Why combining at the Observation Level?

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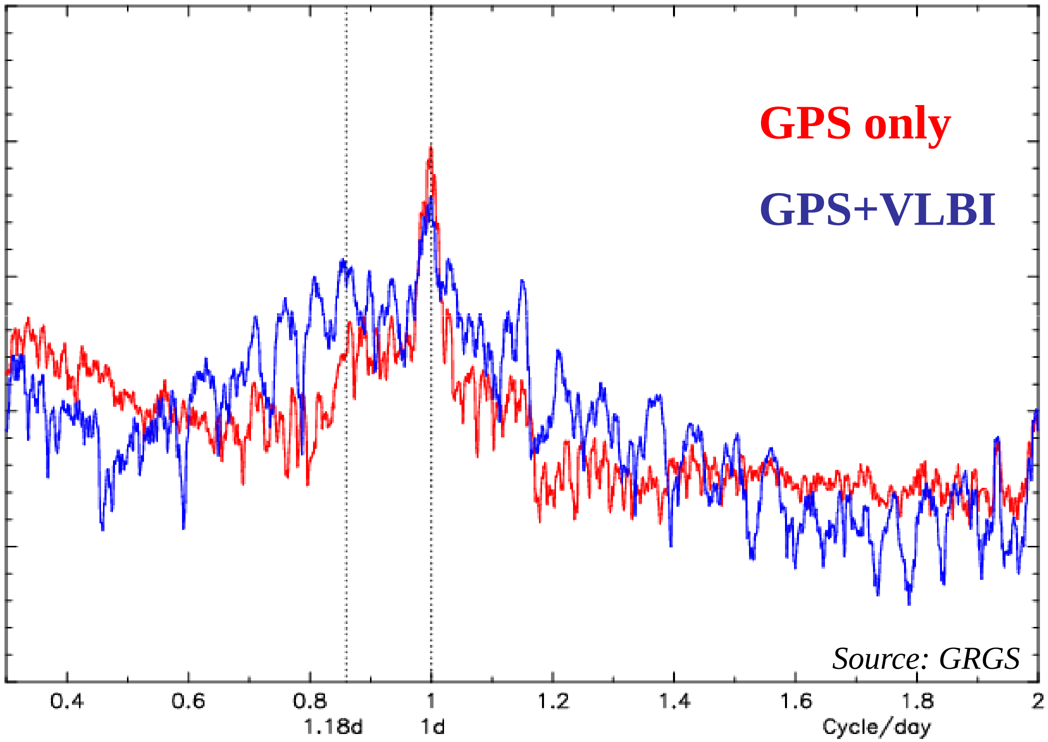
Space geodetic techniques have different strengths and weaknesses for recovering geodetic parameters which makes their combination useful. But they may have also some systematic behaviour which can easier and more efficiently be detected and reduced at the observation level.

That's why the major task of the WG-COL is to study methods and advantages of combining techniques (DORIS, GPS, SLR, VLBI) at the observation level, searching for an optimal strategy to solve for geodetic parameters.

Demonstration should be based on weekly combined SINEX files (containing normal equations of station coordinates, ERPs, nutation parameters and eventually quasar coordinates) from all space geodetic techniques together. 3 weeks encompassing the CONT'08 VLBI campaign are used first for establishing the level of processing adequacy among the participating groups.

Example of ERP residual signal (wrt to IERS-C04) from different techniques (GPS and VLBI)

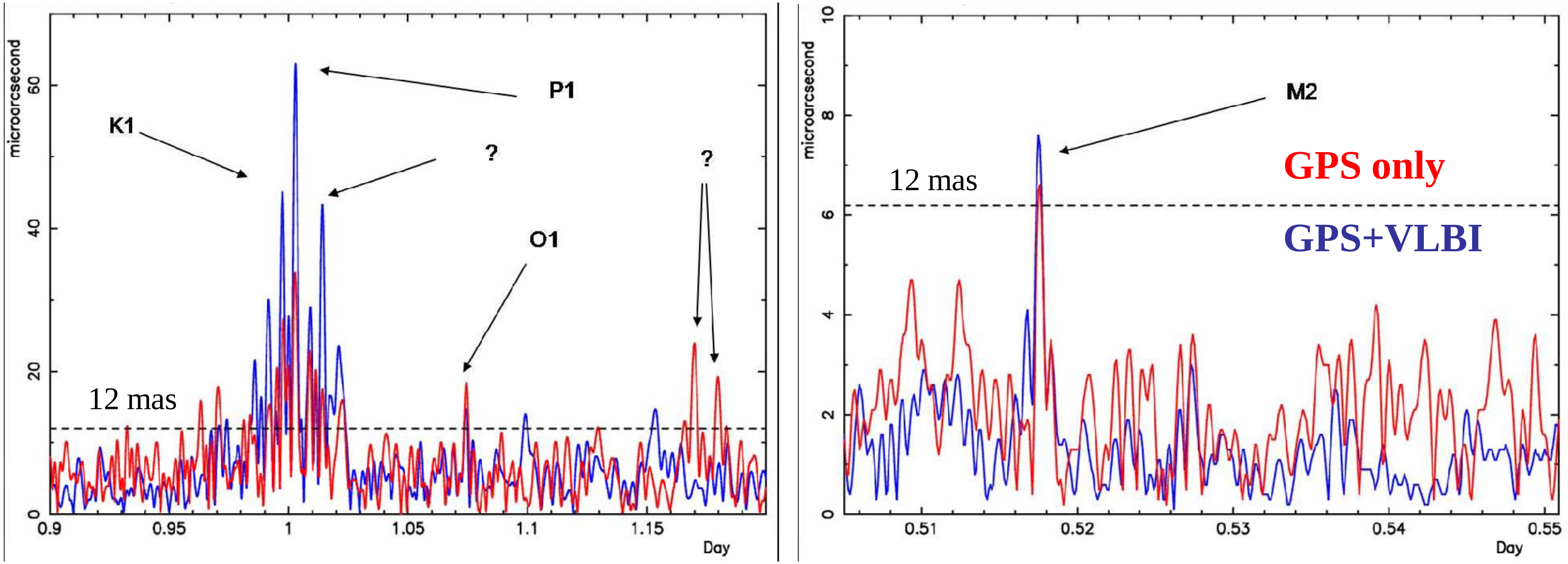
Diurnal and sub-diurnal variations in the Earth rotation from 6h pole parameter adjustment



Prograde part of the complex spectrum of polar motion over 2007-2008. A strong diurnal peak still appears in both series. Another peak at 1.18 d (0.85 cy/d) may be subject to doubt.

Example of ERP residual signal (wrt to IERS-C04) from different techniques (GPS and VLBI)

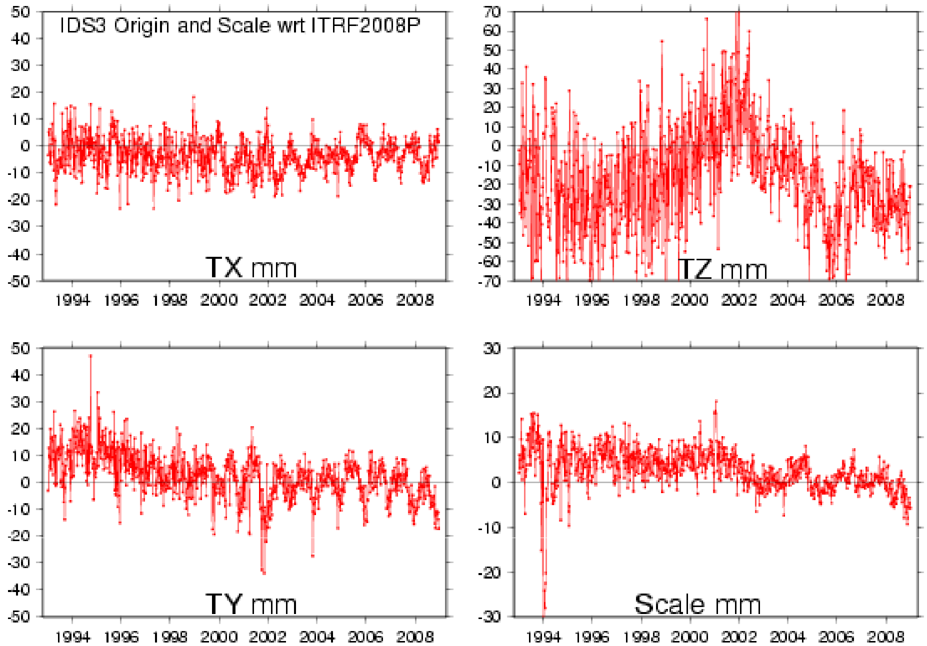
Periodogram of Y-polar motion over 2007-2008.



Source: GRGS

Different peaks (which can be attributed to tide mismodelling) appear over the noise level; they are amplified in the GPS+VLBI combination while the noise level is reduced.

Example of station network behaviour vs. ITRF2008



Source: ITRF2008

Weekly DORIS station solutions exhibit systematic discrepancies in translation (mainly in Z) and scale which express weaknesses of the technique in comparison to combination (ITRF2008). Could rigorous technique combination reduce these discrepancies?

Each technique or network present strengths and weaknesses in terms of accuracy or distribution. Consistency has to be reach by optimal combination with the help of :

- well distributed station co-locations and realistic weighting strategy; an homogeneous network of fundamental geodetic observatories is desirable;

- geodetic satellite missions boarding several tracking equipments (like Jason); why not a dedicated satellite mission combining a VLBI antenna, GNSS receivers, laser retroreflectors… for reducing systematic errors?

Can technique combination at the observation level improve accuracy and consistency of EOP, TRF, CRF?

IERS has created a dedicated framework for studying combination:

2002 – creation of the IERS Combination Research Centres (11 CRCs)
2004 – IERS proposal of Combination Pilot Project (CPP)
2009 (21-22 October) – kick-off meeting of the COL-WG

"Combination at the Observation Level" Working Group charter:
COL-WG major task will be **to study methods and advantages of combining techniques at the observation level**, searching for an optimal strategy to solve for geodetic parameters. Demonstration should be based on weekly combined SINEX files (containing unconstrained normal equations of station coordinates, EOPs, nutation parameters and eventually quasar coordinates) from all space geodetic techniques together.

Goals of the COL-WG

- to improve precision, resolution and consistency of products (EOP, TRF, CRF) creating common standards for a rigorous combination

- to extend the combination approach at the level of observation to several research groups in a planned IERS action

- to mutualize physical parameters (eg. troposphere) and to study technique dependent systematic errors

- to progress in combination methods and strategies (eg. weighting)

- to validate the rigorous combination approach vs. present realizations (C04, ITRF…)

- to prepare future of IERS…

COL Strategy

$$\sum_{CC}^{4}\left(\sum_{AC}^{n} individual\ technique\right) \Rightarrow \sum_{CC'}^{n'}\left(\sum_{COL}^{\geq 2} multi-technique\right)$$

$$\sum_{CC}^{4}\left(\text{IGS}\quad \text{IVS}\quad \text{International Laser Ranging Service}\quad \text{IDS}\right) \Rightarrow \sum_{CC'}^{n'}\left(\text{GINS}\quad \text{DOGS}\quad \text{Bernese}\quad \text{EPOS}\quad \text{NAPEOS}\right)$$

Improving the combination approach by searching for **homogeneity "at the level of observations"** in terms of :

• precision *(considering systematisms and common parameters => troposphere)*

• resolution *(considering observation densification => 3h EOP sampling)*

• consistency *(wrt modelling standard, software => comparison campaign)*

should increase accuracy

Mutual information from the different techniques should complement and improve global products taking advantage of strengths of each technique through an homogeneous processing

Present COL participants

- AIUB: BERNESE
- DGFI: DOGS-OC/-CS (+ OCCAM)
- ESOC: NAPEOS
- GFZ: EPOS
- GRGS: GINS/DYNAMO

Other potential COL participants

- JPL: GIPSY/OASIS
- GSFC: GEODYN/SOLVE
- ASI: GEODYN
- …

Prerequisite

processing must be at the quality level of the Technique International Services

Combination at the NEq level vs. observation level

– with the same software handling several techniques

– with different software packages if they are well homogenized

$\sum_i \frac{\partial Q_i^{calc}}{\partial p_k}\left(\sum_{j=1}^{n}\frac{\partial Q_i^{calc}}{\partial p_j}\Delta p_j - \Delta Q_i\right)=0 \quad \forall k=1,n$	$\Delta Q_i = Q_i^{obs} - Q_i^{calc} = \sum_{j=1}^{n}\frac{\partial Q_i}{\partial p_j}\Delta p_j$
NEQ level	**Observation level**
Consistent processing of the data using the same models and parameterization	
Appropriate **relative weighting** of the techniques	
Corrections to the **original observations** are estimated	
Outlier detection and **weighting** of observations technique-wise	Outlier detection and weighting of observations within the combination process
A priori **reduced parameter** cannot be handled anymore	All parameters are available

Only technique dependent parameters can be reduced for an actual equivalence between NEq level and observation level

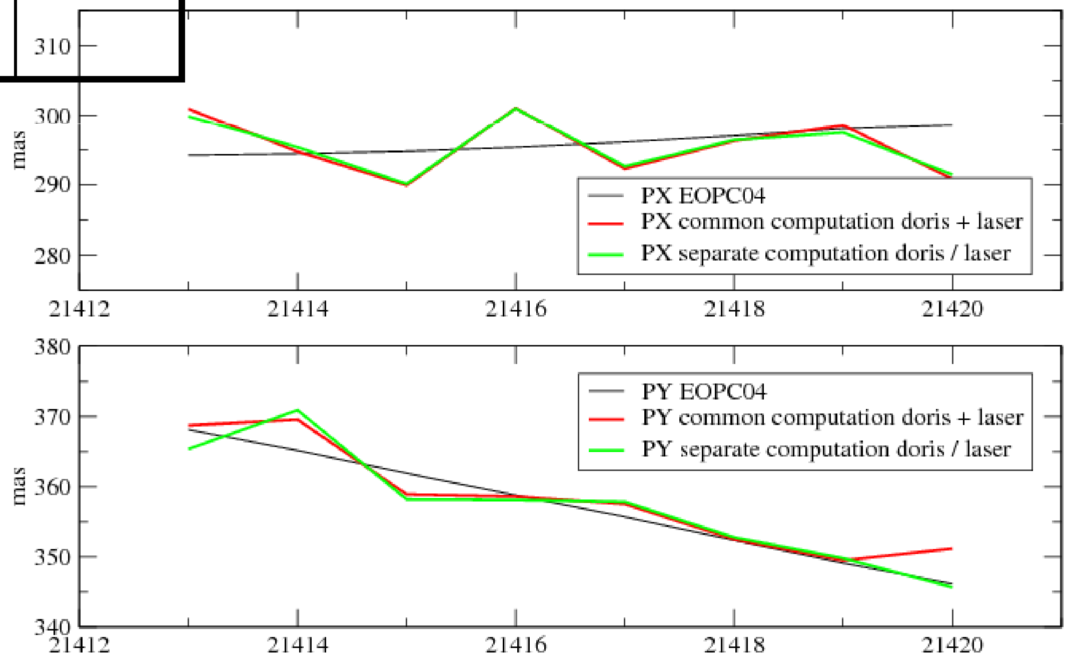
Combination at the observation level vs. NEq level

Example: Jason2 - 7 day arc over the period: 17/8/2008 – 23/8/2008

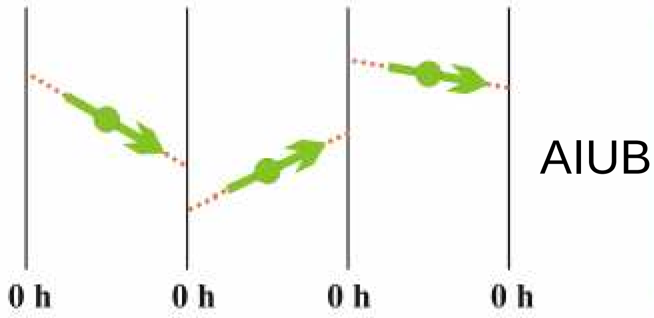
Technique	Nb of observ.	Residuals	Orbit # rms
SLR	2216/224	4.1cm	12.1cm
DORIS	109884/52825	.346mm/s	10.6cm
SLR + DORIS	2247/193 109614/53095	4.2cm .352mm/s	

X-Pole / d

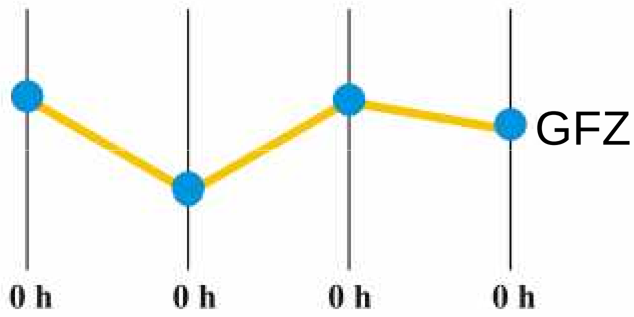
Y-Pole / d



Problem of EOP interpolation

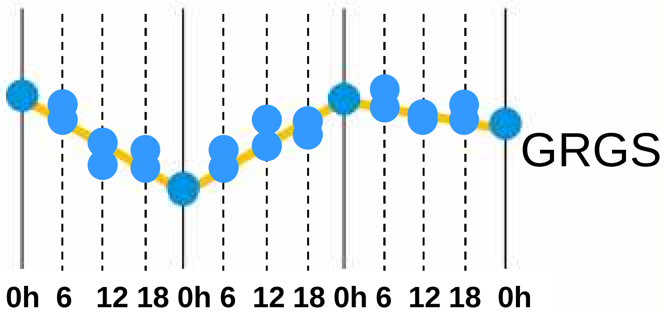


Piece-wise linear **Offset+Drift**
2*n parameters
no continuity at boundaries
continuity constraints reduce #parameters to ***n+1***



Piece-wise linear **Polygon**
n+1 parameters
"real" continuity at boundaries
no continuity constraints needed
not distinguishable from "offset-only" in SINEX

Seitz, Thaller - Workshop on Combination on Observation Level, 21./22.10.09, Warsaw



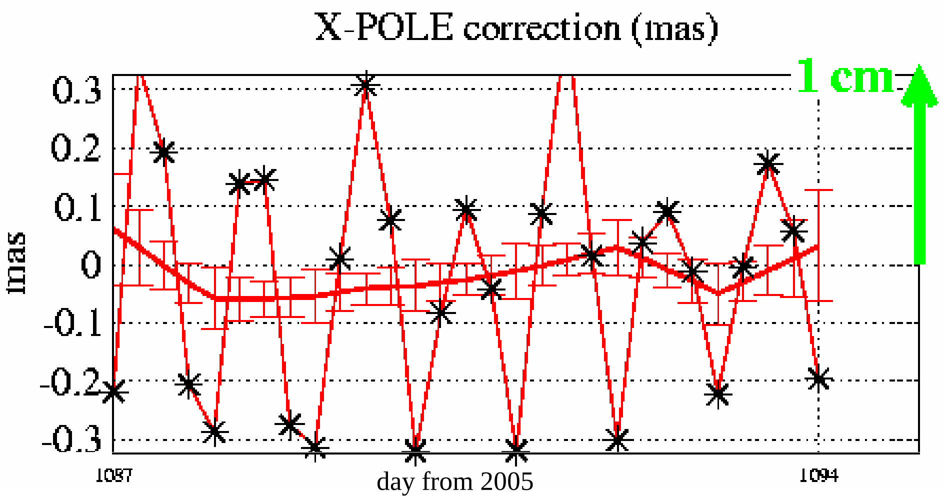
Densified piece-wise linear **Polygon**
4n+1 parameters
"real" continuity achieved
no continuity constraints needed
linearity conditions by segment

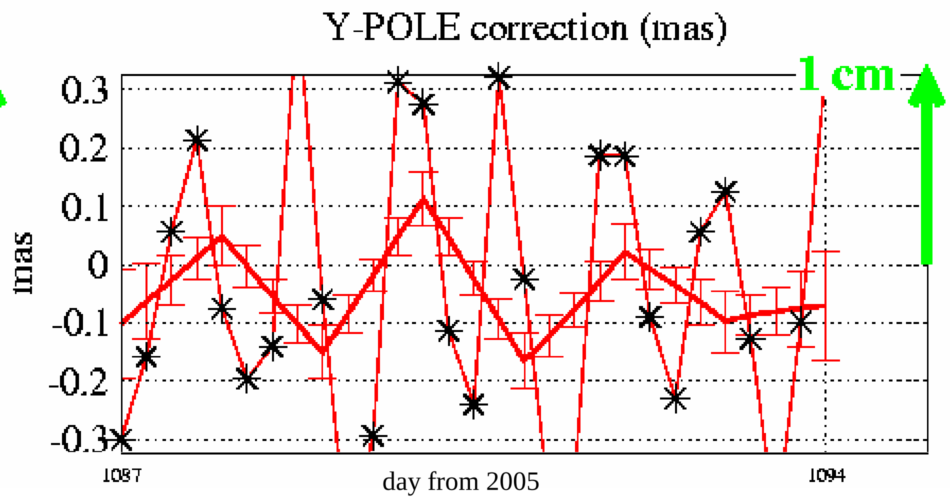
$$\begin{cases} P_j(6h) = \frac{3}{4}P_j(0h) + \frac{1}{4}P_{j+1}(0h) \\ P_j(12h) = \frac{1}{2}P_j(0h) + \frac{1}{2}P_{j+1}(0h) \\ P_j(18h) = \frac{1}{4}P_j(0h) + \frac{3}{4}P_{j+1}(0h) \end{cases}$$

not distinguishable from "offset-only" in SINEX

Example of ERP undersampling

GPS - from 6 hr to 1 day





by linearity constraints:

$$\begin{cases} P_j(6h) = \frac{3}{4}P_j(0h) + \frac{1}{4}P_{j+1}(0h) \\ P_j(12h) = \frac{1}{2}P_j(0h) + \frac{1}{2}P_{j+1}(0h) \\ P_j(18h) = \frac{1}{4}P_j(0h) + \frac{3}{4}P_{j+1}(0h) \end{cases}$$

=> One can densify the EOP parameterization (to 3hr for instance) to be closer to the temporal data distribution (mainly for VLBI) and apply linearity constraints afterwards if needed

First actions of the COL-WG

To intercompare results of different software packages

Defining benchmarks: the period chosen for establishing benchmarks is **from August 10 to August 30, 2008**. It includes the intensive **CONT08 VLBI period** (from 12 to 26/08/08). Combined SINEX will be delivered per week. They could be separated per technique.

Estimating parameters: the non reduced parameter set should include EOP (pole, UT1, nutation parameters per day and possibly drifts), station coordinates (per week), troposphere zenith delay ZTD (per hour). In order to reduce the size of SINEX files, troposphere parameters of non collocated GPS stations can be previously reduced.

Schedule:

2009: creation of the COL forum and discussion on a priori models and parameters
February 2010: first delivery of SINEX
June 2010: second delivery of SINEX
End 2010: need for result discussion and reiteration

Remaining problems in delivered SINEX files

AIUB	**weekly SLR :**	**XPO, YPO, UT at 00h + rates at 12h + stations**
	daily GPS :	**EOP at 00h + stations + CoM + troposphere**
		Erroneous number of unknowns
DGFI	**weekly SLR :**	**XPO, YPO, UT at 00h + stations**
		Blocks STATISTICS and APRIORI inverted
		Units of XPO, YPO "as", must be in unit "mas"
		Units of UT "s", must be in unit "ms"
	daily VLBI	**EOP at 11h + rates at 11h + stations**
GFZ	**daily GNSS+SLR :**	**XPO, YPO, UT at 00h + stations**
		Erroneous number of unknowns
		block: **SOLUTION/MATRIX_ESTIMATE L INFO**
		instead of **SOLUTION/NORMAL_EQUATION_MATRIX L**
ESOC	**weekly DORIS+SLR**	**XPO, YPO, XPOR, YPOR, LOD at 12h + stations + SLR range bias**
		Bad APRIORI for SITE 1873 A 1 L 49000:**:***:*****:
		Erroneous number of unknowns
	weekly GNSS+SLR	**XPO, YPO, XPOR, YPOR LOD at 12h + stations + SLR range bias**
		Erroneous number of unknowns
GRGS	**weekly DORIS/VLBI /GPS**	**XPO, YPO, UT at 0, 6, 12,18h, NUT-OB/LN at 0, 12h + tropo.**
		absolute a priori zenital delay and station number missing (not domes)
	weekly SLR	**EOP at 00h**

Roadmap (where we are)

1) **review the approach of the various groups**
and their capability to process two or more techniques.
2) establishing common processing standards
for all techniques in order to guarantee homogeneity and consistency.
3) optimizing and unifying parameterization
for instance for tropospheric parameters in order to minimize globally the degree of freedom of the whole inverse system.
4) studying the appropriate weighting between techniques
and the use of local ties or identical satellites tracked by several techniques.
5) **elaborating benchmarks**
to intercompare results between groups from the same data set.
6) **insuring SINEX compatibility**
between techniques and with the international technique services and IERS.
7) studying stabilization methods
and looking for high temporal resolution of parameters.
8) evaluating and comparing results
to search for compatibility between groups.
9) organizing routine operations
for a new TRF realization, either in the framework of the next ITRF or as ITRF assessment.

Thanks for attention