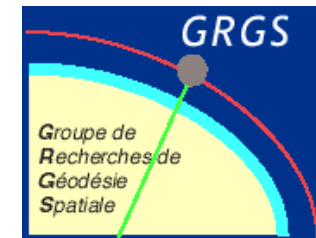


Combination of space geodesy techniques for monitoring the kinematics of the Earth

*D. Coulot ⁽¹⁻²⁾, P. Berio ⁽²⁾, R. Biancale ⁽³⁾,
A.-M. Gontier ⁽⁴⁾, S. Loyer ⁽³⁻⁵⁾, L. Soudarin ⁽⁶⁾,
J.-M. Lemoine ⁽³⁾, J.-C. Marty ⁽³⁾, Z. Altamimi ⁽¹⁾,
N. Capitaine ⁽⁴⁾, P. Exertier ⁽²⁾ and D. Gambis ⁽⁴⁾*



- (1) IGN/Laboratoire de REcherche en Géodésie - Marne-la-Vallée - France*
- (2) OCA/département GEMINI - Grasse - France*
- (3) CNES/Observatoire Midi-Pyrénées - Toulouse - France*
- (4) Observatoire de Paris - Paris - France*
- (5) Société Noveltis - Toulouse - France*
- (6) Société CLS - Toulouse - France*

Summary



1- Objectives and organization

2- Observations

3- Method of combination

4- Results

5- Summary

6- CPP participation

Objectives and organization

♣ Objectives

to prove the efficiency of space technique combinations for computation of Earth Orientation Parameters and Terrestrial Reference Frames

- ♠ *techniques used: SLR, DORIS, GPS, VLBI, LLR*
- ♠ *parameters: polar motion (x_p and y_p), universal time UT1-UTC, nutation corrections (every 6 hours) and station positions (every week)*
- ♠ *homogeneous computational framework*
(same software used for all individual computations)
- ♠ *computations made over one year (2002)*
- ♠ *combinations worked out at the level of observations*

♣ Organization

Computations based on GRGS' experience and expertise

♠ *with teams of OCA, CNES, IGN, Noveltis, CLS and Paris' Observatory*

♠ *work started in 2000 with P. Yaya 's PhD (July 2002, 1st) under direction of N. Capitaine, D. Gambis (Paris' Obs.) and in cooperation with CNES team (R. Biancale)*

Summary



1- Objectives and organization

2- Observations

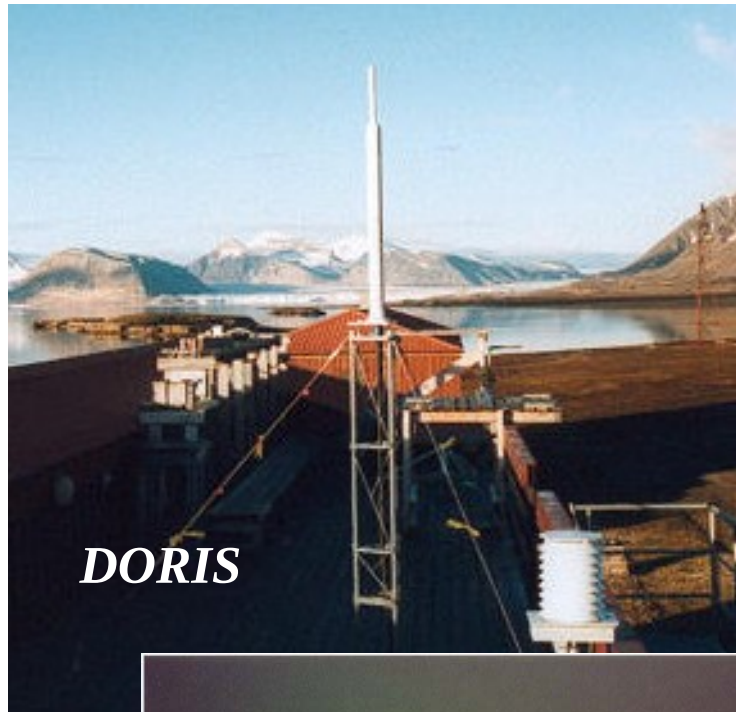
3- Method of combination

4- Results

5- Summary

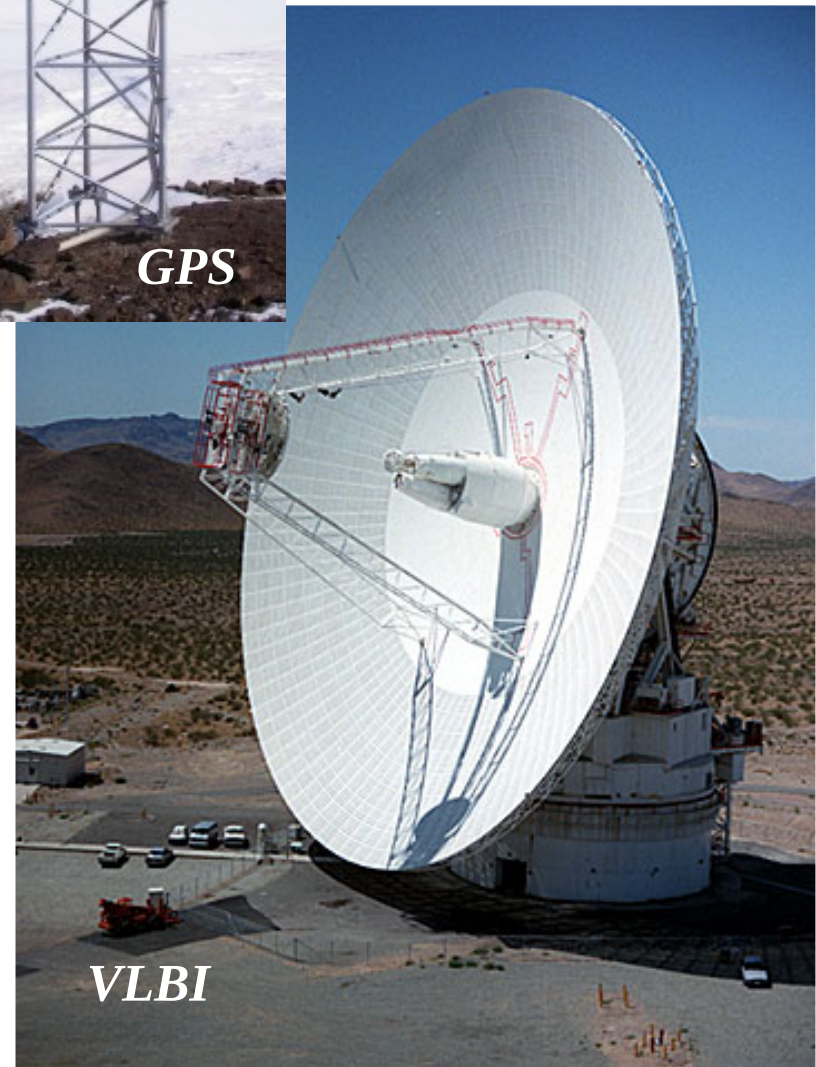
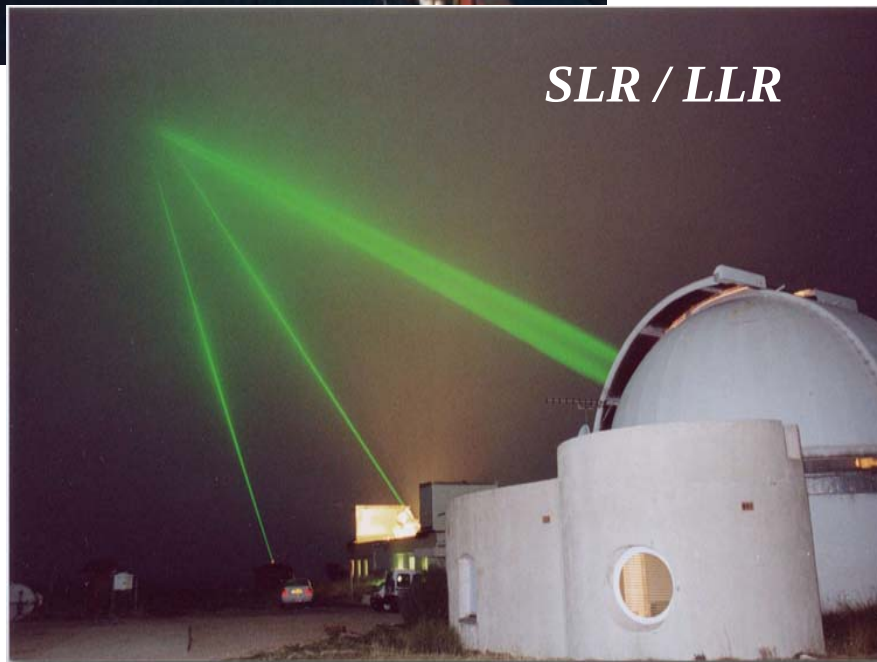
6- CPP participation

from 5 geodetic techniques



may be collocated...

⇒ additional constraints
between networks



Satellite Laser Ranging LAGEOS-1

on April 5th, 2002, at 3:19:11 IAT above the
Pacific ocean; lat. : 23° , long : 141°

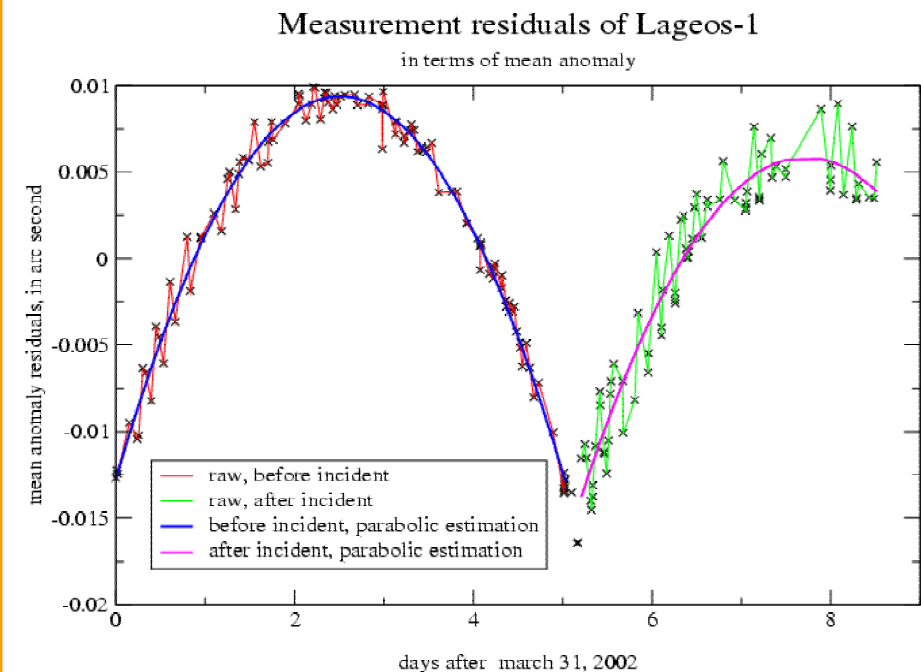
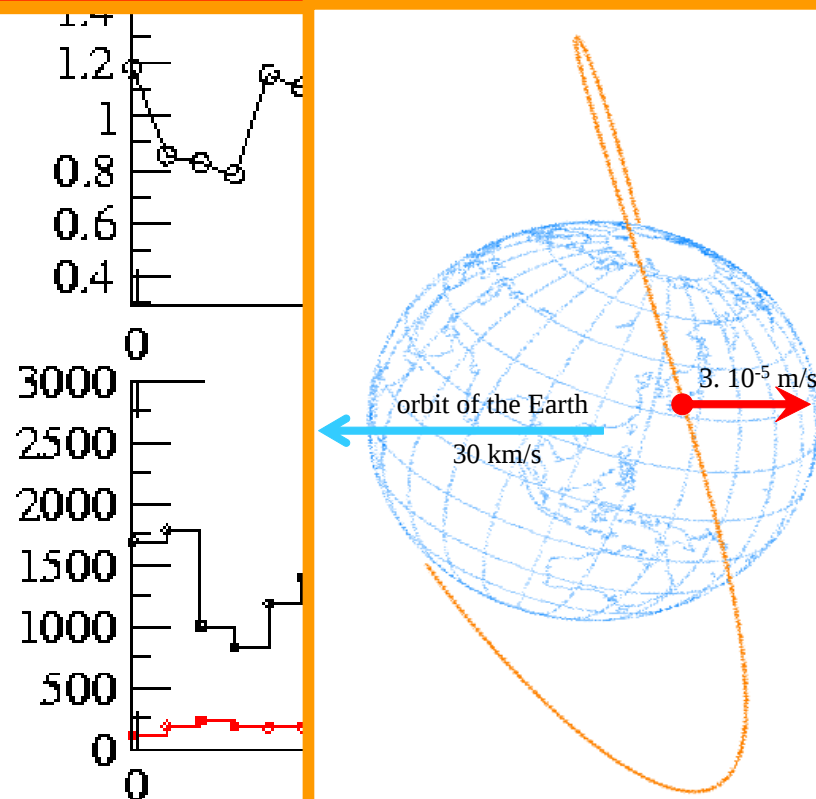
Impulse (given by some mg space particle ?):

$0.66 \cdot 10^{-5}$ m/s radial

$-0.77 \cdot 10^{-5}$ m/s along track

$-2.84 \cdot 10^{-5}$ m/s cross track

**Impact with
a particle**

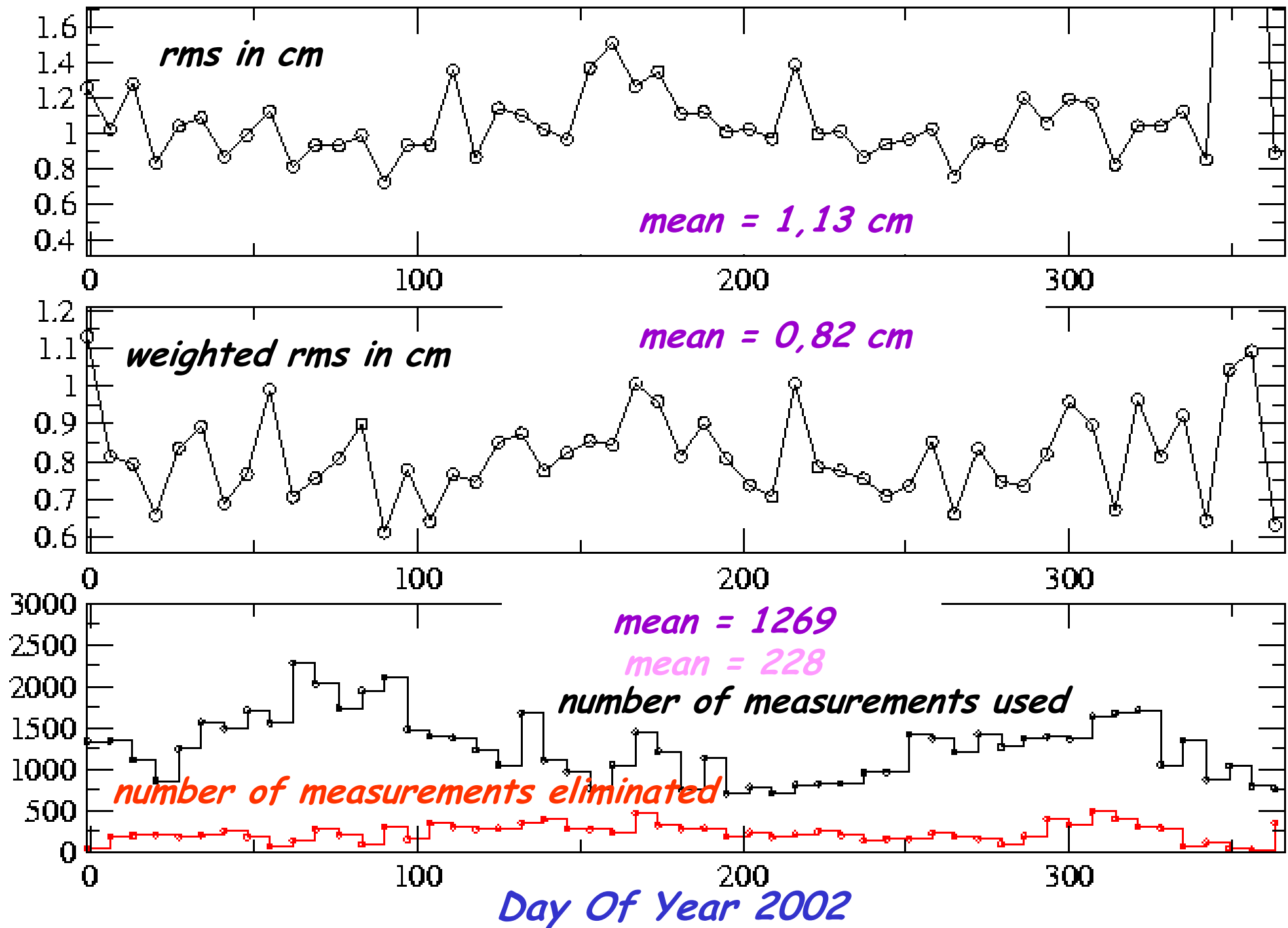


of eliminated measurements

Day Of Year 2002

Satellite Laser Ranging

LAGEOS-2



GPS

CNES/OMP/Noveltis : S. Loyer

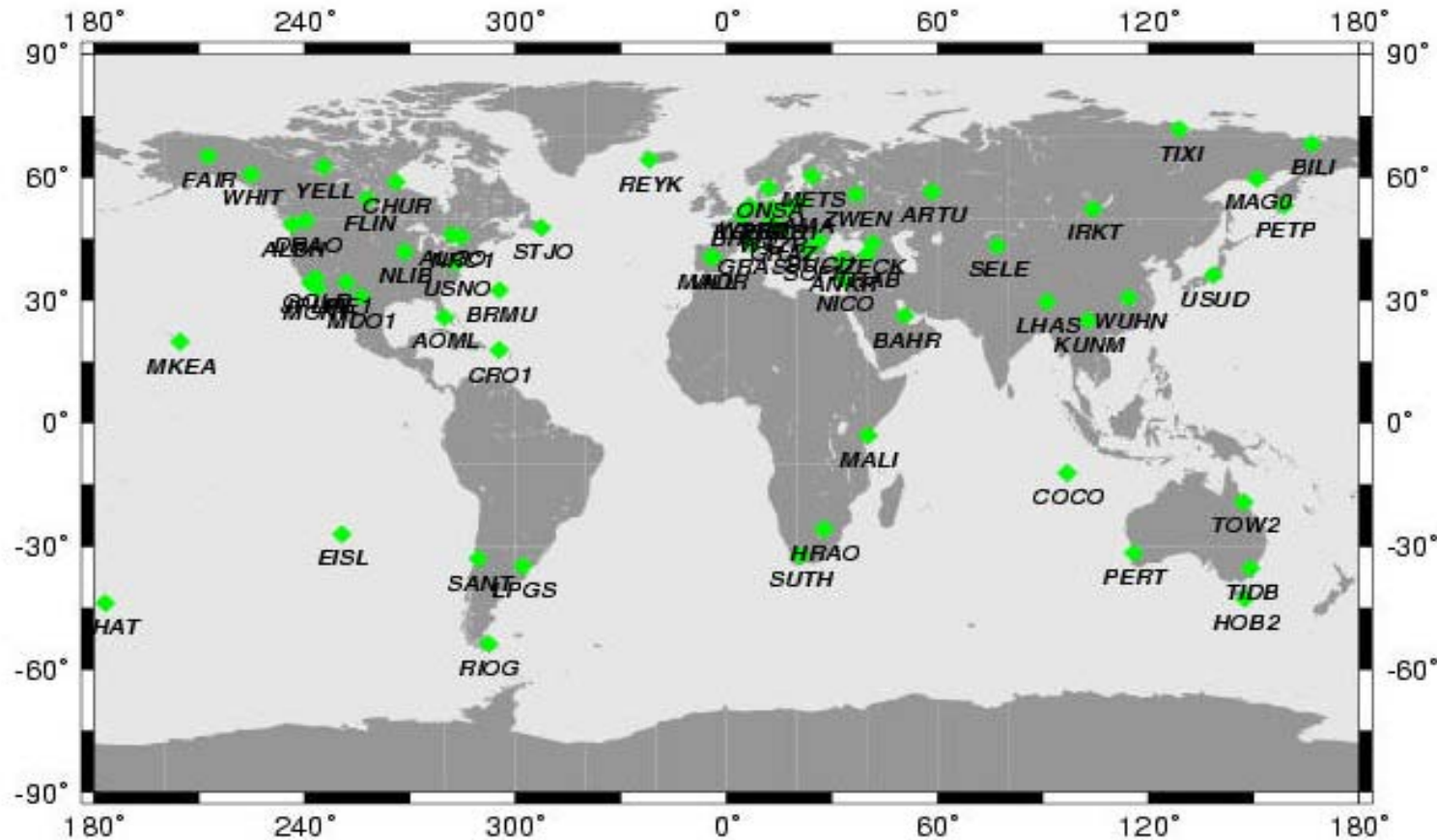
♣ *2-day orbital arcs*

♣ *Strategy*

*Solar Radiation Pressure : Bar-Sever 2003 for blocks II + 1 scale factor/day
+ Y-bias/day*

Atmospheric drag neglected

Undifferenced iono-free observations



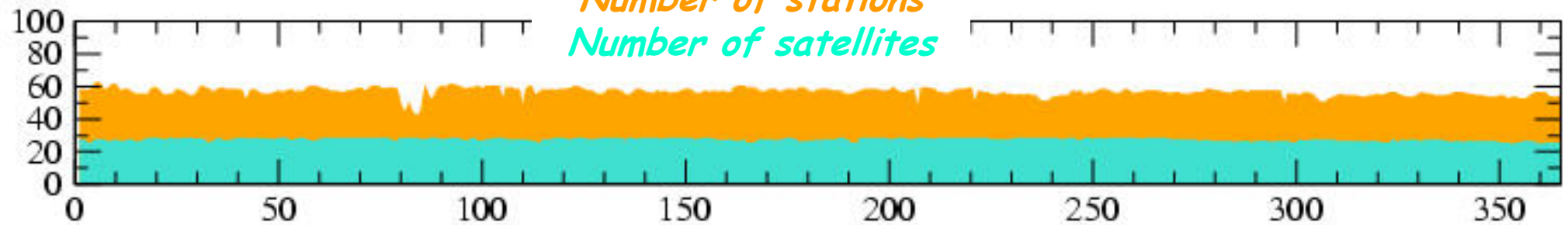
Station network

GPS

Average of orbit residuals and processed data per arc

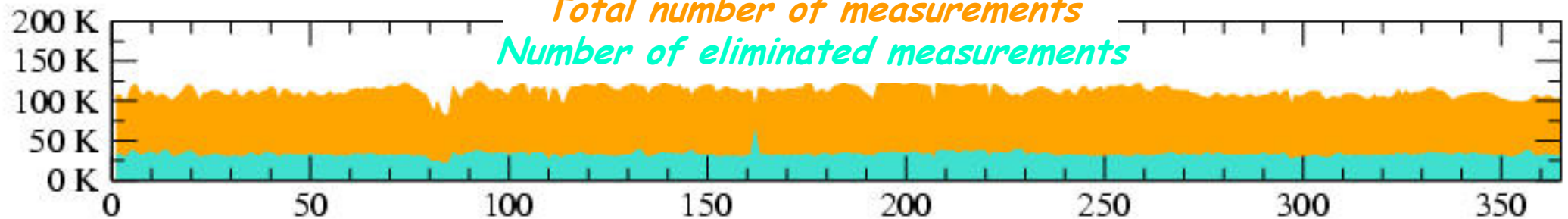
Number of stations

Number of satellites

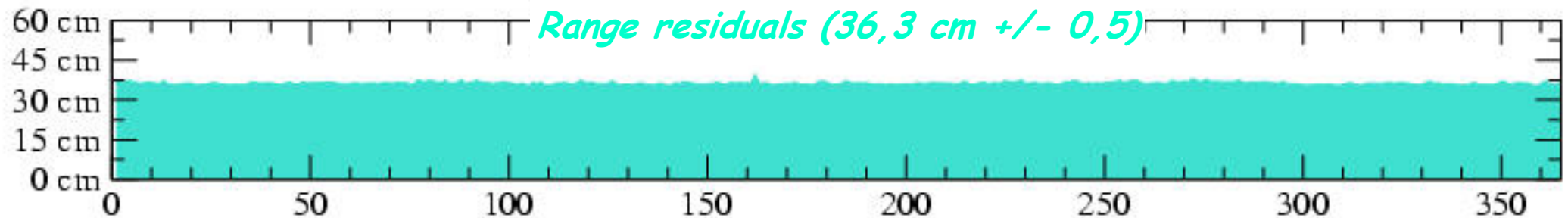


Total number of measurements

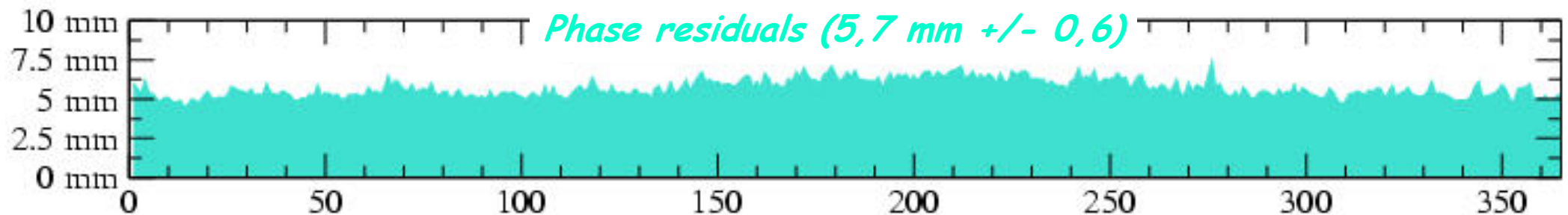
Number of eliminated measurements



Range residuals (36,3 cm +/- 0,5)



Phase residuals (5,7 mm +/- 0,6)

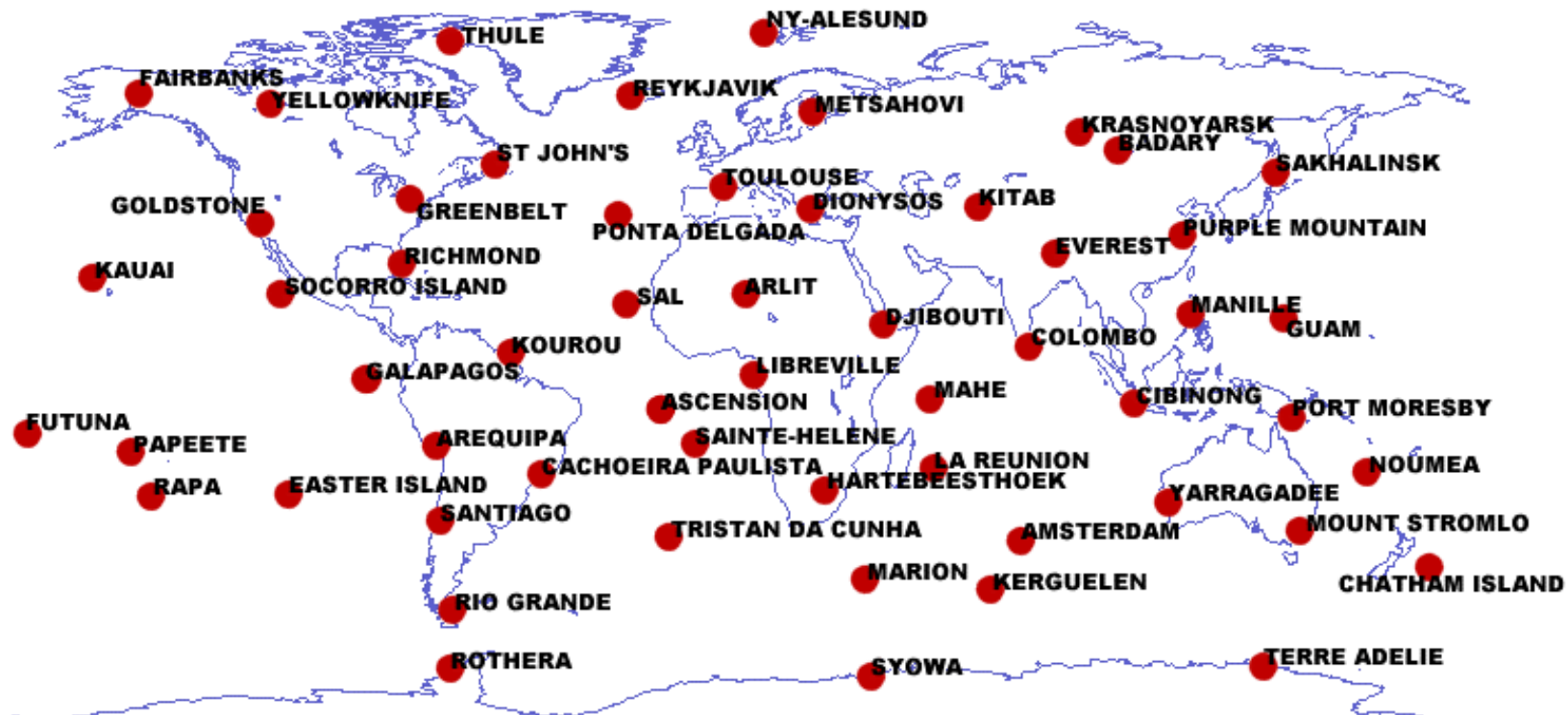


Day of Year 2002

DORIS

CLS : L. Soudarin

- ♣ *From Sun 06.01.2002 (GPS week 1148 day 0) to Sat 28.12.2002 (GPS week 1198 day 6)*
- ♣ *Arc length: 3.5 days starting on Sunday 0:00 or Wednesday 12:00 (between 1 and 3.5 days in case of orbit correction manoeuvres or data lacks)*
- ♣ *Satellites: SPOT2, SPOT4, TOPEX, SPOT5 (start 16.06.2002 = GPS week 1171 day 0) and ENVISAT (start 21.07.2002 = GPS week 1176 day 0)*
- ♣ *Reduced parameters: orbit, drag coefficients, solar pressure coefficients, tropospheric zenital bias, frequency bias, Hill parameters*

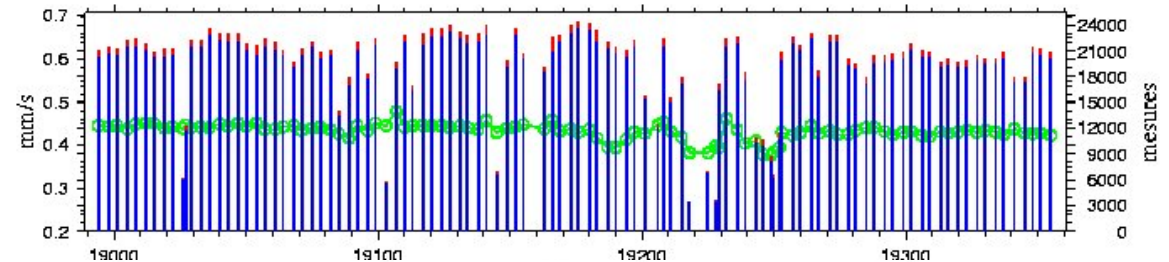


Station network

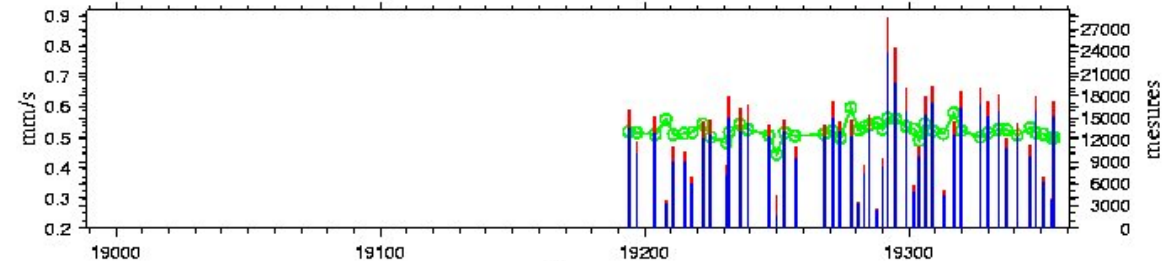
DORIS

Average of orbit residuals and processed data per arc

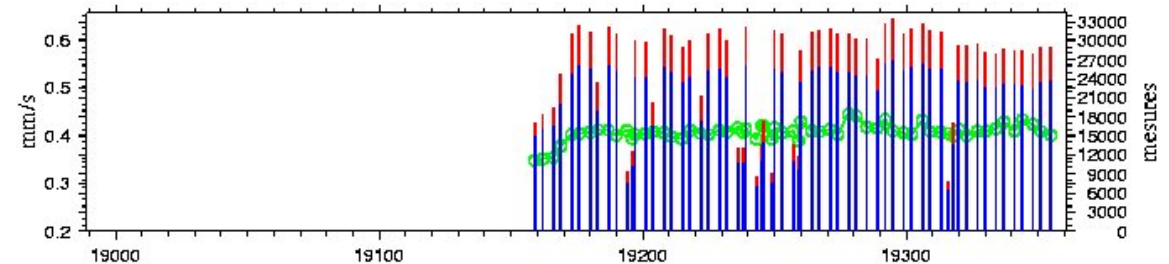
*Topex: 106 arcs, residuals rms 0.44 mm/s
18763 measurements (752 rejected)*



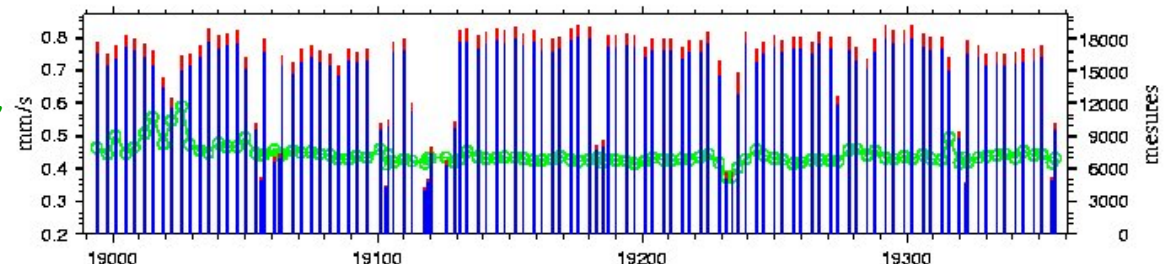
*Envisat: 48 arcs, residuals rms 0.53 mm/s
11174 measurements (1754 rejected)*



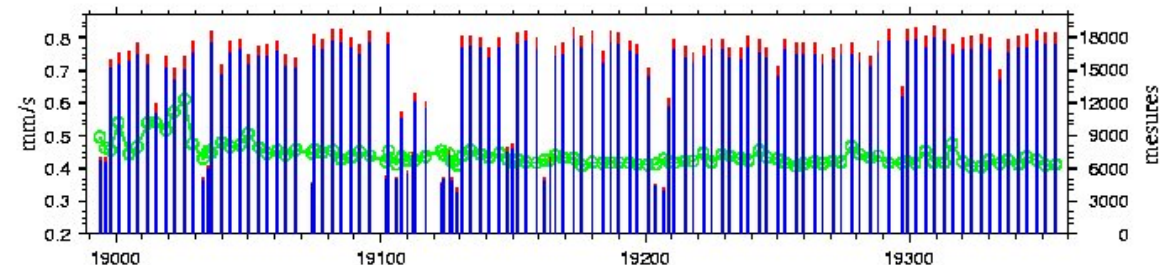
*Spot5: 63 arcs, residuals rms 0.41 mm/s
20929 measurements (4926 rejected)*



*Spot4: 112 arcs, residuals rms 0.45 mm/s
14719 measurements (1018 rejected)*



*Spot2: 113 arcs, residuals rms 0.45 mm/s
14273 measurements (892 rejected)*

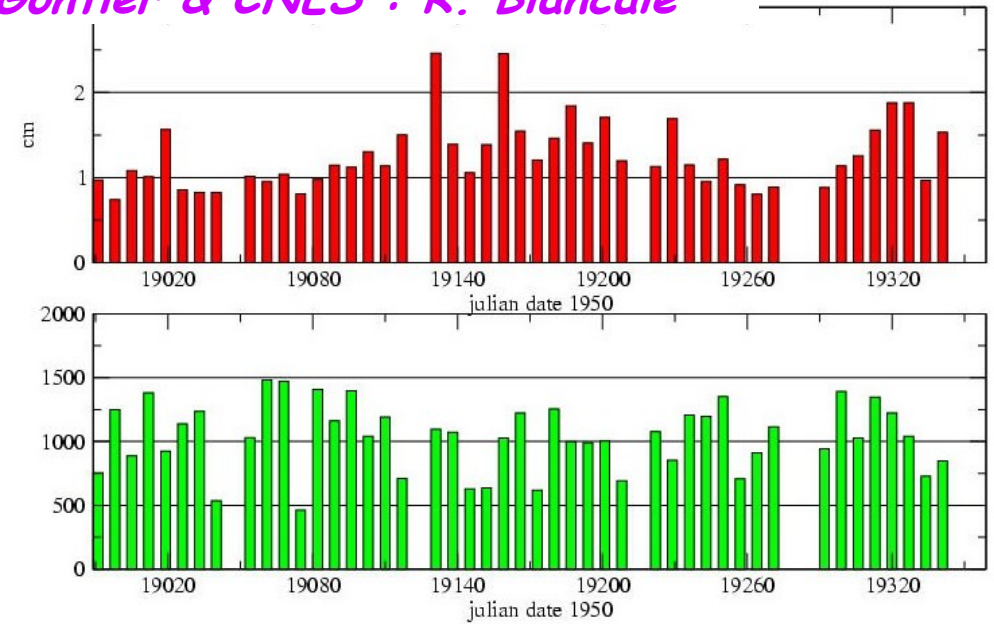
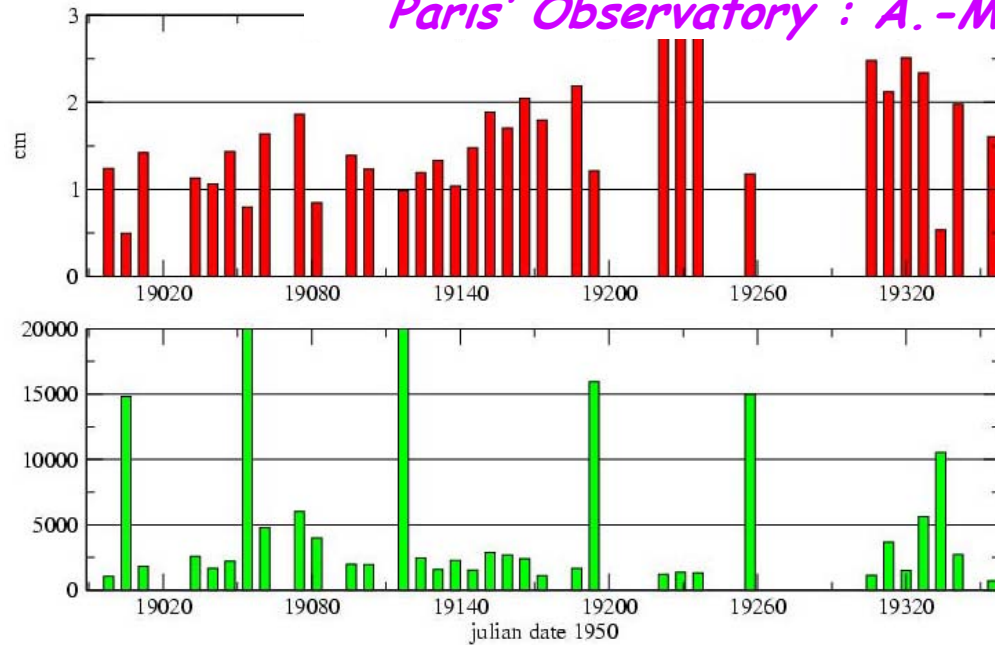


VLBI

Session A : astronomical sessions

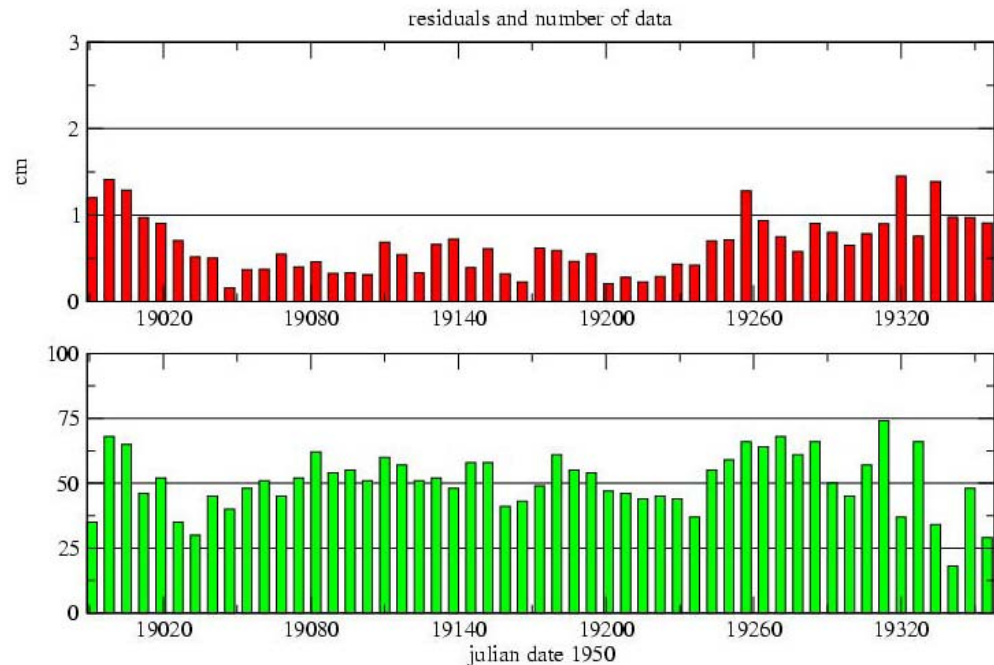
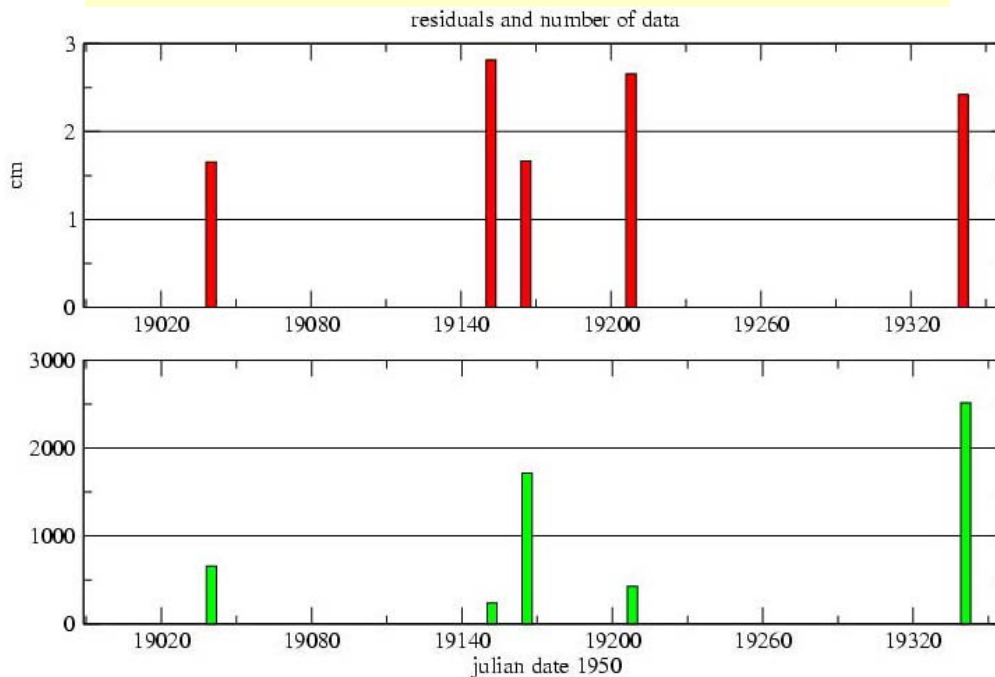
Session E : sessions dedicated to Earth's rotation

Paris' Observatory : A.-M. Gontier & CNES : R. Biancale



Session F : sessions of Japanese network

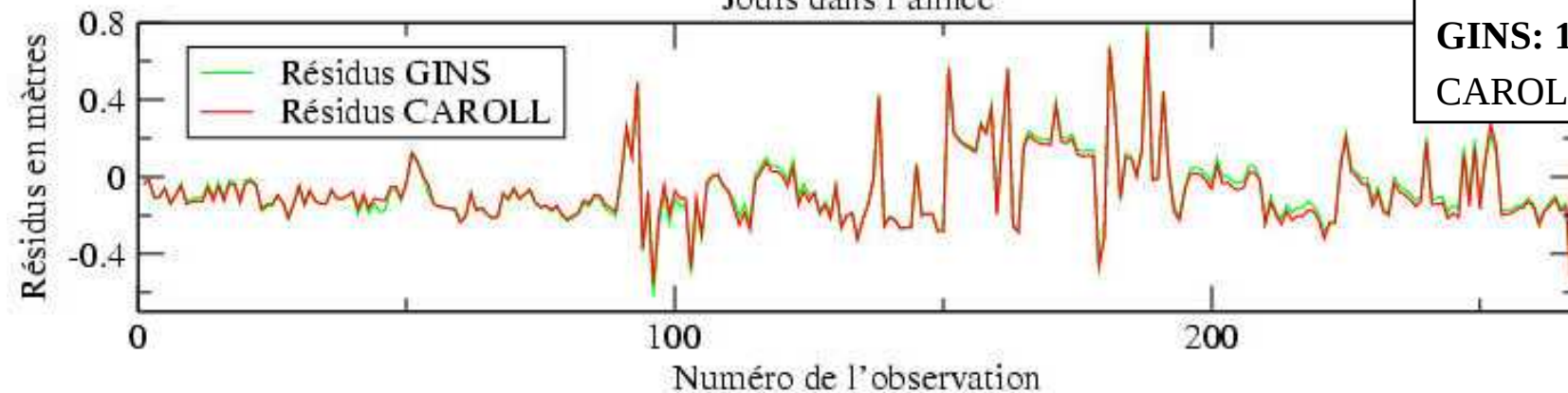
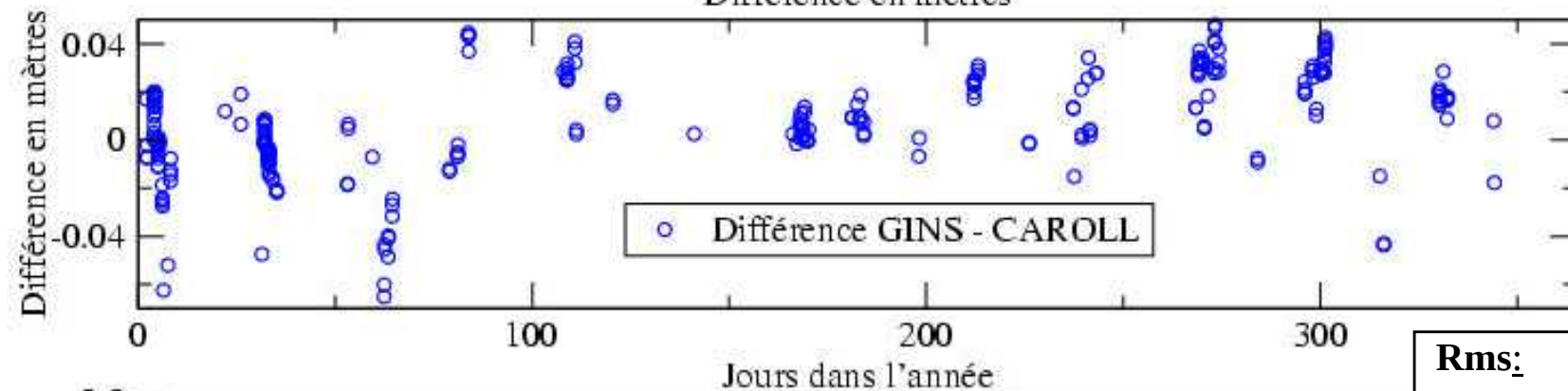
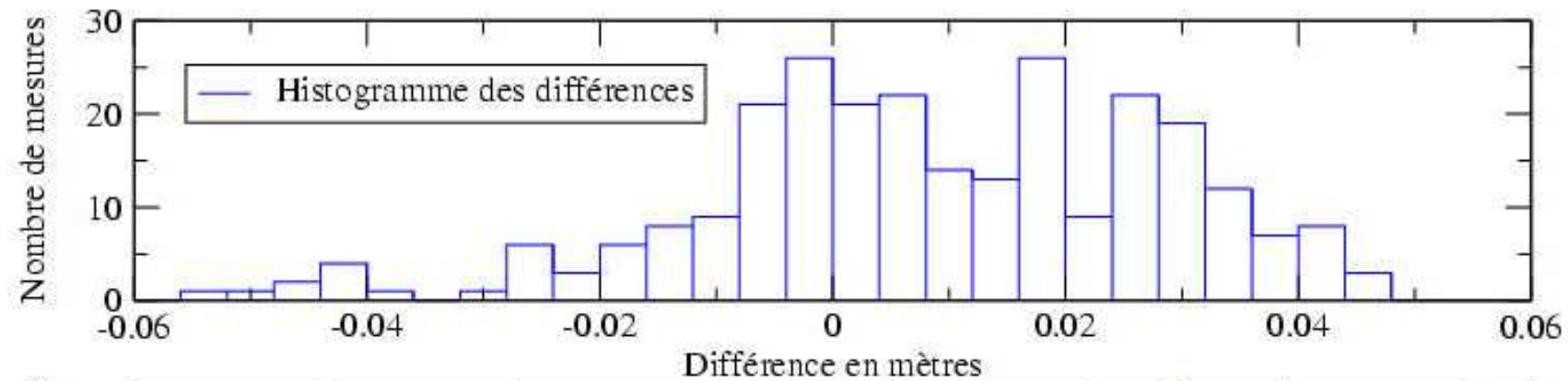
Session U : intensive sessions for baseline Kooke-Wettzell



LLR

Obs. Paris : G. Francou, CNES : J-C Marty

Only 2 stations: Fort Davis (Texas) and Grasse (France)



Rms:
GINS: 13.4 cm
CAROLL: 13.5 cm

Summary



1- Objectives and organization

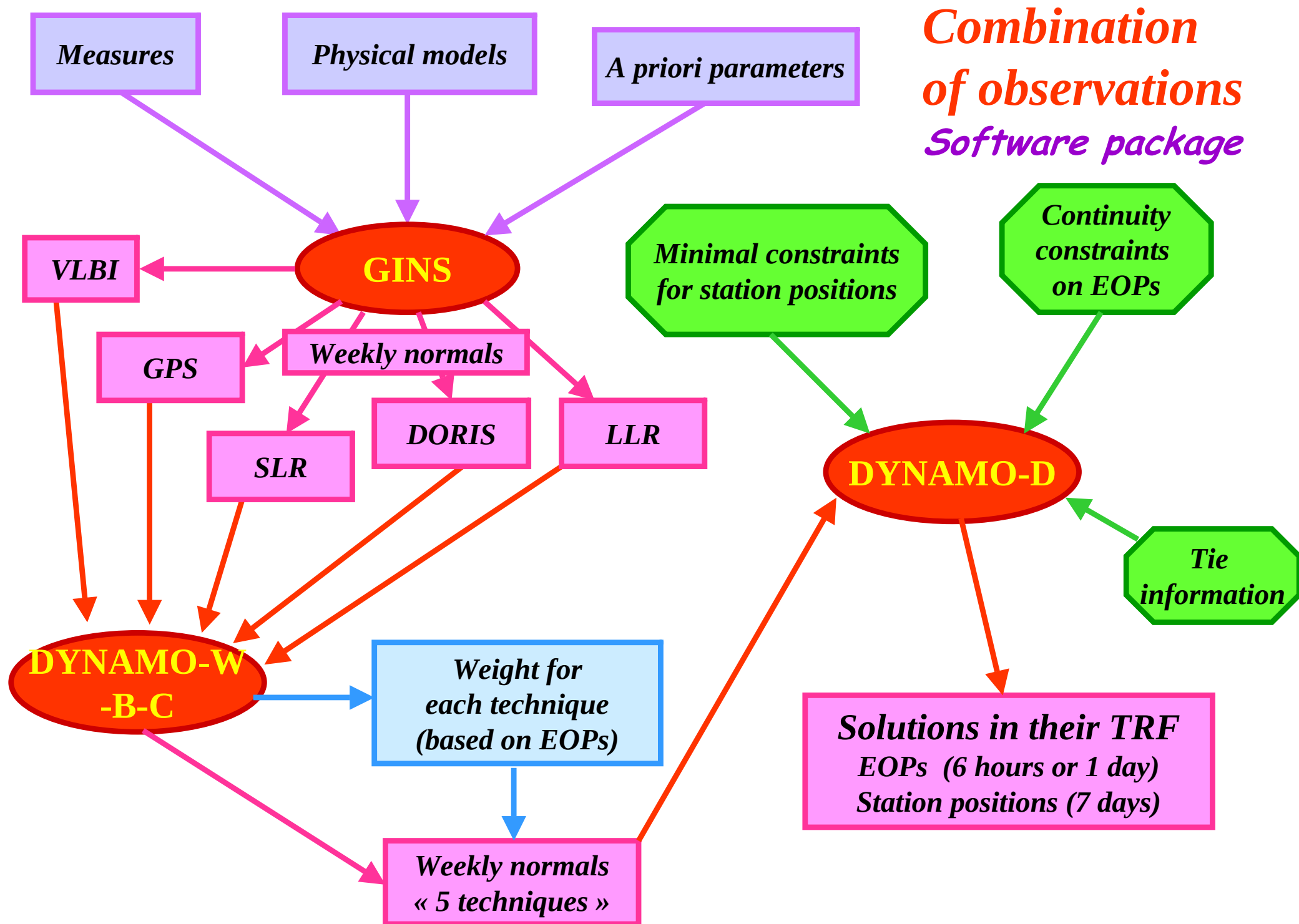
2- Observations

3- Method of combination

4- Results

5- Summary

6- CPP participation



Minimal constraints (on station positions)

→ To minimize global system transformation wrt a priori

for a station i

$$X_2^i = X_1^i + T + D \cdot X_1^i + R \cdot X_1^i$$

translations $T = \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix}$

scale factor D

rotations $R = \begin{bmatrix} 0 & -R_z & R_y \\ R_z & 0 & -R_x \\ -R_y & R_x & 0 \end{bmatrix}$

positions $X_j^i = \begin{pmatrix} x_j^i \\ y_j^i \\ z_j^i \end{pmatrix}$

For a station i

$$X_2^i = X_1^i + A^i \cdot \theta$$

where $\theta^T = (T_x, T_y, T_z, D, R_x, R_y, R_z)$

and

$$A^i = \begin{bmatrix} 1 & 0 & 0 & x_1^i & 0 & z_1^i - y_1^i \\ 0 & 1 & 0 & y_1^i - z_1^i & 0 & x_1^i \\ 0 & 0 & 1 & z_1^i & y_1^i - x_1^i & 0 \end{bmatrix}$$

Minimal constraint through least squares adjustment of:
 $\hat{\theta} = (A^T A)^{-1} A^T (X_2 - X_1) = 0$
 with $\Sigma = 1 \text{ mm}$

Continuity constraints (on EOPs)

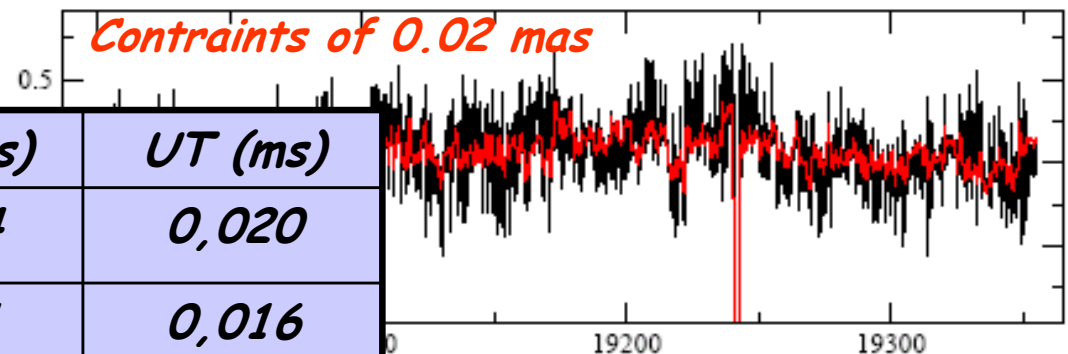
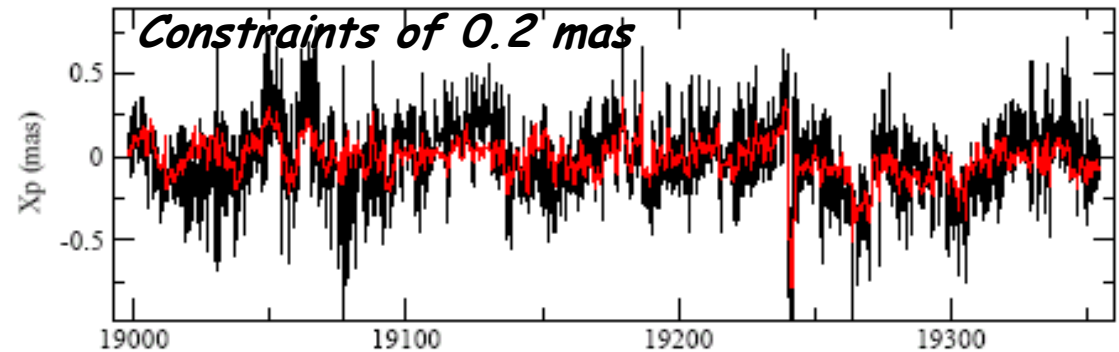
→ *To filter the high frequencies of EOPs*

writing between 2 consecutive points :

$$\delta x_p(t+1) = \delta x_p(t) \left(\sigma_{x_p} \right)$$

$$\delta y_p(t+1) = \delta y_p(t) \left(\sigma_{y_p} \right)$$

$$\delta UT(t+1) = \delta UT(t) \left(\sigma_{UT} \right)$$

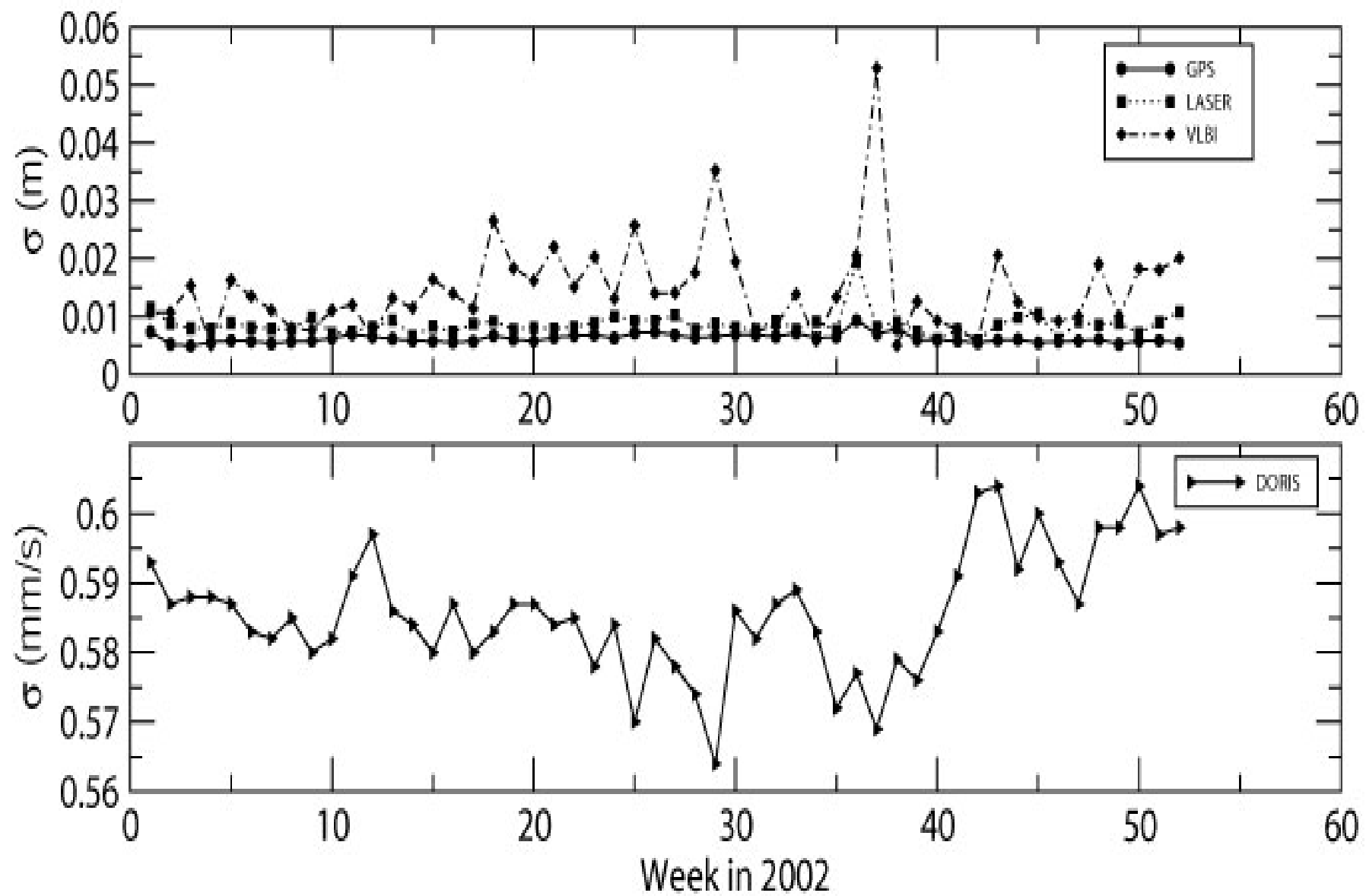


1950 Julian Day

<i>technique</i>	<i>Xp (mas)</i>	<i>Yp (mas)</i>	<i>UT (ms)</i>
<i>LASER</i>	<i>0,181</i>	<i>0,164</i>	<i>0,020</i>
<i>GPS</i>	<i>0,166</i>	<i>0,181</i>	<i>0,016</i>
<i>DORIS</i>	<i>0,681</i>	<i>0,575</i>	<i>0,055</i>
<i>VLBI</i>	<i>0,384</i>	<i>0,452</i>	<i>0,013</i>
<i>COMBI 1J</i>	<i>0,086</i>	<i>0,081</i>	<i>0,008</i>
<i>COMBI 6H</i>	<i>0,686</i>	<i>0,669</i>	<i>0,015</i>

→ *Relative weighting is computed by the Helmert's method of optimal variance*

Weighting of techniques



Summary



1- Objectives and organization

2- Observations

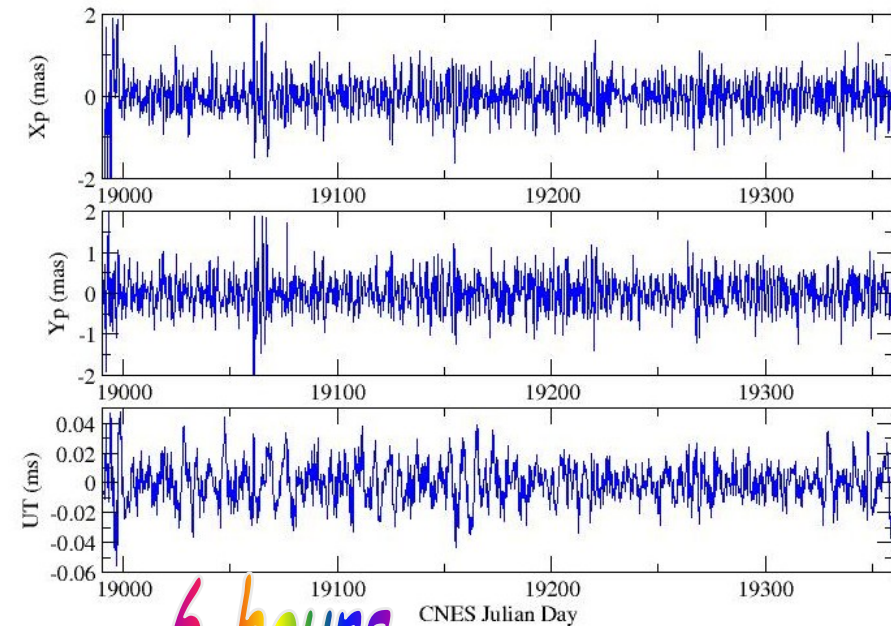
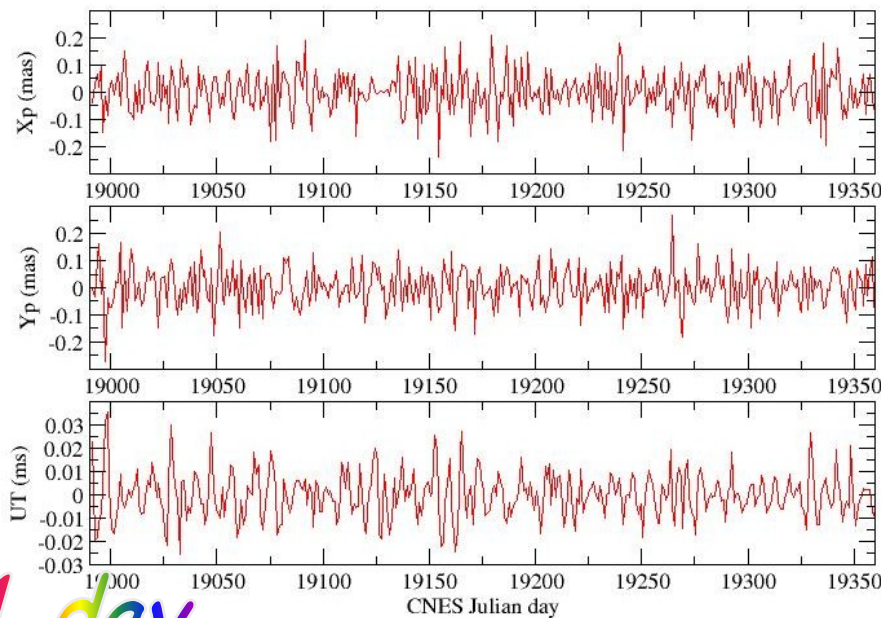
3- Method of combination

4- Results

5- Summary

6- CPP participation

Solutions with respect to EOPCO4



1 day

GPS and SLR orbit parameters constraints to C04 series !!!

6 hours

<i>rms</i>	<i>Xp (mas)</i>	<i>Yp (mas)</i>	<i>UT1 (ms)</i>
<i>LASER</i>	<i>0,146</i>	<i>0,131</i>	<i>0,019</i>
<i>GPS</i>	<i>0,079</i>	<i>0,083</i>	<i>0,009</i>
<i>DORIS</i>	<i>0,706</i>	<i>0,551</i>	<i>0,122</i>
<i>VLBI</i>	<i>0,363</i>	<i>0,381</i>	<i>0,009</i>

<i>Ref. IERS</i>	<i>Xp/Yp (mas)</i>	<i>UT1 (ms)</i>
<i>CSR</i>	<i>.40</i>	<i>.01</i>
<i>GFZ</i>	<i>.09</i>	<i>.35</i>
<i>CNES</i>	<i>1.5</i>	<i>-</i>
<i>GSFC</i>	<i>.13</i>	<i>.01</i>

<i>Formal error</i>	<i>Xp (mas)</i>	<i>Yp (mas)</i>	<i>UT1 (ms)</i>
<i>LASER</i>	<i>0,056</i>	<i>0,053</i>	<i>0,004</i>
<i>GPS</i>	<i>0,016</i>	<i>0,017</i>	<i>0,001</i>
<i>DORIS</i>	<i>0,292</i>	<i>0,301</i>	<i>0,048</i>
<i>VLBI</i>	<i>0,388</i>	<i>0,530</i>	<i>0,013</i>

<i>rms</i>	<i>Xp (mas)</i>	<i>Yp (mas)</i>	<i>UT1 (ms)</i>
<i>1 day</i>	<i>0,075</i>	<i>0,070</i>	<i>0,010</i>
<i>6 hrs</i>	<i>0,442</i>	<i>0,433</i>	<i>0,013</i>

(2002 solutions)

1 cm $\Leftrightarrow$.3 mas

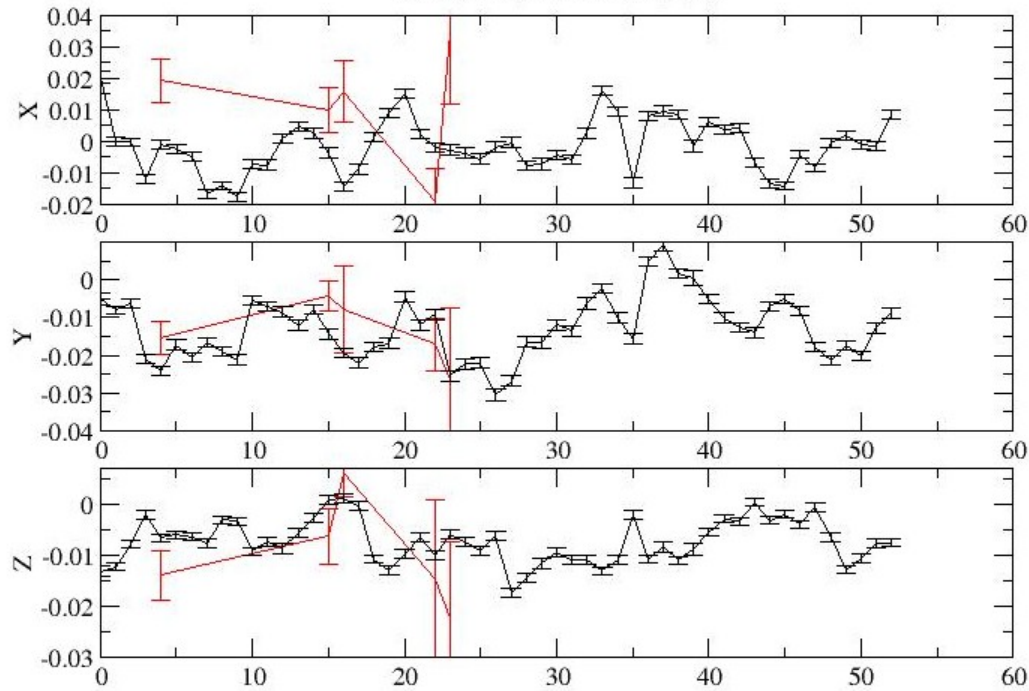
1 cm $\Leftrightarrow$.02 ms

<i>Formal error</i>	<i>Xp (mas)</i>	<i>Yp (mas)</i>	<i>UT1 (ms)</i>
<i>1 day</i>	<i>0,021</i>	<i>0,023</i>	<i>0,001</i>
<i>6 hours</i>	<i>0,129</i>	<i>0,129</i>	<i>0,002</i>

Earth's reference system

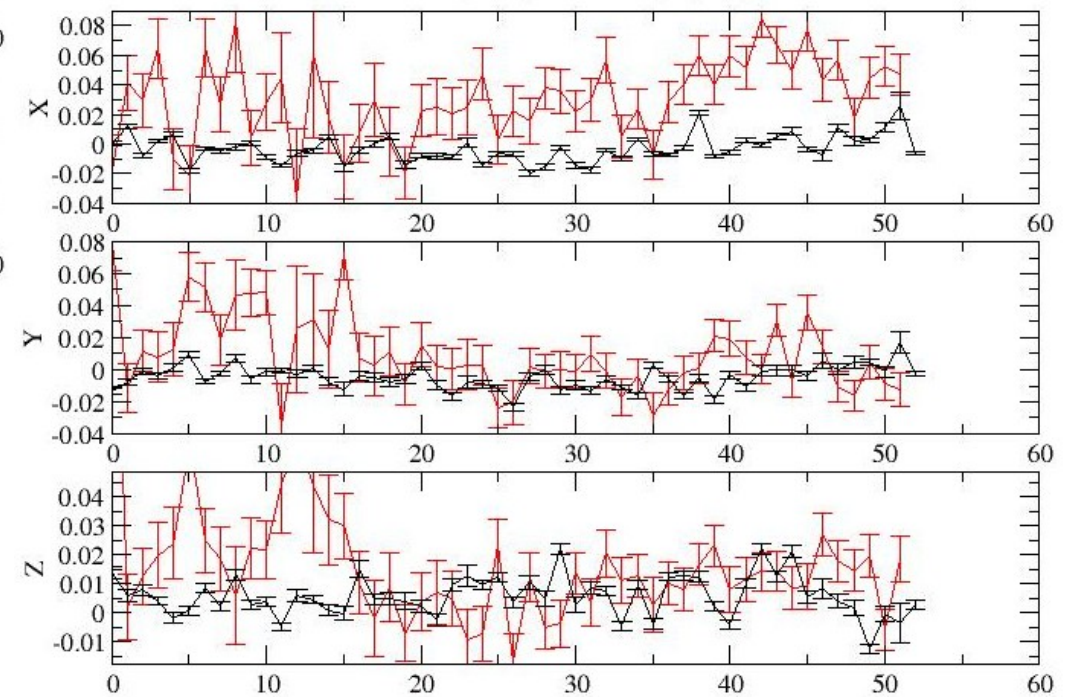
Hartebeesthoek

GPS (black) & VLBI (red) (m)



Yarragadee

SLR (black) & DORIS (red) (m)



Summary



1- Objectives and organization

2- Observations

3- Method of combination

4- Results

5- Summary

6- CPP participation

Summary

- ♣ *Combination at the level of observations demonstrated*
=> *with GINS / DYNAMO software package*
- ♣ *5 techniques are included*
=> *interest of LLR has still to be evaluated*
- ♣ *Weighting of individual techniques*
=> *with Helmert's optimal variance method on EOPs only*
- ♣ *Need to apply constraints on parameters*
=> *continuity constraints on EOPs*
=> *minimal constraints on site positions*
- ♣ *Nutation corrections still to be checked*
=> *with VLBI only?*
- ♣ *Processing improvement on going*
=> *GPS integer ambiguities, VLBI, tropospheric delay*
- ♣ *Imminent participation to the IERS pilot project of CRCs*
=> *beginning of 2005*

Summary



1- Objectives and organization

2- Observations

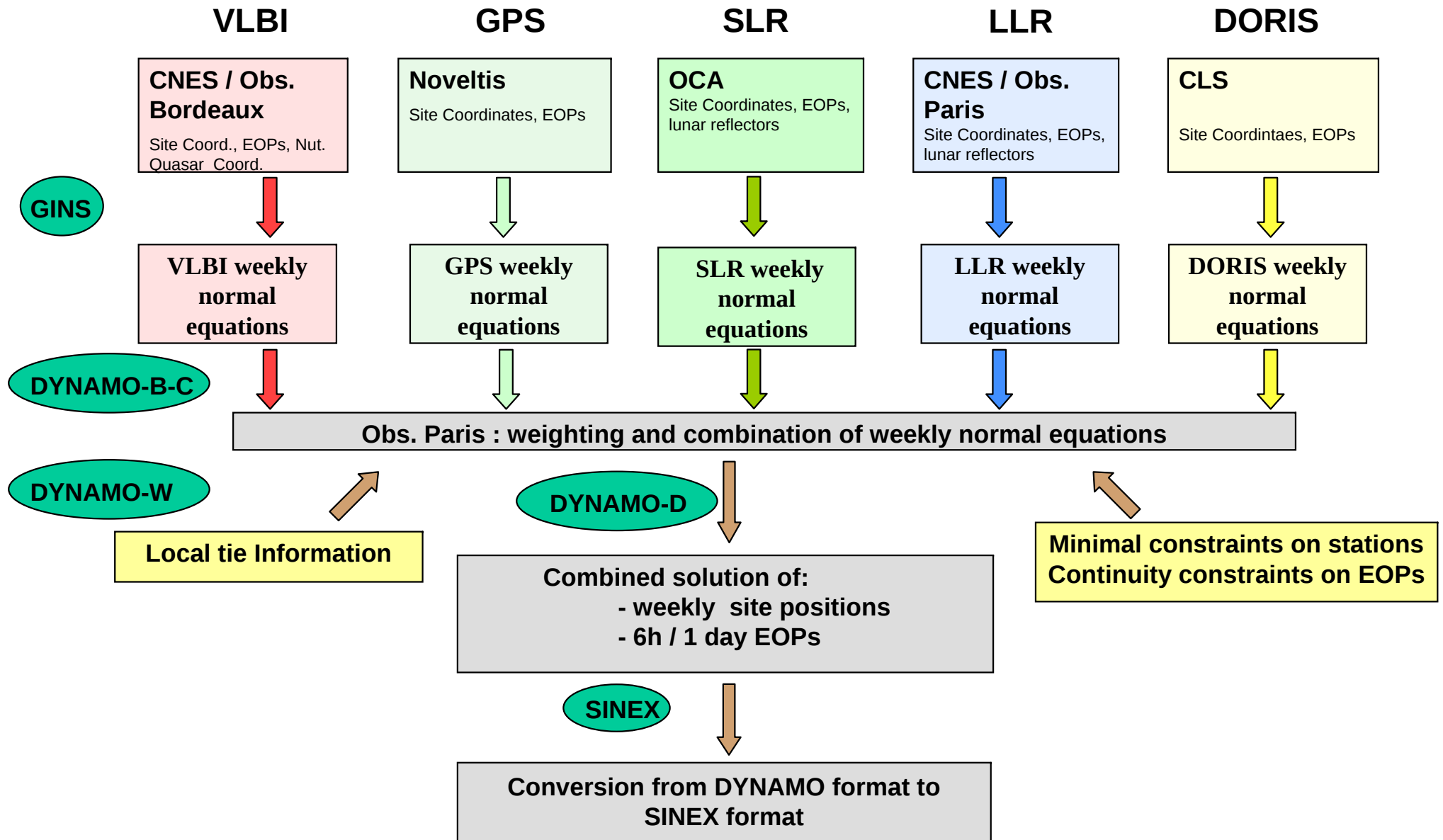
3- Method of combination

4- Results

5- Summary

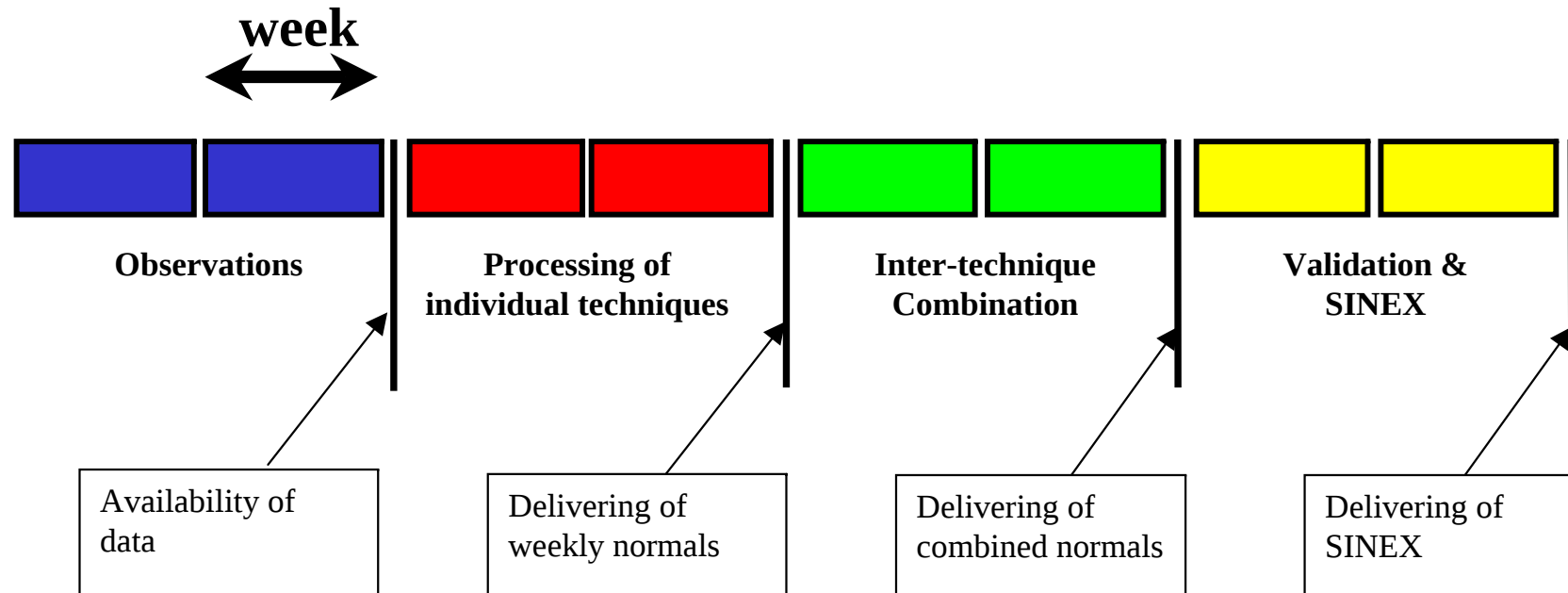
6- CPP participation

GRGS organization



Time table

. Schedule objective :



- **Beginning of processing : early 2005**
- **Still some processing improvements expected**
- **Period of running in from 3 to 6 months probably**
- **Need of validation and feedback**