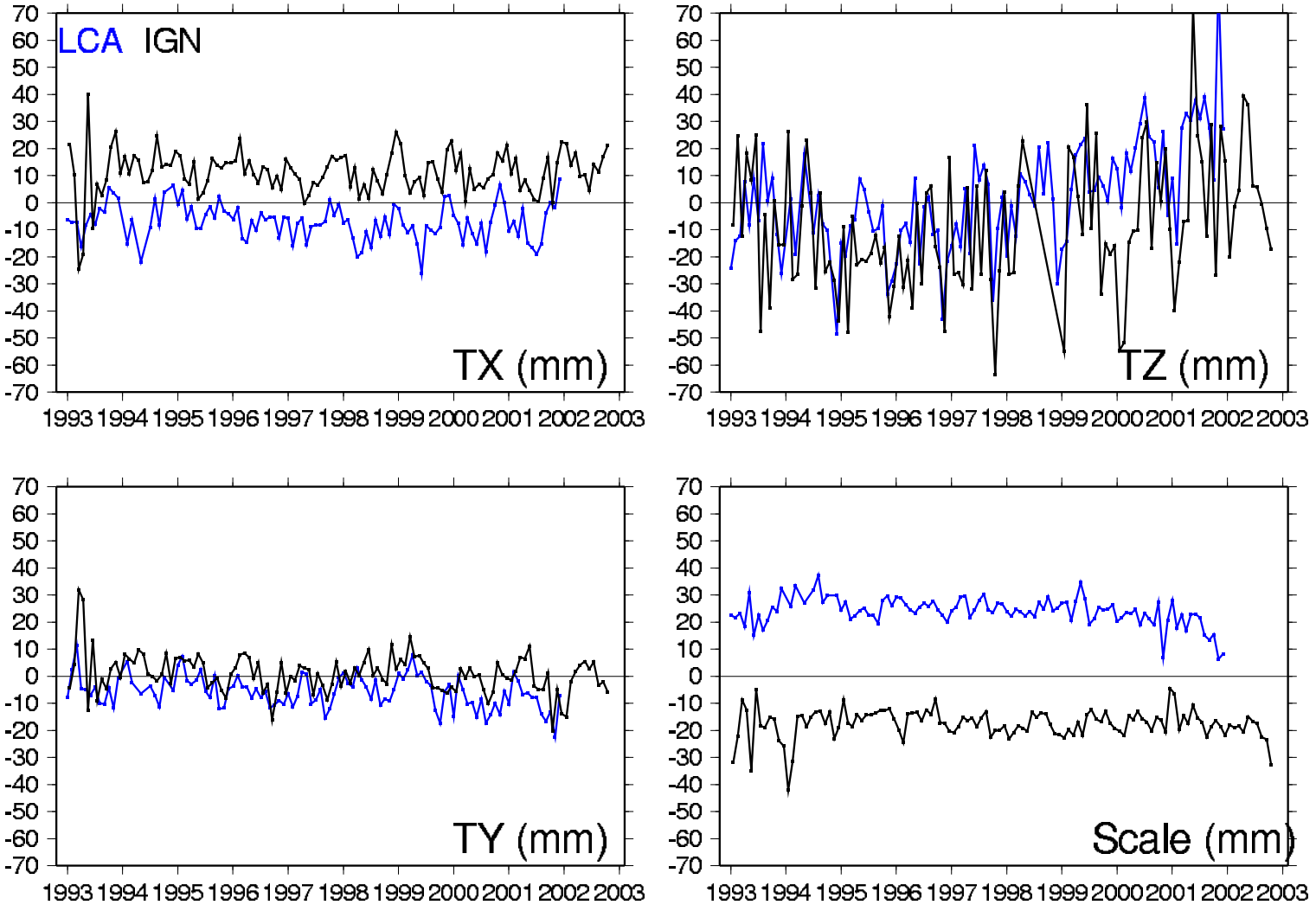
unit : cm

Station	E	N	Up
KITB	3.3	0.5	0.8
HBLA	4.5	0.2	0.7
HBKB	3.9	0.4	0.5
PAQB	3.4	0.0	1.7
PDEL (GPS)	4.6	0.0	7.7

Strategy for time series analysis

- Apply minimum constraints equally to all loosely constrained solutions
- Use as they are the minimally constrained solutions
- Perform per-technique combinations (TRF + EOP), all expressed in ITRF2000
- Combine the per-technique combinations + Local ties
- Estimate variance components and iterate as necessary

Origin & Scale Variation (SLR CSR)



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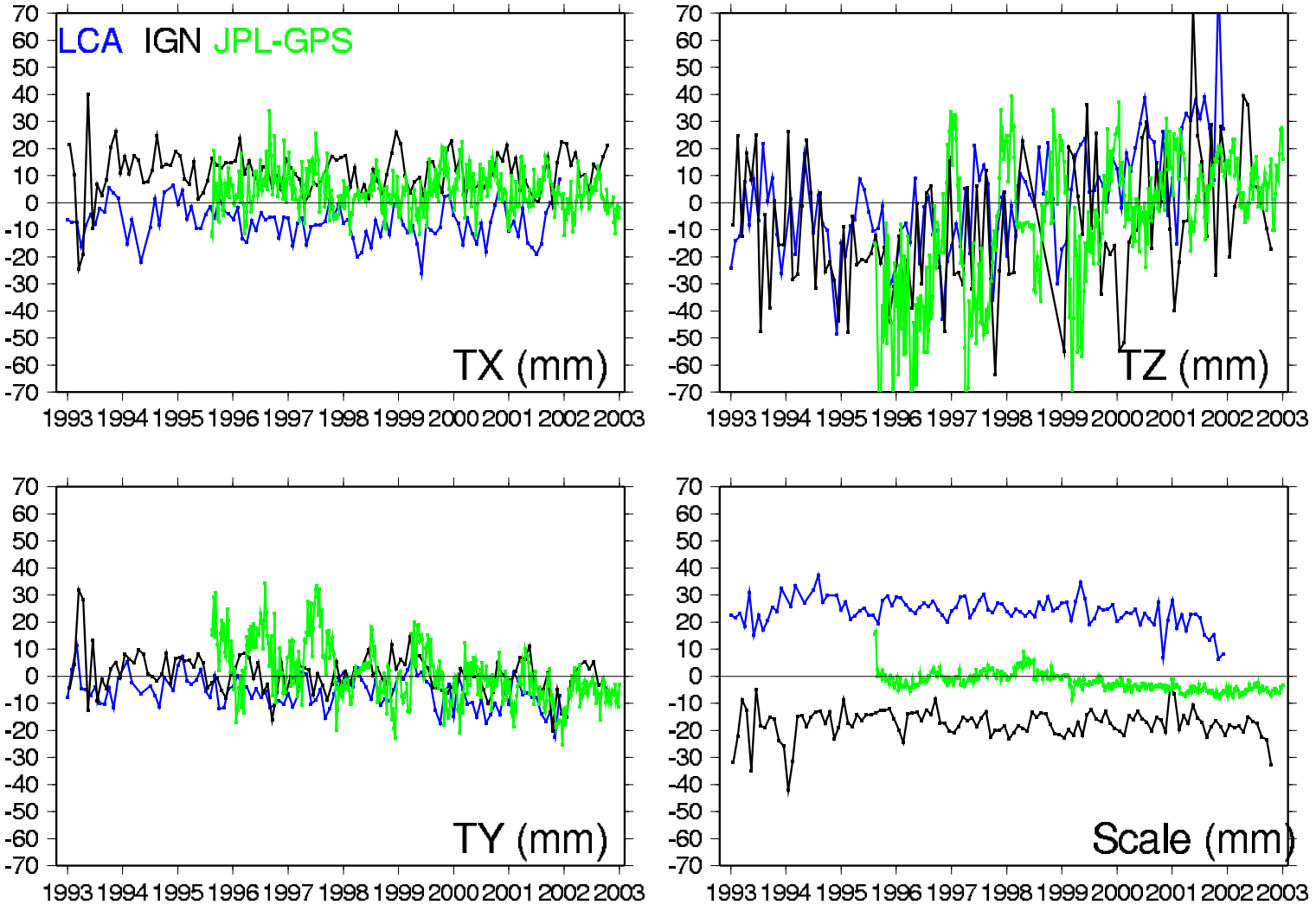

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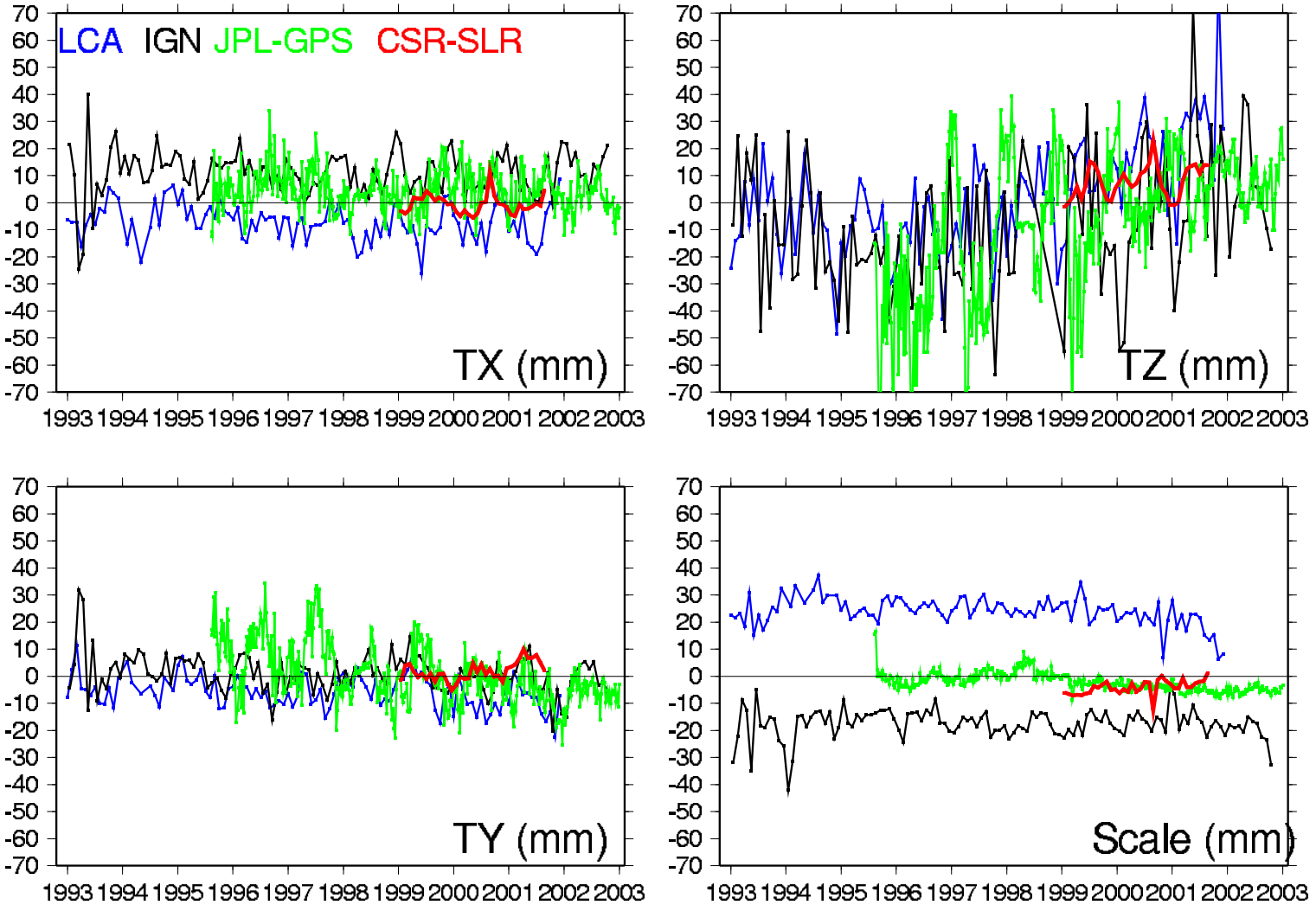
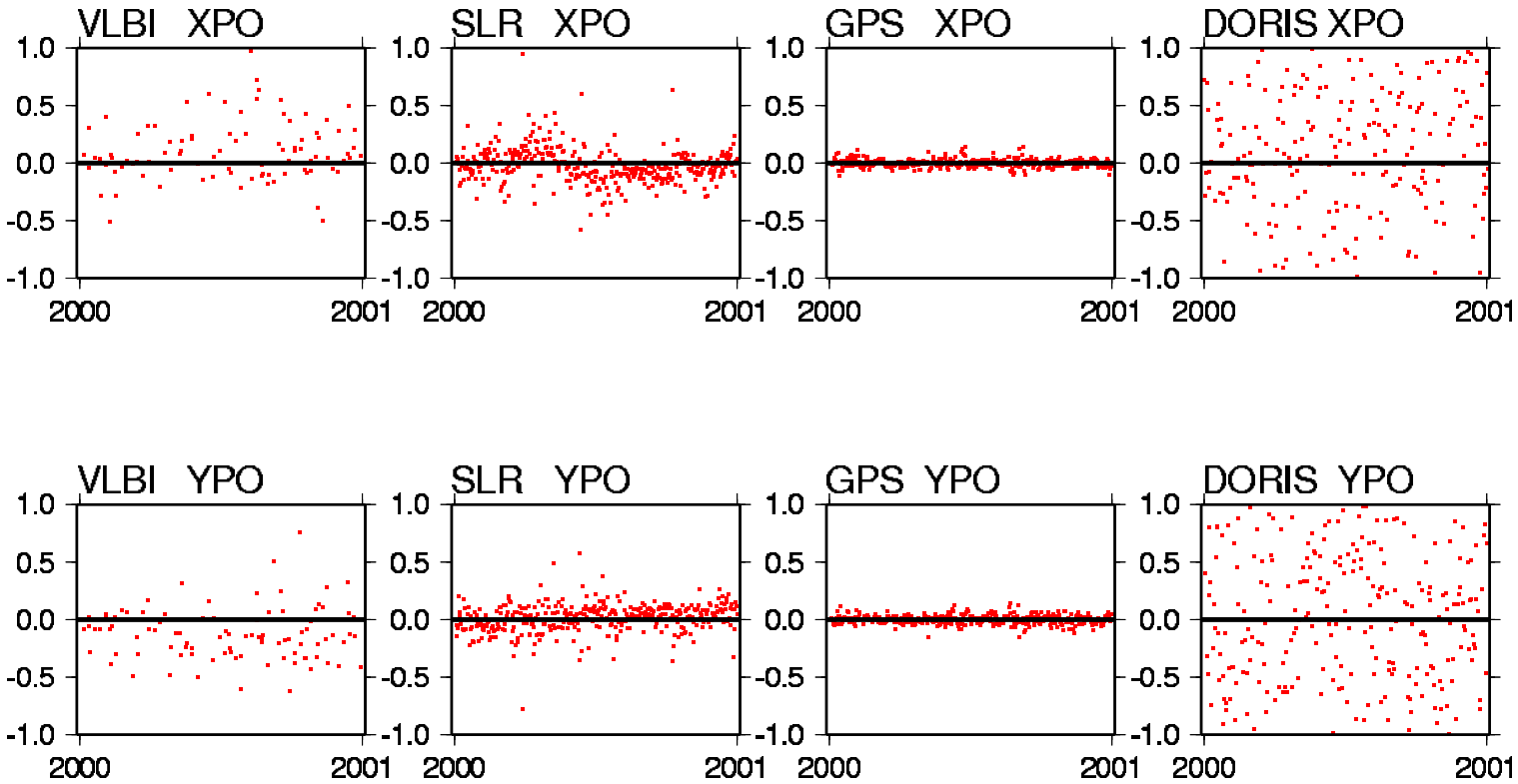
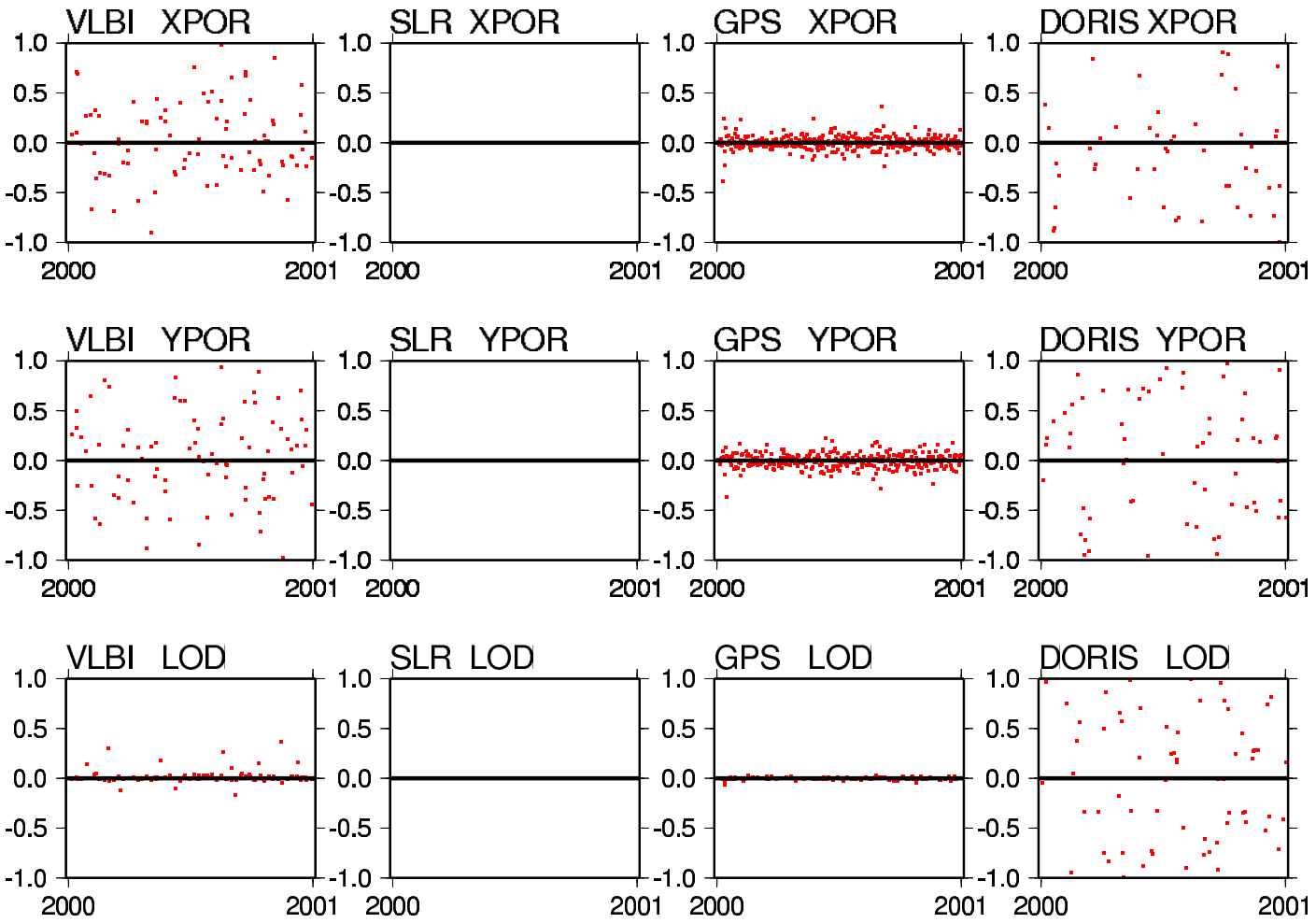


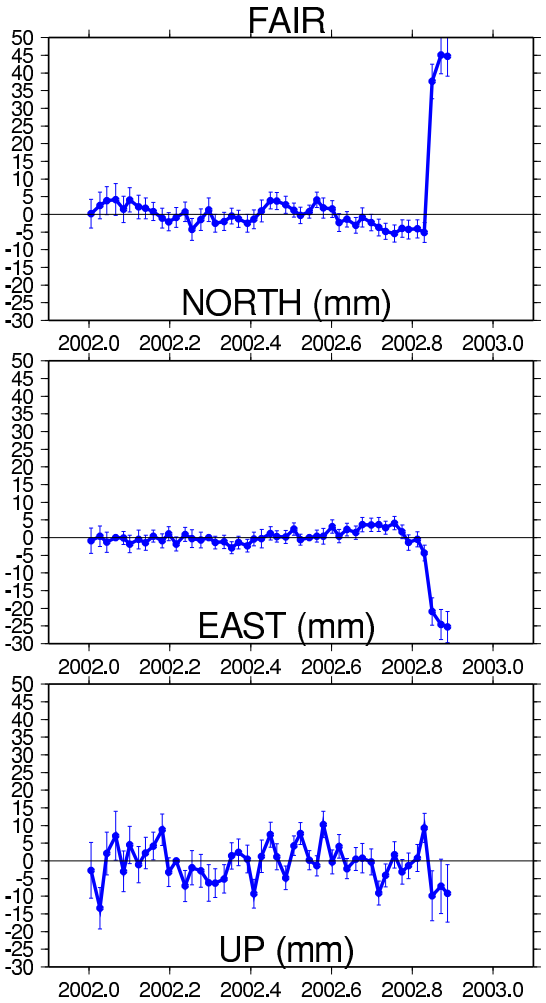
2000 multi-technique combination : X & Y_pole Residuals (mas)



2000 multi-technique combination : X & Y_pole Rate (mas/d) & LOD (ms/d) Residuals



Fairbanks Earthquake



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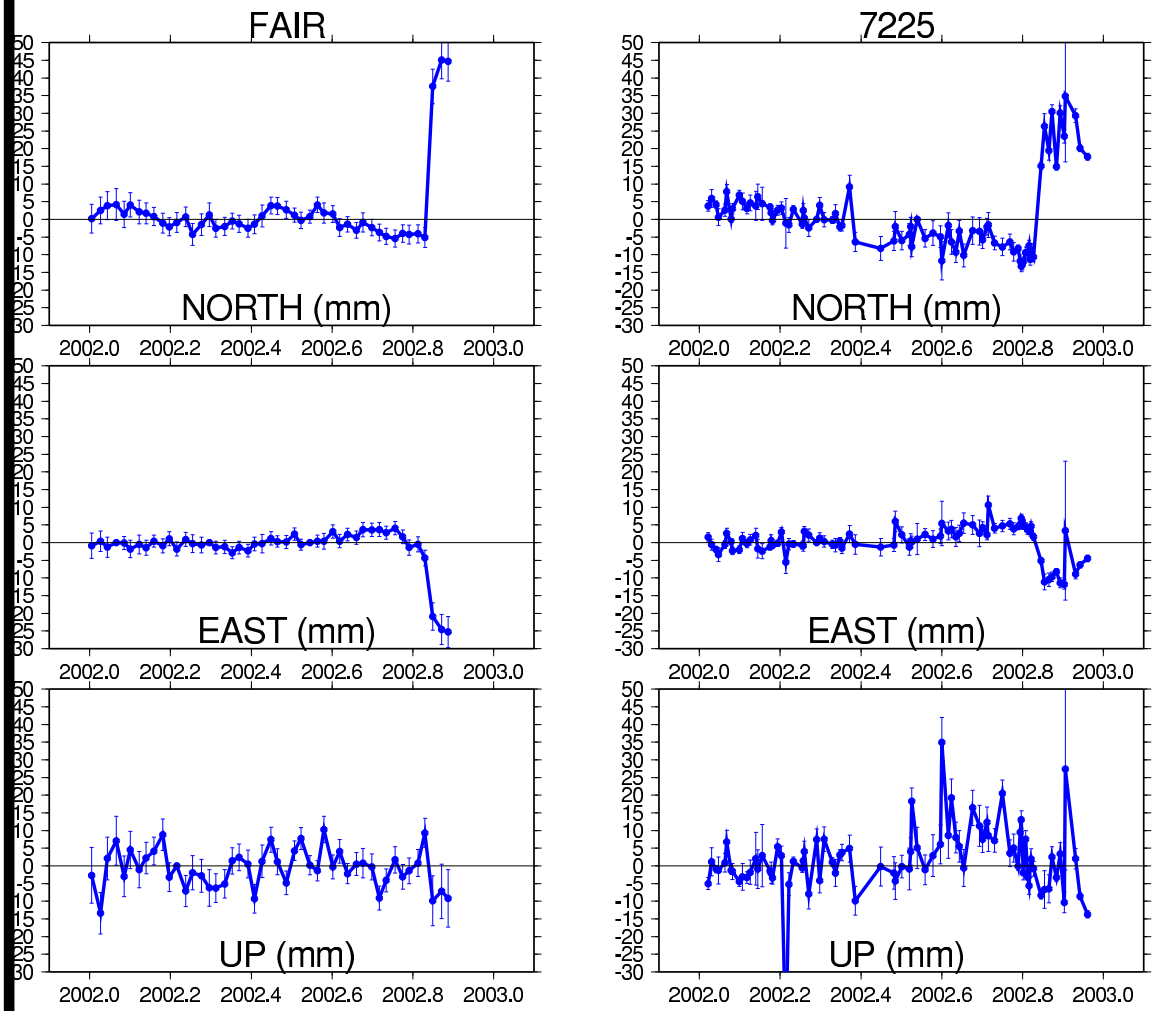

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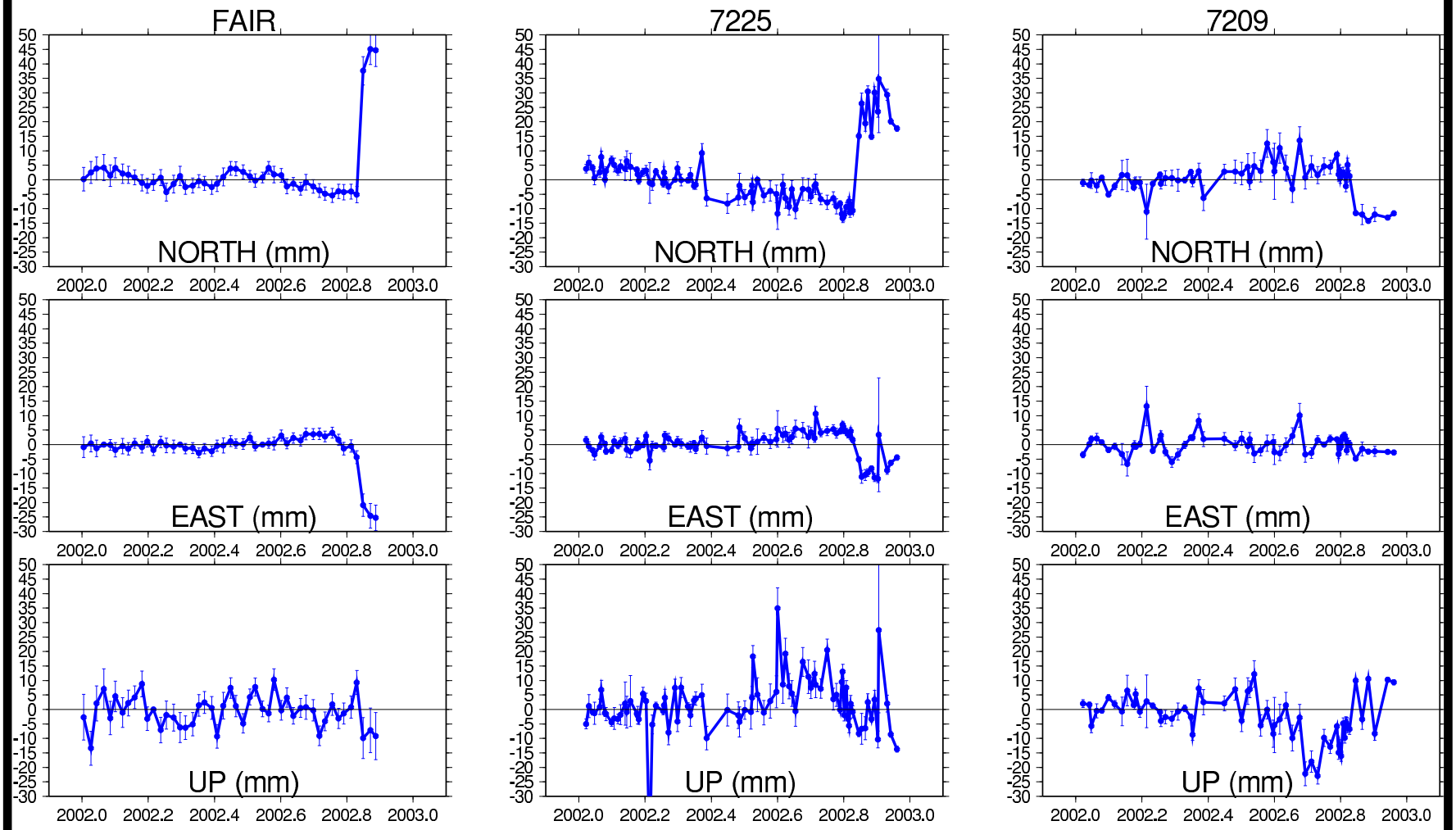
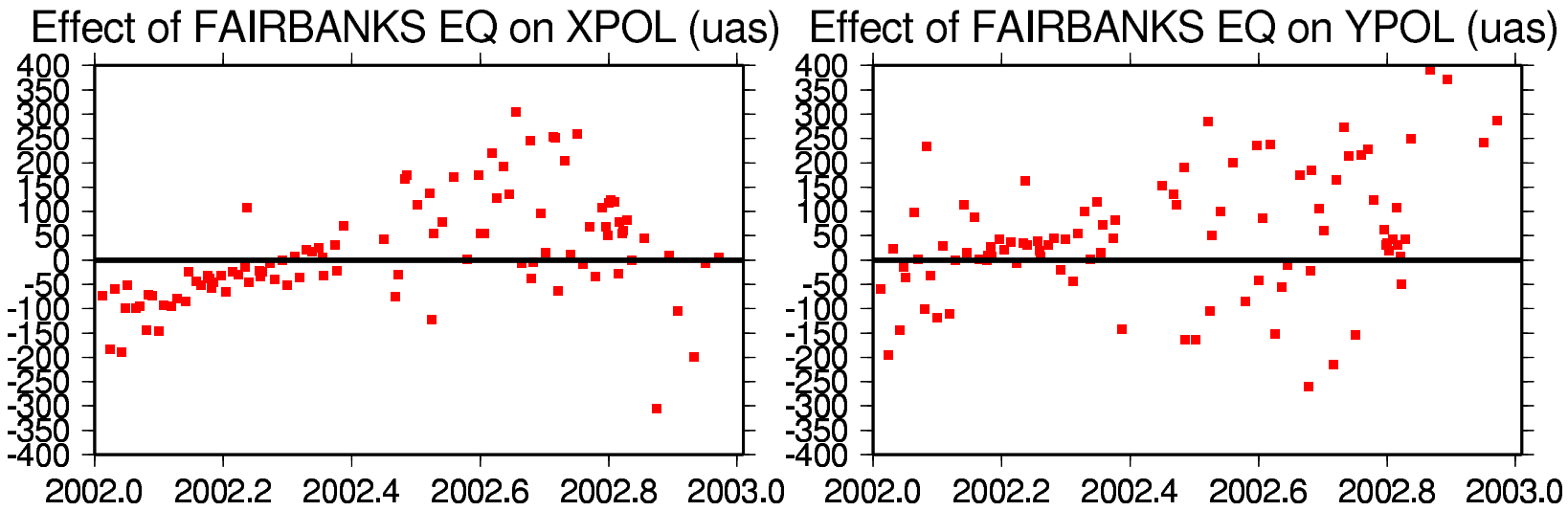
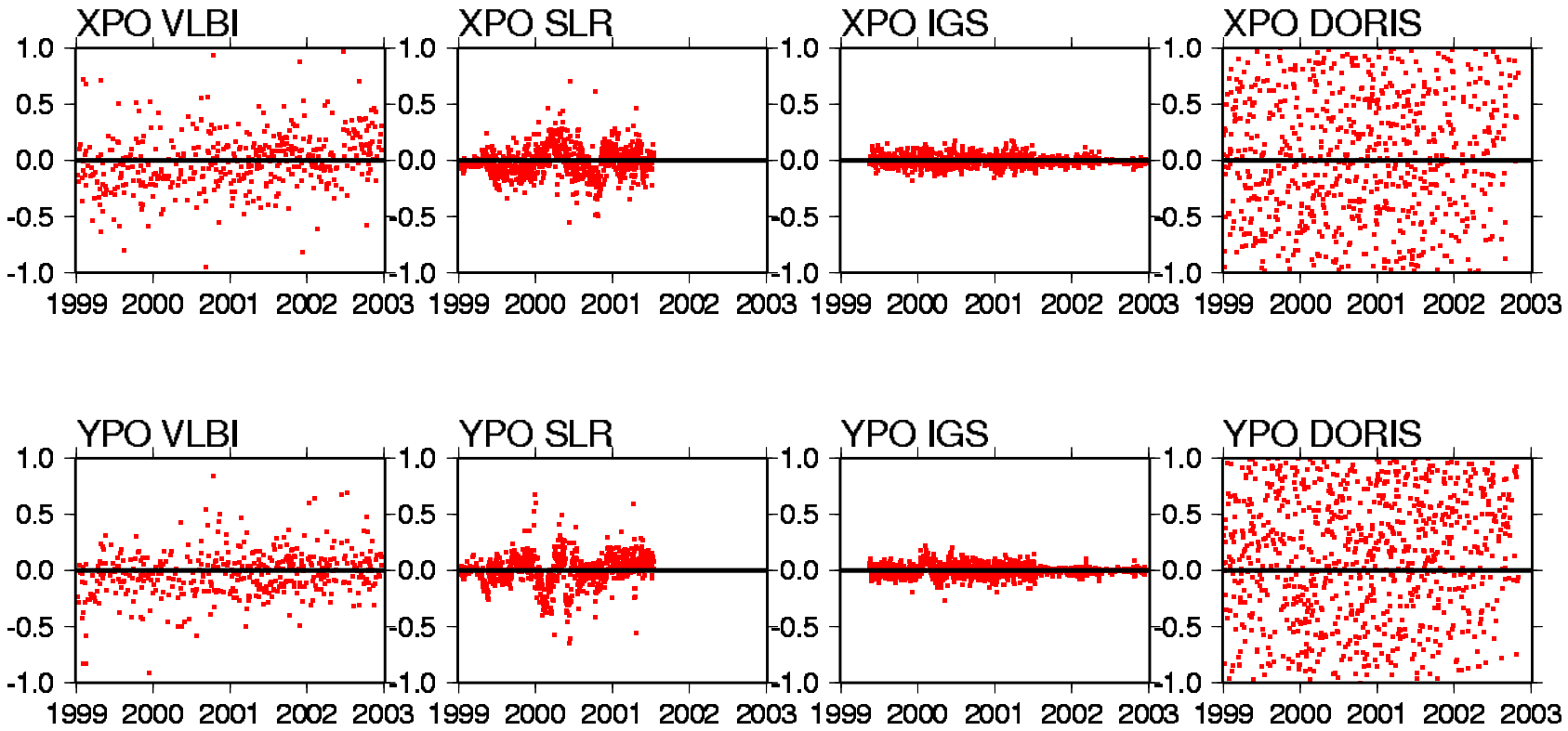


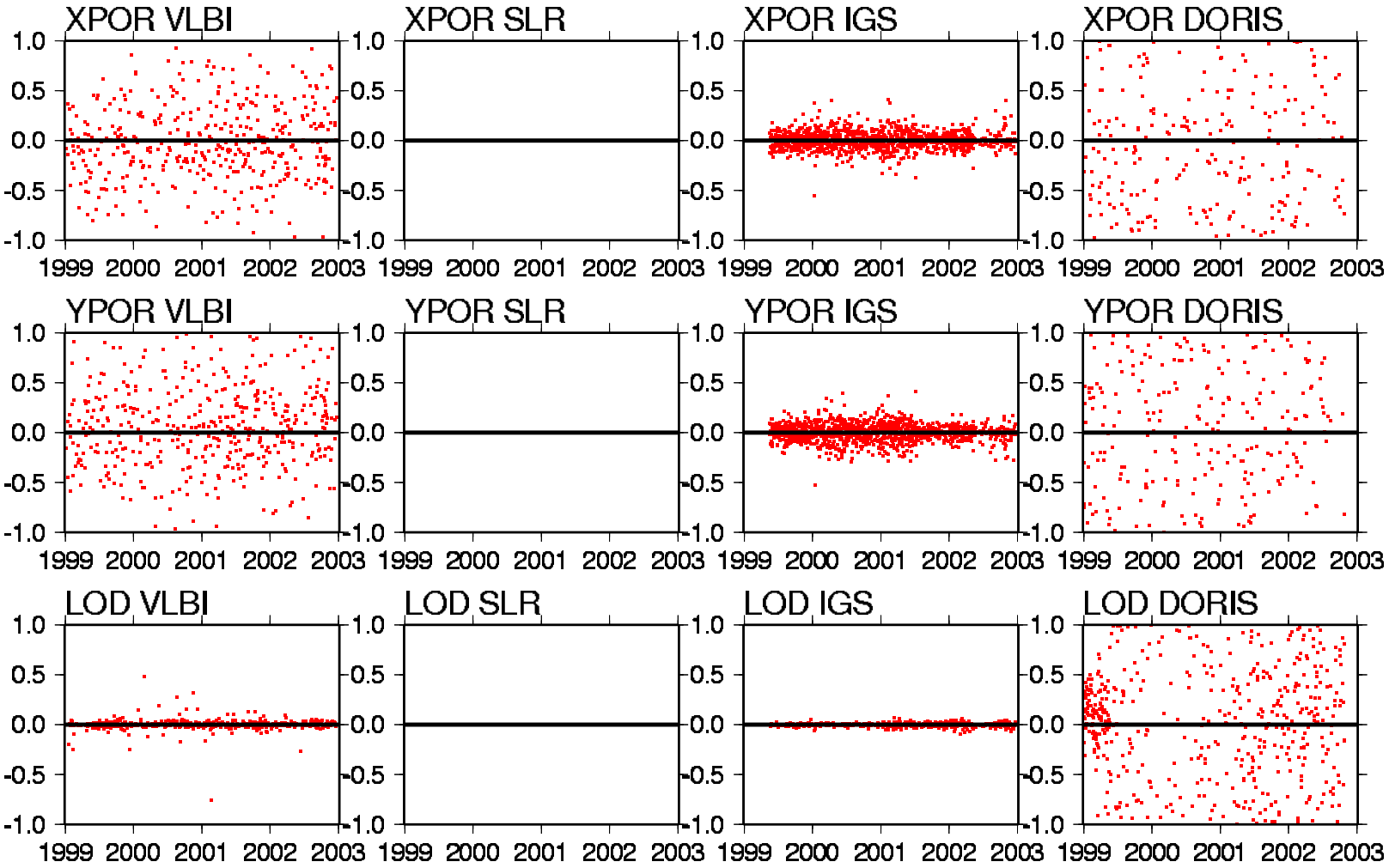
Fairbanks EQ Effect on Polar Motion



(4-Years) multi-technique combination : X & Y_pole Residuals (mas)



(4-Years) multi-technique combination : X & Y_pole Rate & LOD Residuals



Quality of DORIS EOP compared to other Techniques

Solution	Xpole mas	Ypole mas	X-rate mas/y	Y-rate mas/y	LOD ms/y	Span Years
VLBI-GSFC	0.18	0.15	0.33	0.34	0.02	4
SLR-CSR	0.13	0.12	-	-	-	3
GPS-IGS	0.04	0.04	0.07	0.08	0.01	4
DORIS-IGN	1.87	1.34	6.12	6.35	10.	1
DORIS-LCA	1.59	1.38	-	-	-	1
DORIS-COMB	1.51	1.17	5.61	6.26	6.15	4

Local Tie impact on the combination

Example : SLR-VLBI Tie in Shanghai : 4 cm discrepancy

If not de-weighted :

- **SLR-VLBI Scale change $\approx$ 0.4 ppb**
- **SLR-VLBI coordinates change : 1-3 cm**
- **Large VLBI coordinate residuals : 4 cm**
- **EOP change : negligible $\approx$ 0.02 mas**

Conclusion

- **DORIS Global TRF :**
  - **Better than 2 cm in position**
  - **Better than 3 mm/y in velocity**
  - **There is a need for a unique list of station discontinuities**

- **Origin and Scale differences between IGN and LCA**
  - **15 mm in T_x**
  - **40 mm in scale**
- **EOP : $\approx$ 1 mas**
- **EOP Rates may disturb the EOP estimates**
- **There is a Need for more Analysis Centers within IDS**