GNSS orbits and ERPs from CODE's repro2 solutions

S. Lutz[1], P. Steigenberger[2], G. Beutler[1],
S. Schaer[3], R. Dach[1], A. Jäggi[1]

[1] Astronomical Institute of the University of Bern, Bern, Switzerland
[2] Technische Universität München, Munich, Germany
[3] Federal Office of Topography swisstopo, Wabern, Switzerland

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Summary

CODE's repro2 solutions

- Time span between January 1994 and December 2013
  (i.e., 20 years or a total of 7305 days)
  - GPS-only from Jan-1994 to Dec-2001
  - GPS/GLONASS combined from Jan-2002 to Dec-2013
- Number of stations per day between 40 in 1994 and 290 in 2010
- Two product lines:
  - Clean 1-day solution (CF2)
    Based on the observations of single calendar days with no constraints at the day boundaries
  - 3-day long-arc solution (CO2)
    Based on the normal equations from three consecutive CF2 solutions and with continuity conditions at the boundaries of the middle day

Poster presentation in session PS01 – Analysis Centers:
CODE Contribution to the 2nd IGS Reprocessing
by P. Steigenberger et al.

CODE's repro2 solutions

- Additional solution for comparison purposes:
  - 1-day solution with long-arc orbits over three days (COL)
    Based on the normal equations from three consecutive CF2 solutions, but all parameters are pre-eliminated "BEFORE_STACKING" for the first and the third day with no day boundary constraints except for a continuity condition for the satellite orbits

	CRD	ERP	ORB	SORB	TRP
CF2	**1/1d**	**2/1d**	**1/1d**	**1/1d**	**13/1d**
CO2	**1/3d**	**4/3d**	**1/3d**	**5/3d**	**37/3d**
COL	**1/1d**	**2/1d**	**1/3d**	**5/3d**	**13/1d**

Table 1 Number of parameter sets (constant station coordinates, piece-wise linear Earth rotation parameters, orbital elements, pseudo-stochastic pulses at 12 and 00 UTC, and troposphere parameters every two hours) per number of associated days. "1d" in the COL solution refers to the middle of the three days.

GPS and GLONASS satellite orbits

- Analysis of the orbit misclosures
  Discrepancy of an orbital arc at the midnight epoch between two successive daily solutions
- From the 3-day long-arc solutions only the orbits attributed ("tailored") to the middle days are considered
- Satellites in eclipsing phases are included in the products but excluded from this analysis

GPS and GLONASS satellite orbits

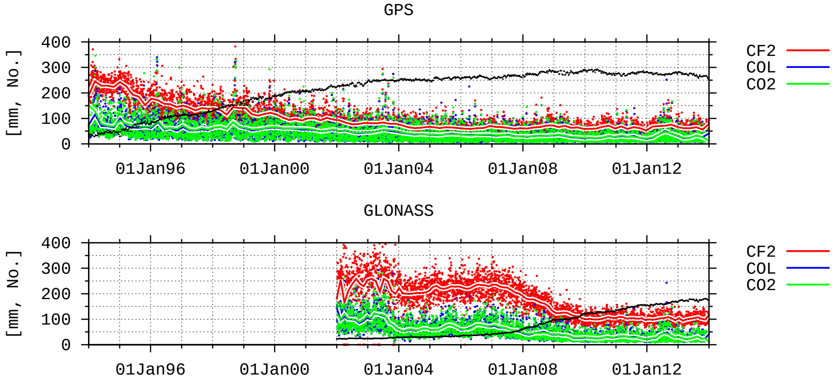
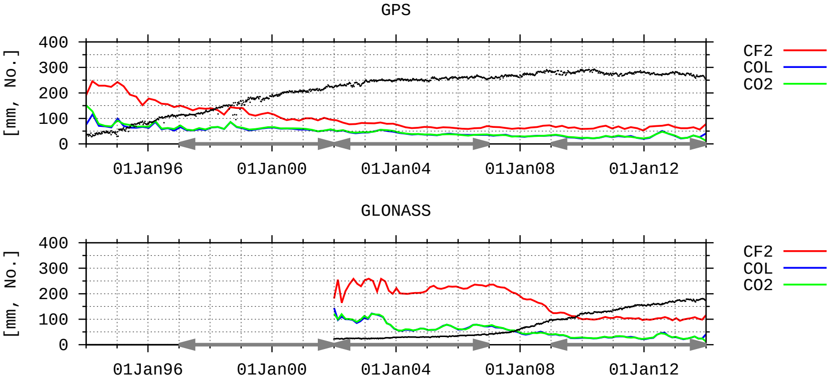


Figure 1 Time series and Bézier curves of the mean three-dimensional orbit misclosures of the non-eclipsing satellites in the inertial frame. When the number of tracking stations exceeds 100 (for GPS in 1997, for GLONASS in 2009) the smoothed values go below 15 cm for CF2 and to 5 cm for COL and CO2.

GPS and GLONASS satellite orbits



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GPS and GLONASS satellite orbits

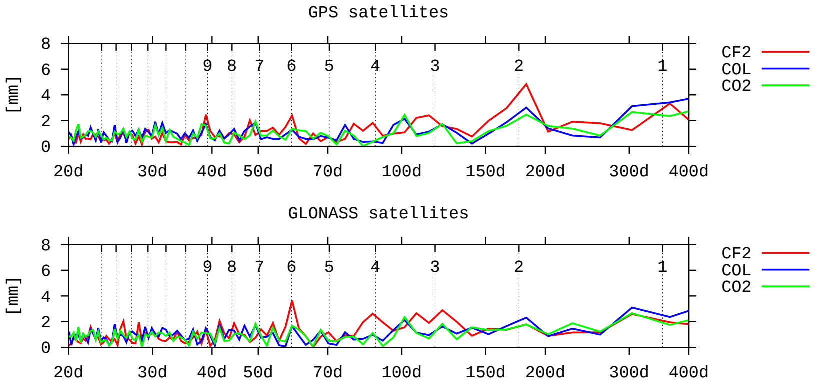

Figure 2 Spectra of the mean three-dimensional orbit misclosures in the **inertial frame** *between Jan-2009 and Dec-2013*. The first harmonics of the mean draconitic year (352.35 days) are indicated by vertical lines. Signatures in the CF2 solution (e.g. 2, 6, and 4 cpy) are considerably reduced in the CO2 and COL solutions.

GPS and GLONASS satellite orbits

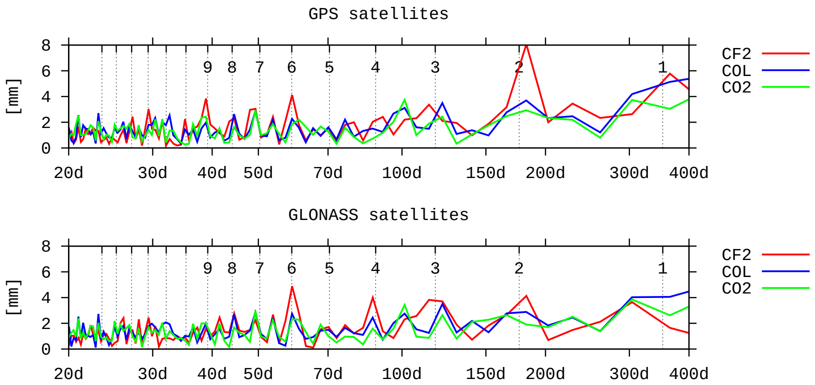

Figure 3 Spectra of the mean three-dimensional orbit misclosures in the **Earth's fixed frame** *between Jan-2009 and Dec-2013.* Existing periods in the inertial frame are amplified in all solutions.

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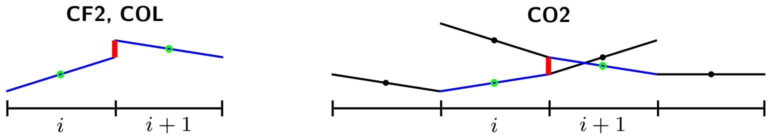
Earth rotation parameters

- Analysis of the pole misclosures

$$Xm_{i,i+1} = \left(X_{i+1} - \frac{Xrt_{i+1}}{2}\right) - \left(X_i + \frac{Xrt_i}{2}\right)$$

$$Ym_{i,i+1} = \left(Y_{i+1} - \frac{Yrt_{i+1}}{2}\right) - \left(Y_i + \frac{Yrt_i}{2}\right)$$

$Xm_{i,i+1}$, $Ym_{i,i+1}$	Misclosure of X and Y pole between day i and $i+1$
X_i, Y_i	Polar motion in X and Y at 12 UTC on day i
Xrt_i, Yrt_i	Polar motion rate per day in X and Y for day i



- Analysis of the formal a posteriori errors

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Earth rotation parameters

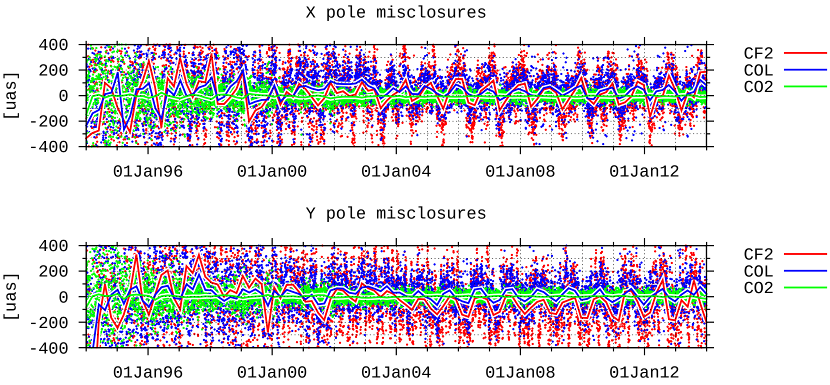
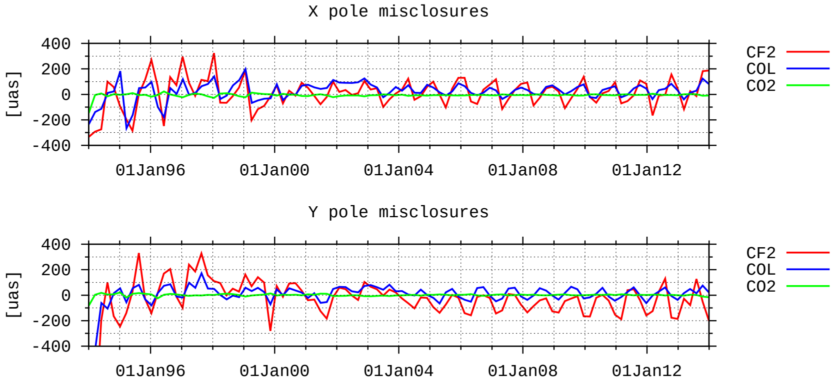


Figure 4 Time series and Bézier curves of the pole misclosures. There is almost no variation in the CO2 solution after Jan-2000. Low frequency periods in CF2 and COL are obvious.

Earth rotation parameters



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Earth rotation parameters

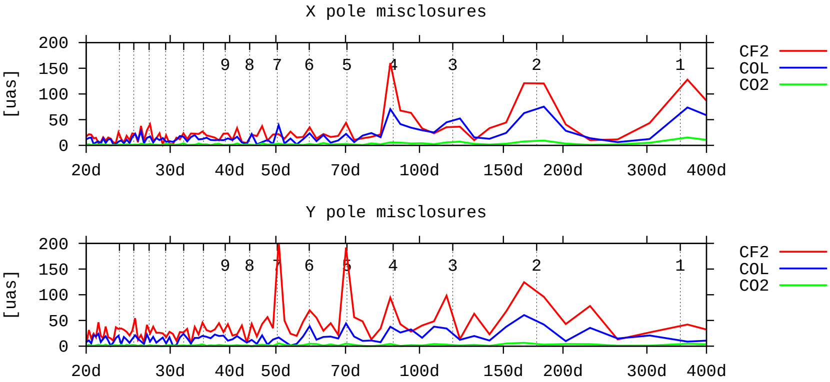

Figure 5 Spectra of the pole misclosures *between Jan-1997 and Dec-2001* (**GPS-only**). Signatures in the CF2 solution are considerably reduced in the COL and nonexistent in the CO2 solution.

Earth rotation parameters

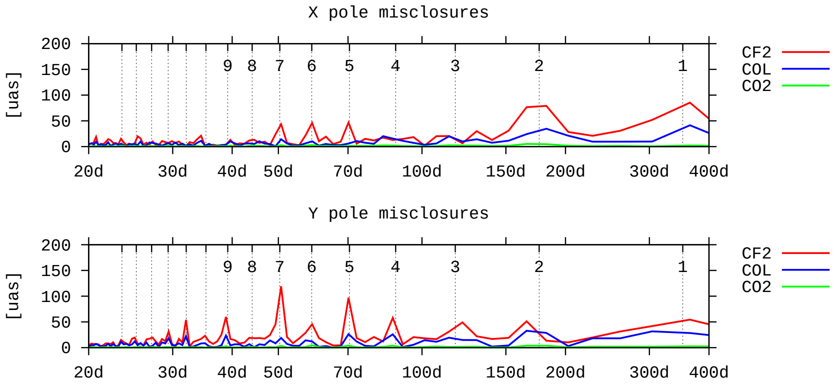

Figure 6 Spectra of the pole misclosures *between Jan-2002 and Dec-2006* (**improved GPS tracking and poorly observed GLONASS**). Some dominating periods in CF2 (e.g. 4 cpy in X and the semi-annual period in Y) are reduced compared to the earlier years.

Earth rotation parameters

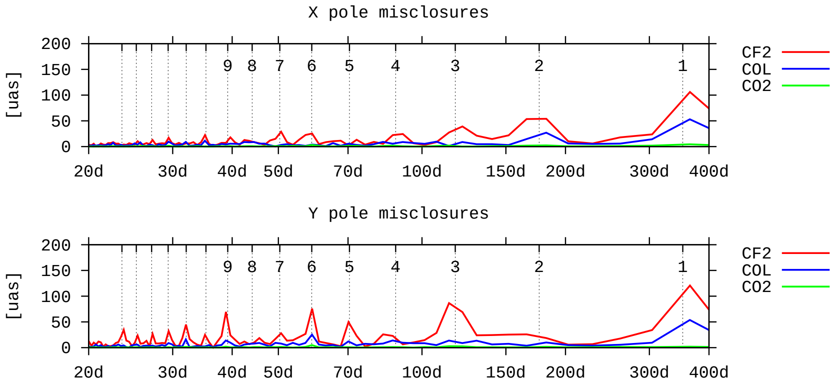

Figure 7 Spectra of the pole misclosures *between Jan-2009 and Dec-2013* (**GPS and GLONASS**). The improved GLONASS tracking reduces especially the 7 and 4 cpy periods, but increases the 3 cpy period in Y of CF2. An annual signal remains in the COL solution.

Earth rotation parameters

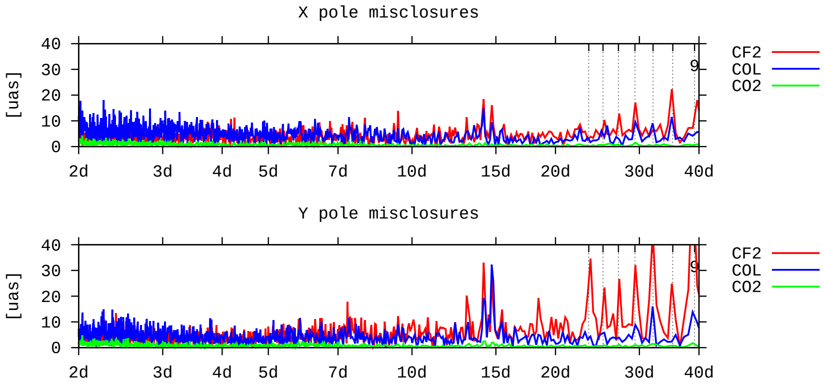

Figure 8 Spectra of the pole misclosures at higher frequencies *between Jan-2009 and Dec-2013*. Periods of 18 days and longer in the CF2 solution are considerably reduced, but the higher terms are preserved in the COL solution. There are almost no spectral lines in the CO2 solution.

Earth rotation parameters

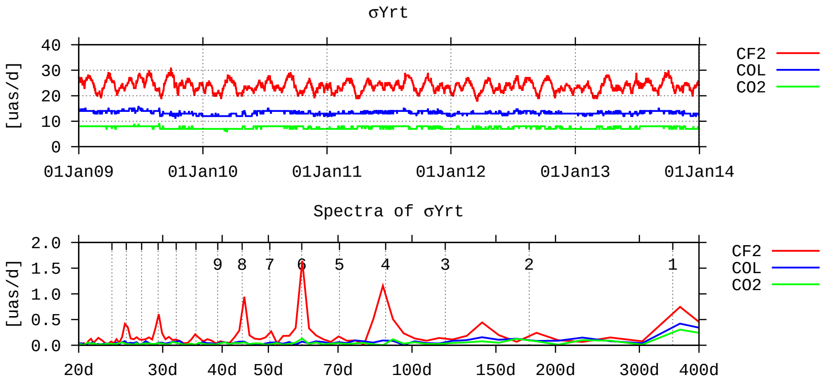

Figure 9 Formal a posteriori errors of the polar motion rate in Y and their spectra *between Jan-2009 and Dec-2013*. The long-arc solutions are clearly superior to the clean 1-day solution. The estimation of the rate parameter in the CF2 solution is systematically degraded.

Earth rotation parameters

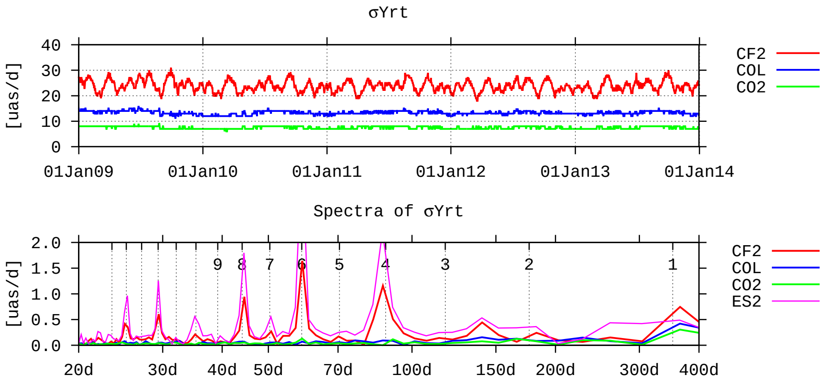

Figure 9 Formal a posteriori errors of the polar motion rate in Y and their spectra *between Jan-2009 and Dec-2013*. The long-arc solutions are clearly superior to the clean 1-day solution. The estimation of the rate parameter in the CF2 solution is systematically degraded.

Summary (1/2)

- CODE provides **two complete sets** of homogeneously reprocessed solutions for repro2 covering the time span from Jan-1994 to Dec-2013: a clean 1-day solution (CF2) and a 3-day long-arc solution (CO2).
- **GPS orbits** are available for the complete time interval, **GLONASS orbits** after Jan-2002.
- **GPS** is dominating the solutions over all years. **GLONASS** starts contributing with some importance in 2009, when the number of tracking stations exceeds 100.
- The **orbit misclosures** at the end of the time interval reach a level of about 6 cm for GPS and 10 cm for GLONASS in the CF2 solution and a level of about 3 cm for both systems in the CO2 solution.

Summary (2/2)

- The **clean 1-day solution (CF2)** has the distinct advantage of statistical independence, but it contains spurious spectral lines related to the satellite constellations.
- The **3-day long-arc solution (CO2)** is statistically questionable due to the triple use of data, but draconitic signals are substantially mitigated or even removed thanks to the better separation of the orbit and Earth rotation parameters (ERPs).
- The **additional COL solution** shows that the artifacts from the orbits, especially in the ERP rates, can be reduced by considering 3-day orbital arcs, even if all other parameters (including station coordinates and ERPs) refer to the middle day only.
- **Open issues:** 1-day vs. 3-day solutions; draconitic vs. geophysical signals; single system vs. combined solutions; inclusion of further GNSS constellations (e.g. Galileo, BeiDou)