CENTRE NATIONAL D'ÉTUDES SPATIALES

Widelane biases, code-carrier phase biases, application to PPP ambiguity resolution

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Summary

Zero difference reference equations
- phase equation
- phase clock definition, general properties
- link with current approaches
- widelane biases and solutions comparison

Comparison of different igs solutions (esa, jpl, grg)
- observed code/phase bias daily mean values
- observed precision of these biases

Widelane ambiguity fixing
- formulation
- satellite widelane biases (WSB)

PPP
- some examples, day boundaries effects

Phase and pseudo-range equations

Rinex measurements

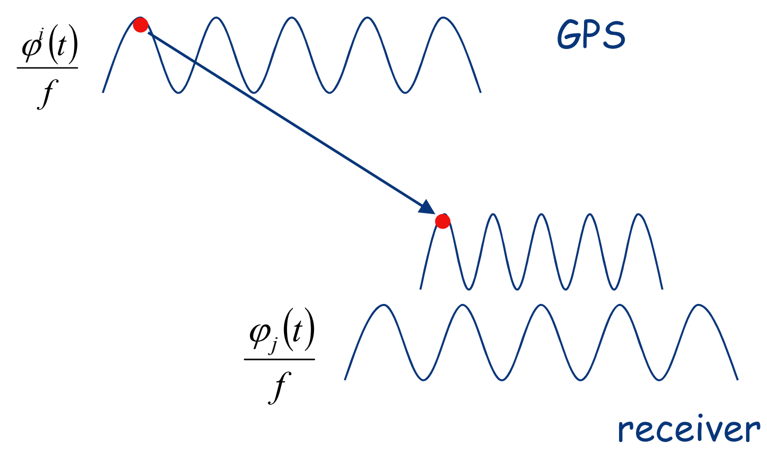
$$L = \varphi_j - \varphi^i \quad [1]$$

$$\lambda L = c\left(\frac{\varphi_j}{f} - \frac{\varphi^i}{f}\right) \quad [\lambda]$$

receiver time
at reception event

satellite time
at emission event

$$P = c\left(T_j - T^i\right)$$



Phase measurement ⟷ Pseudo-distance and wavelength modulo

Phase and pseudo range clocks

$$\lambda L = \rho_L - e + c\left(dt_{L,j} - dt_L^i\right) - \lambda N$$

receiver j clock offset

satellite i clock offset

$$P = \rho_P + e + c\left(dt_{P,j} - dt_P^i\right)$$

Continuous tracking along a pass : N integer, common for all measurements in the pass

→ Possible biases between dt_L (phase) and dt_P (pseudo-range)

Questions :

- these are hardware biases (different delays between code and phase)
- stability of these biases ?
- are these biases needed to solve the phase equation ?
- do we observe these biases in the current IGS clock solutions ?

Dual frequency phase measurements

Elimination of the first order ionosphere effect

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 L_2}{\gamma - 1} = \rho + \lambda_c d_{windup} + \Delta dt - \frac{\gamma\lambda_1 N_1 - \lambda_2 N_2}{\gamma - 1}$$

integer ambiguities

propagation model (with tropo, phase maps)

windup (modulo 1)

Ionosphere free phase clocks offsets (expressed in meters)

Widelane solution : $N_w = N_2 - N_1$ is known for each pass

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 (L_2 + N_w)}{\gamma - 1} = \rho + \lambda_c d_{windup} + \Delta dt - \lambda_c N_1$$

$$\lambda_c = \frac{\gamma\lambda_1 - \lambda_2}{\gamma - 1}$$ ~10.7 cm (narrowlane)

Ionosphere free phase equation

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 (L_2 + N_w)}{\gamma - 1} = \rho + \lambda_c d_{windup} + \Delta dt - \lambda_c N_1$$

measurements → $\frac{\gamma\lambda_1 L_1 - \lambda_2 (L_2 + N_w)}{\gamma - 1}$

propagation model → $\rho + \lambda_c d_{windup}$

ionosphere free phase clocks → Δdt

integer ambiguity → $\lambda_c N_1$

Solved for the constellation over a global network giving orbits and phase clocks → grgxxxxx.sp3 at IGS (http://igsac-cnes.cls.fr/, poster)

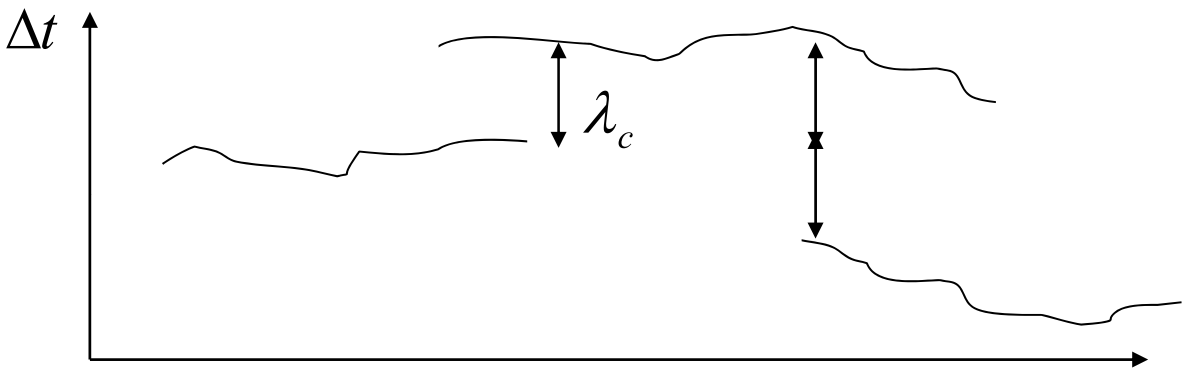
Main characteristic : this is a modulo λ_c equation, due to the unknown values for each pass N_1

Infinite set of solutions (producing exactly the same phase residuals) which differ only by an integer number of λ_c cycles bias for each clock

This property can be used for a continuous clock reconstruction (example : time transfer applications) →

Comparison of phase clocks solutions

For a given set of widelane biases all clocks solutions obtained for different time intervals or different networks differ by integer multiples of the narrowlane wavelength (10.7 cm).

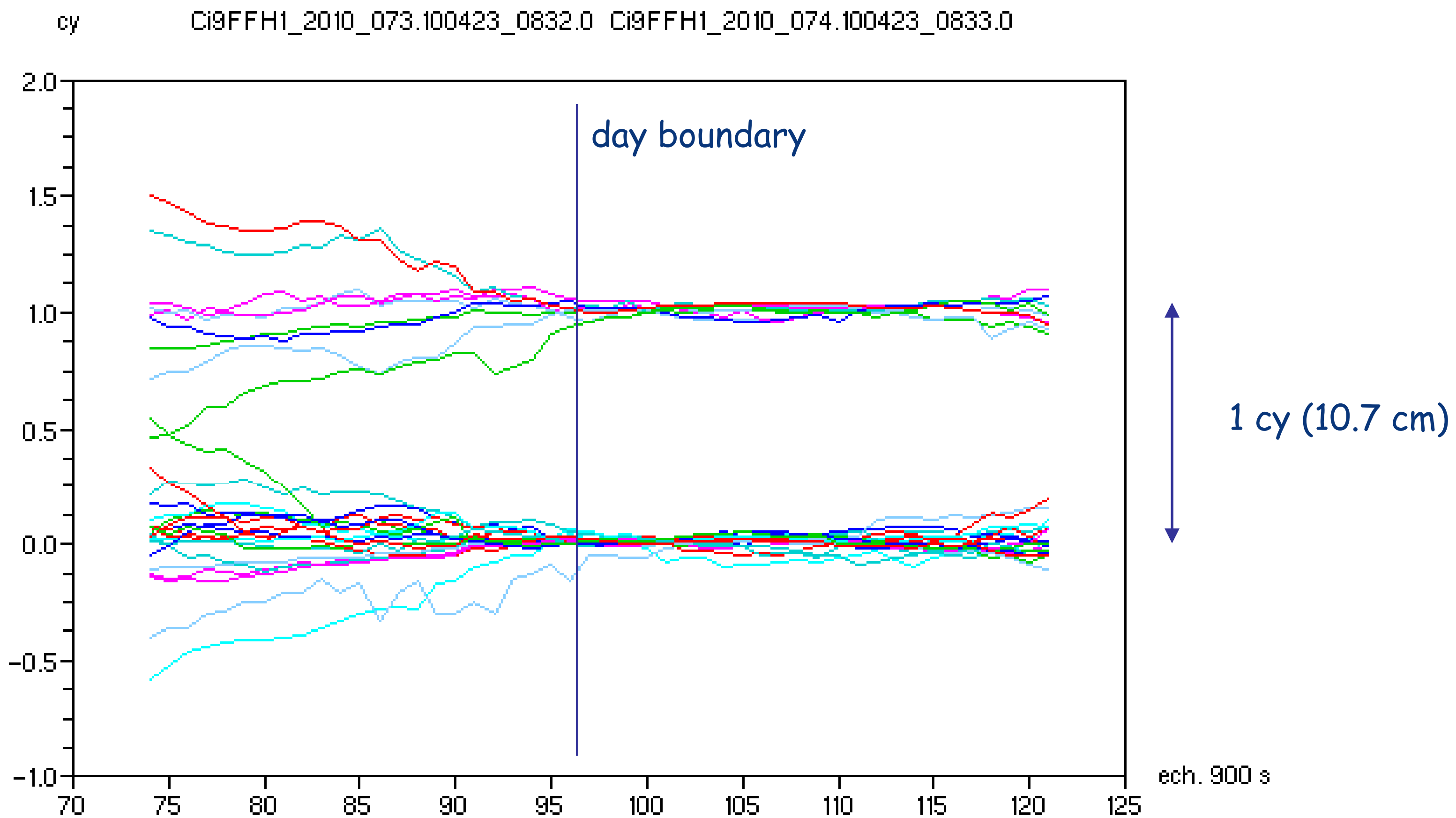


Very useful property when processing overlapping solutions

→ no possible clock drifts, the frequency is perfectly determined

Alignment of independent analyses

Arcs overlap : integer cycle property



grg clocks solutions overlap : integer number of narrowlane cycles

on the left, problem of windup initialisation close to the beginning of the second arc (to be corrected)

Floating ambiguities solutions

Integer valued ambiguity

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 (L_2 + N_w)}{\gamma - 1} = \rho + \lambda_c d_{windup} + \Delta dt - \lambda_c N_1$$

Real valued ambiguity

$$\frac{\gamma P_1 - \lambda_2 P_2}{\gamma - 1} = \rho_p + \Delta dt_f$$ Pseudo-range

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 L_2}{\gamma - 1} = \rho + \lambda_c d_{windup} + \Delta dt_f - A$$ Phase

Usually, due to the small weight of the pseudo-range, and the use of independent daily solutions Δdt_f and Δdt differ mainly by a daily bias (real valued)

Remark : the floating phase equation could also be solved independently, procedure similar to the integer case (fixing the same reference ambiguity data set).

Comparison of different orbit/clocks solutions :

esa
jpl
grg

→

Analysis of $\Delta dt_f - \Delta dt$

Observation of the code-phase bias

Application, comparison of clocks solutions

jpl, esa, grg solutions, days 66-121 2010, 900 s sampling

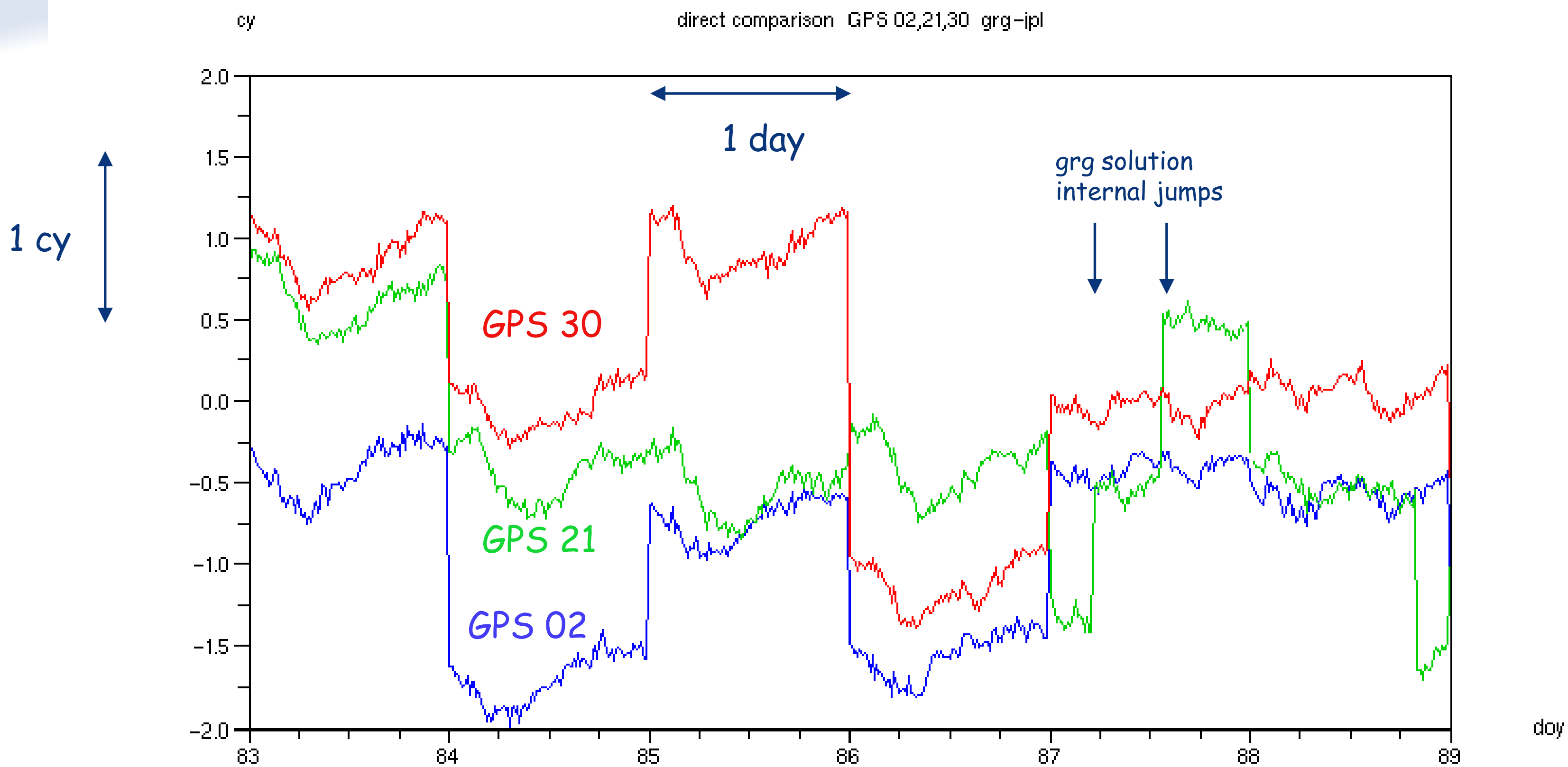
jpl, esa solutions, clocks aligned on the pseudo-range

grg solution : phase clocks, independent between successive days
globally aligned on the pseudo-range

All solutions referenced here to GPS20 (common to all solutions, without interruption)

Radial correction applied to compare the clocks

Example, grg-jpl

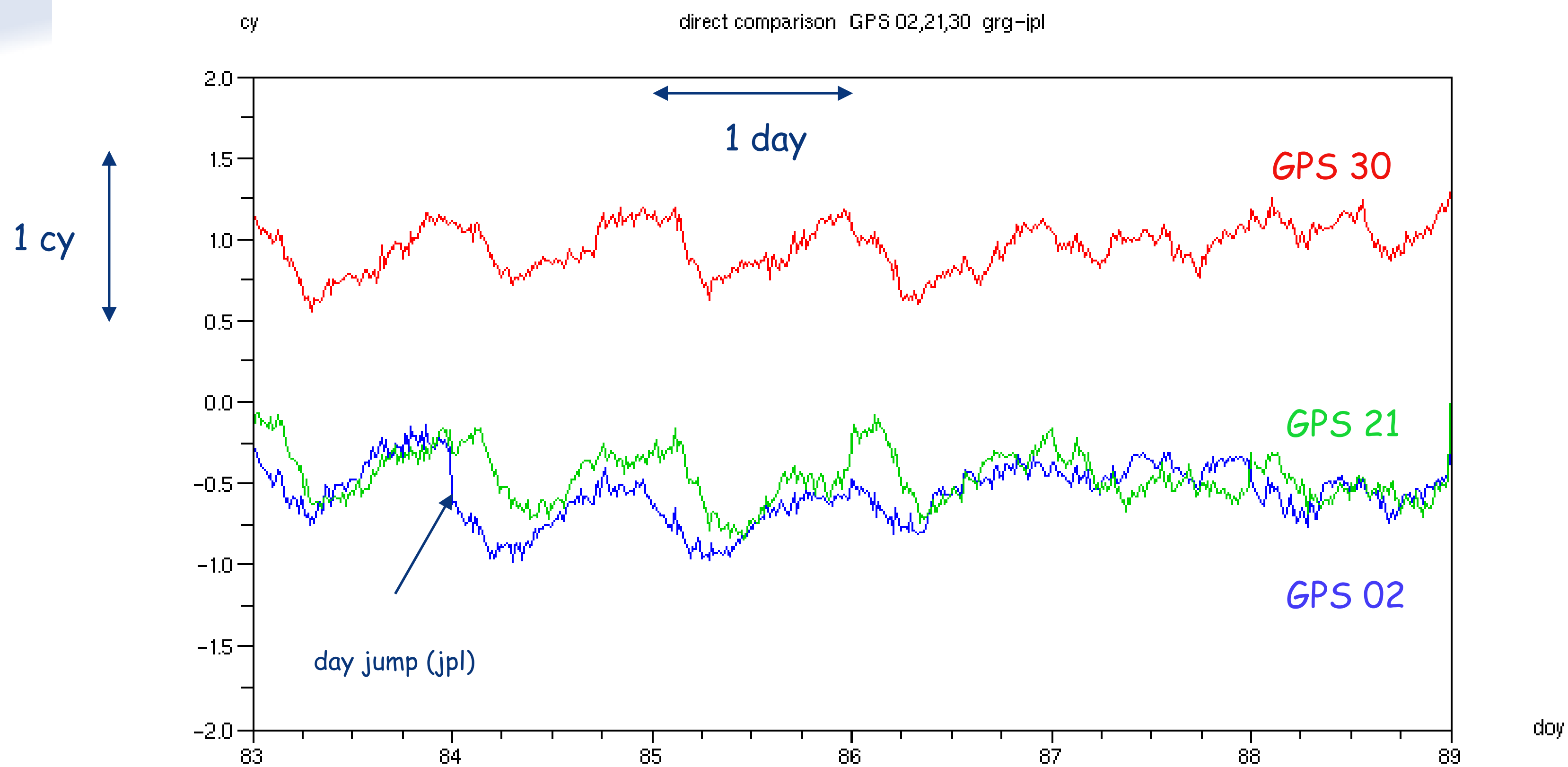


Possible jumps at day boundaries (multiple of λ_c)

Some other jumps (due to phase continuity interruption in grg solution)

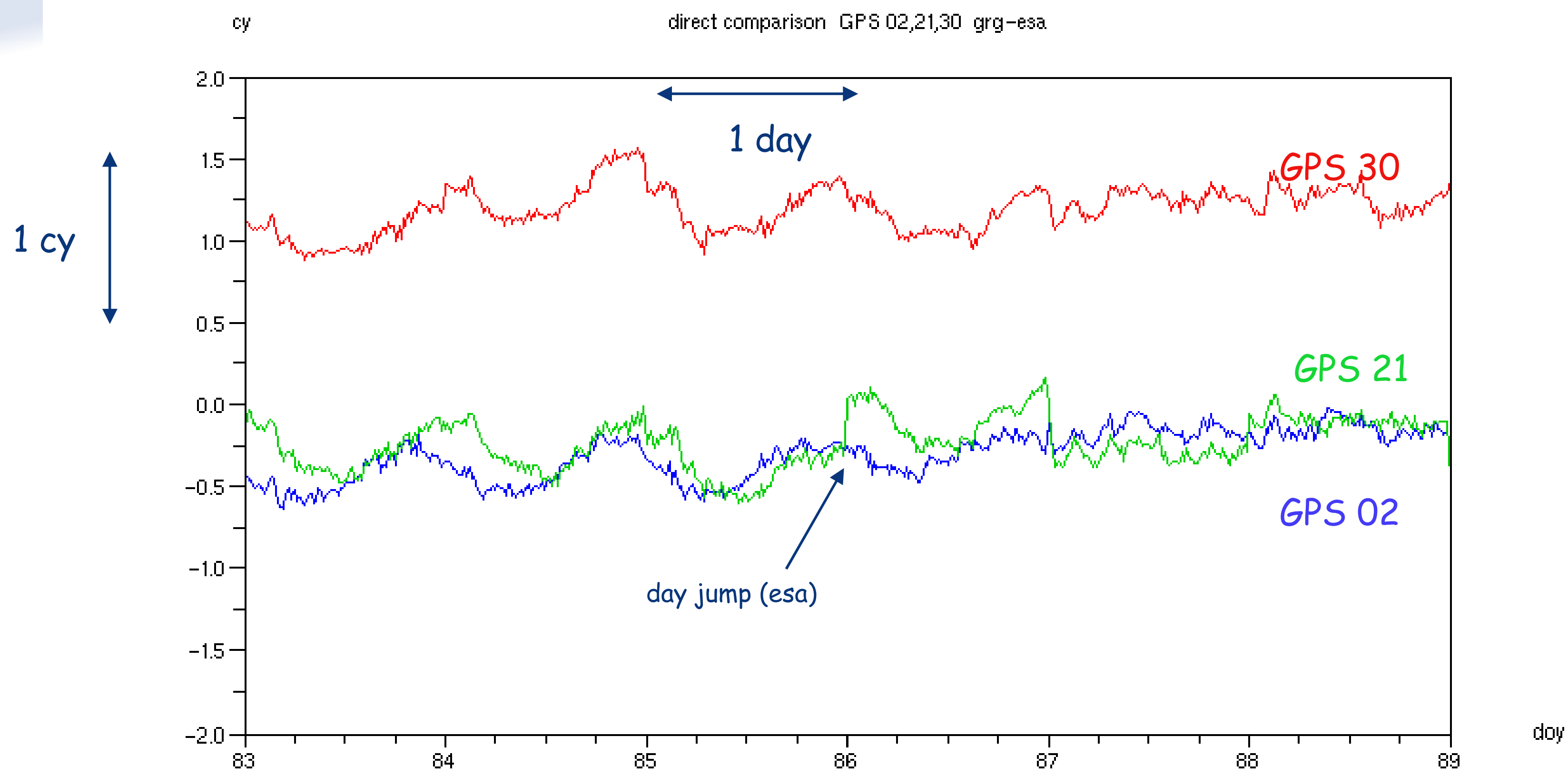
→ Possible reconstruction ?

Example, grg reconstructed - jpl



All jumps in the grg solution seem correctly reconstructed

Example, grg reconstructed - esa



This integer cycle reconstruction is validated independently on jpl and esa solutions

Possible small day discontinuities in the current jpl or esa solutions (~4 cm)

Application, long comparisons mean code-phase bias

The differences between the three solutions give some information about the iono-free code-phase biases

The observed difference depends on :

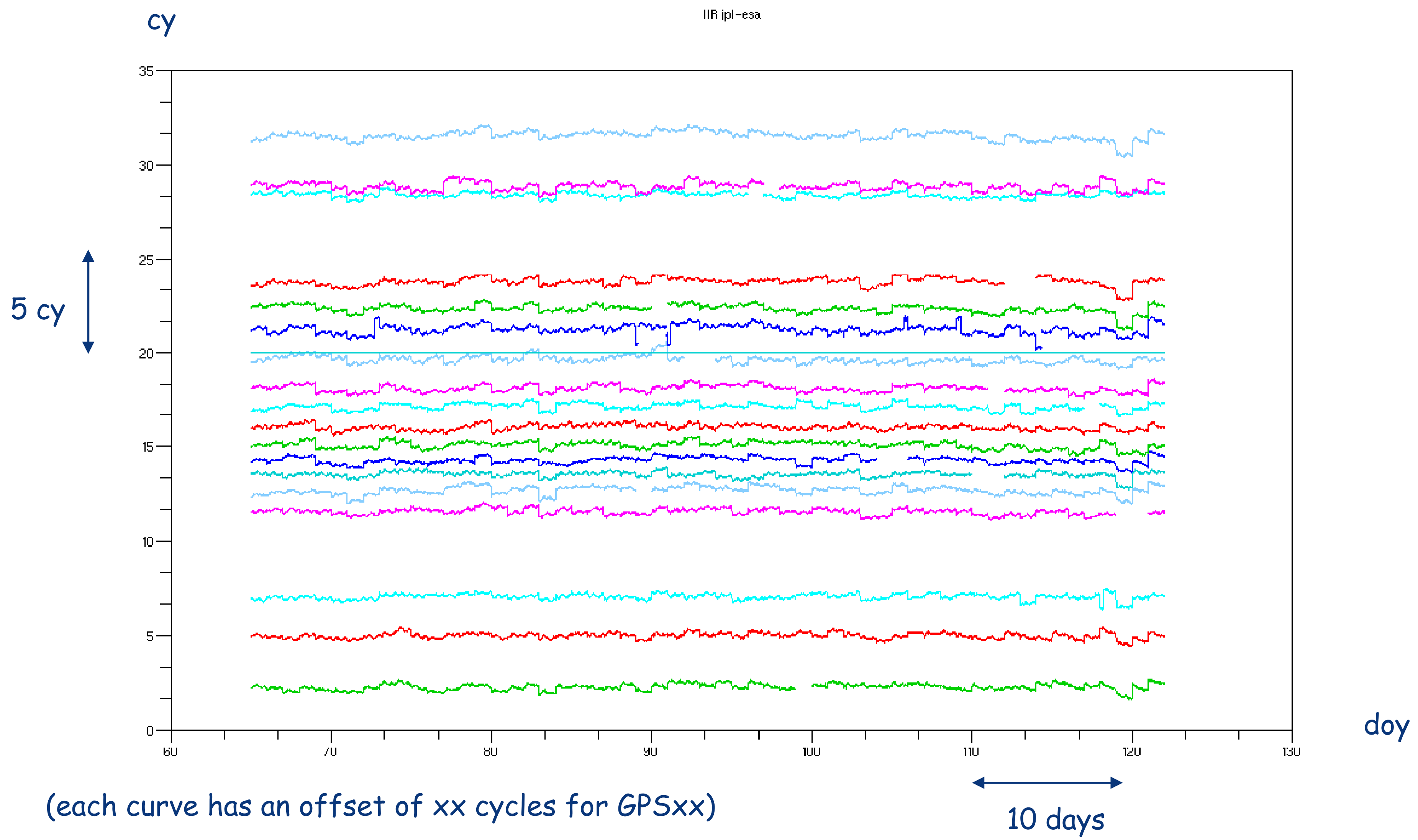
- code-phase bias
- precision of the different solutions

Method :

- esa-jpl : precision, some offsets, repeatability

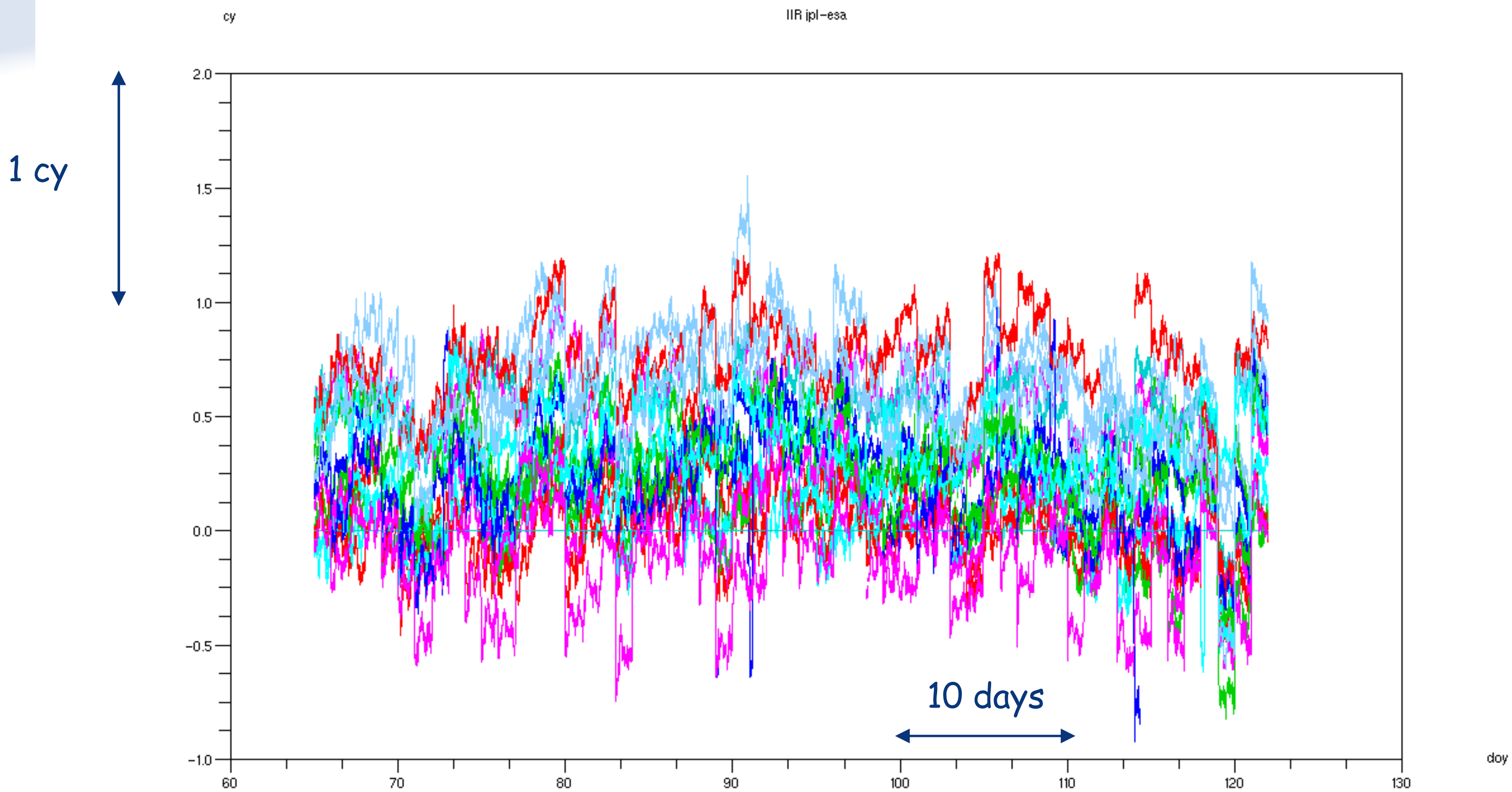
- esa-grg or jpl-grg : evolution of the bias fractional part (two months of data)

jpl-esa IIR clocks difference (1)



(each curve has an offset of xx cycles for GPSxx)

jpl-esa IIR clocks difference (2)

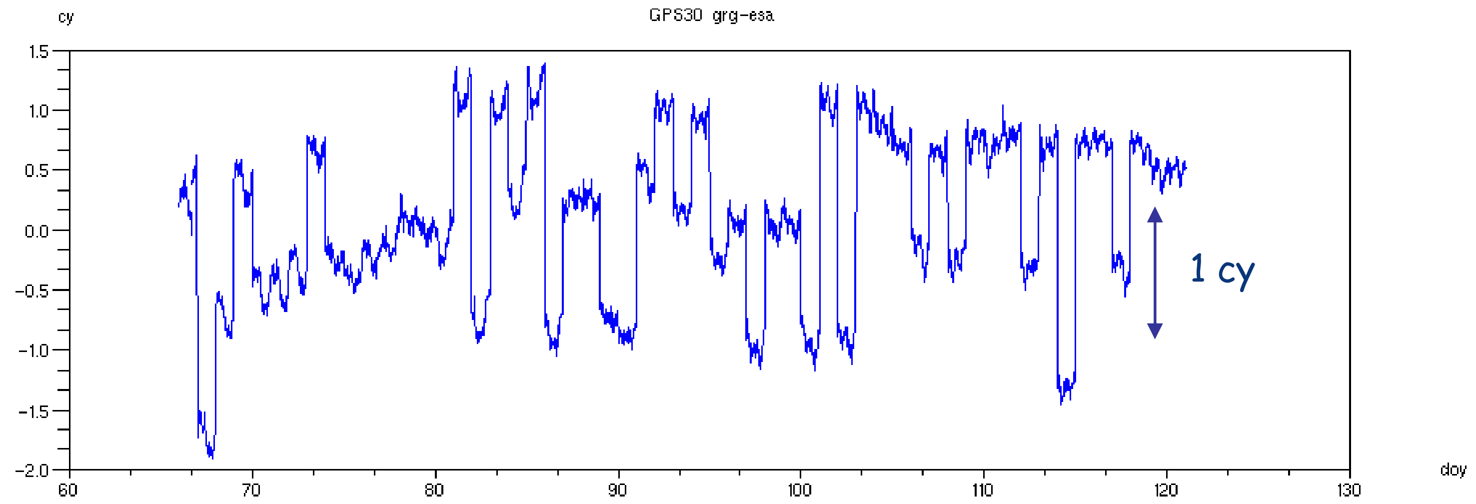


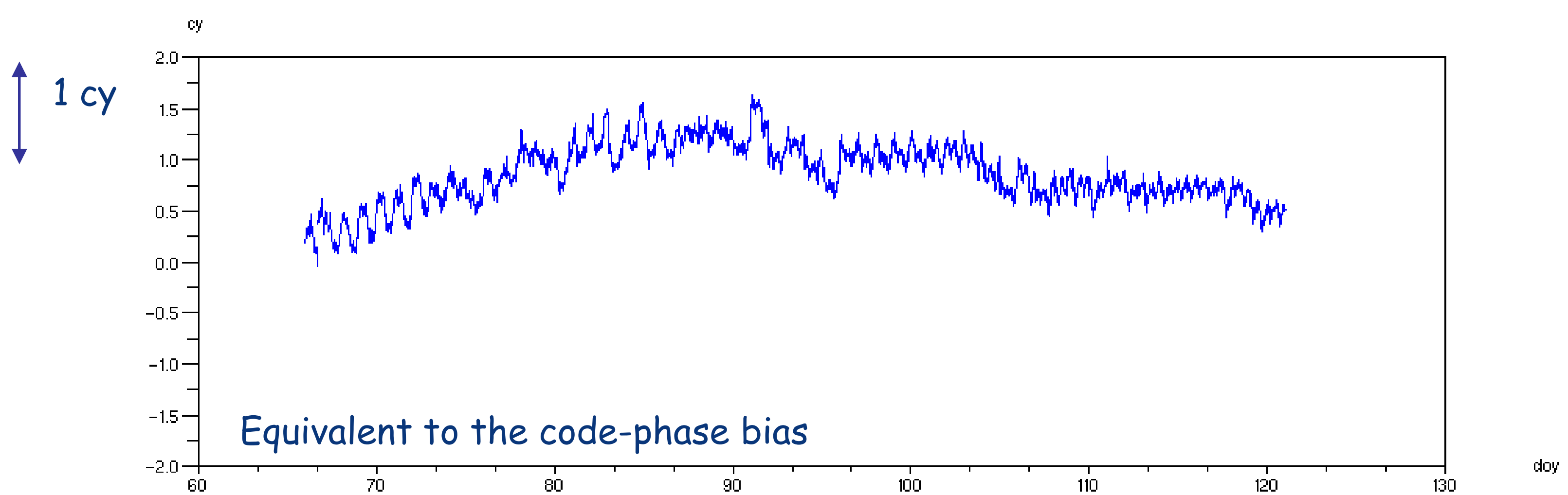
Some systematic biases between esa and jpl solutions

Daily variations can be high (more than 0.5 cycle)

⇒ A common set of code-phase biases values to recover phase clocks is not possible

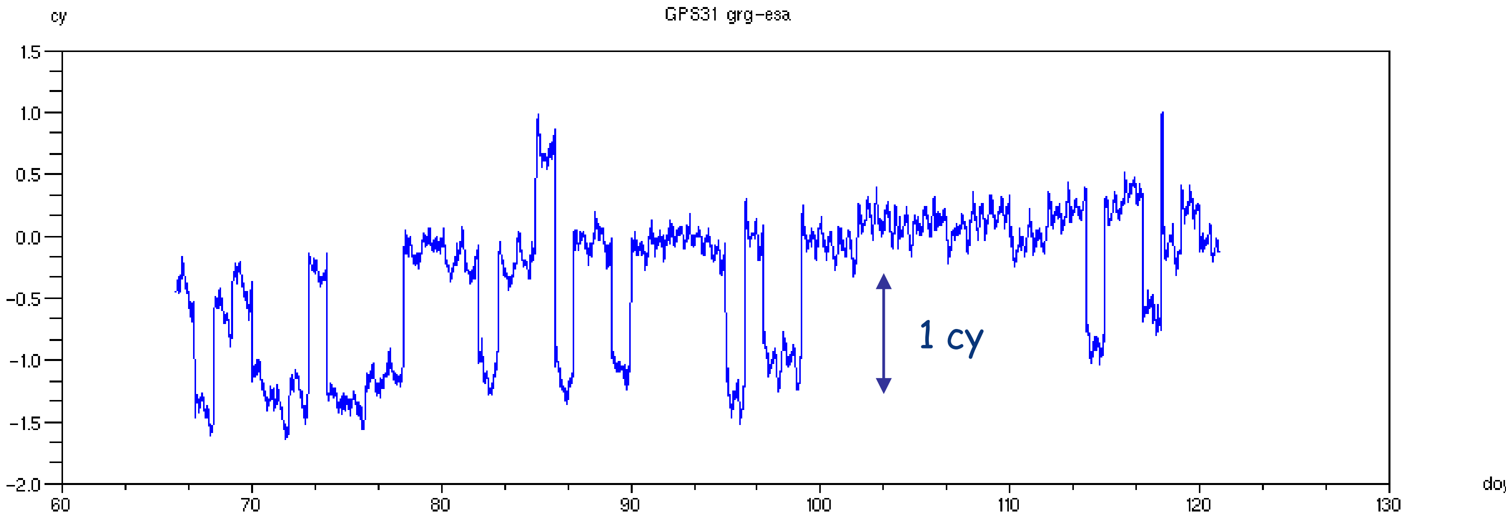
Reconstruction of the clock integer ambiguity (IIA, GPS30, ref. GPS20, grg-esa)

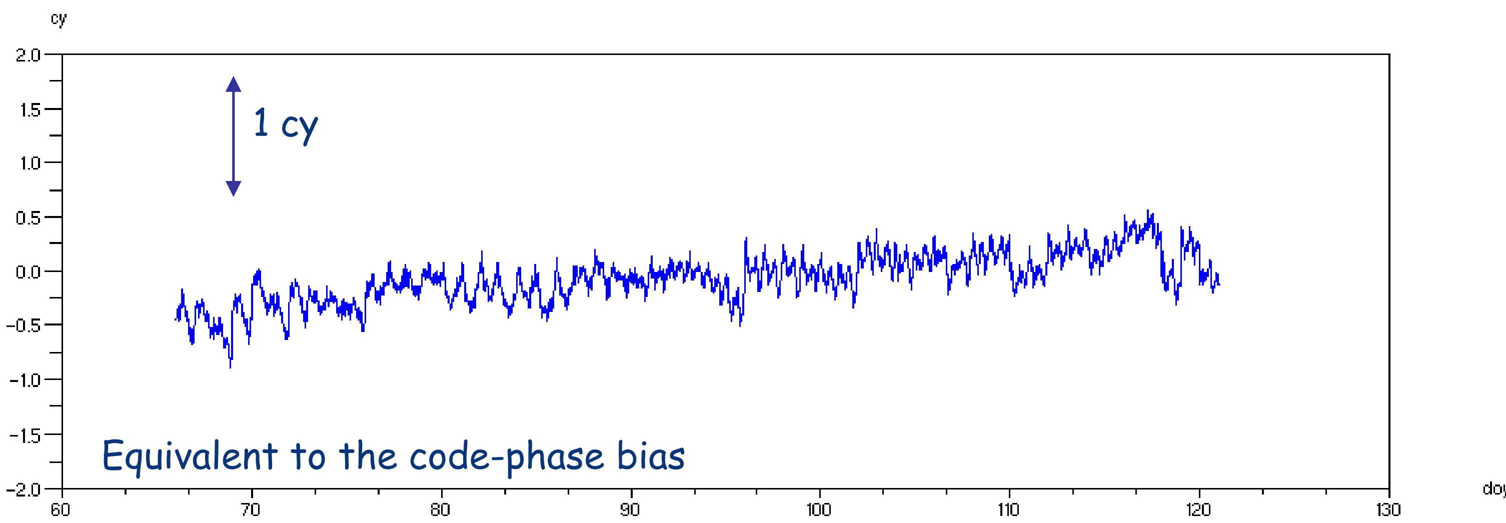




The code-phase daily bias is very stable, even on GPS IIA
Possible evolution of ~1 cy over 2 months observed

Reconstruction of the clock integer ambiguity (IIR, GPS31, ref. GPS20, grg-esa)





Global characteristics of the solutions

The grg clock integer cycle jumps are clearly observed on grg-esa or grg-jpl.

There is no apparent drift between the different solutions (grg solution remains close to the esa and jpl solutions), tbc on longer durations.

The jumps can be reconstructed (continuity and integer number of cycles) to produce a continuous phase clock solution thanks to the high quality of the current igs solutions

The difference between phase clocks (grg reconstructed) and standard solutions (esa or jpl) shows the possible evolutions of the daily code phase bias over the two months of data processed (maximal evolution 1 cycle, for IIR and not eclipsing IIA)

The observed code-phase biases are very stable (~daily mean values) a pseudo-range clock can be easily reconstructed with required performance using only daily biases

However, the difference between current solutions (jpl – esa) shows that the use of a common set of code-phase biases to reconstruct phase clocks is not yet possible

Positioning

Present processing :

- Widelane

estimation of the widelane ambiguity value for each pass using
the reference satellite widelane biases WSBs (available at http://igsac-cnes.cls.fr)

- Positioning and narrowlane ambiguity fixing

solution of the iono-free phase equations with integer ambiguity per pass (wavelength λ_c)

the pseudo-range equation is used to stabilize the process
small weight (10 m for 0.01 m for the phase)

This processing is performed using the igs available data (orbits/clocks, 900 s, WSBs)
the PPP software is independent from GINS (software used for grg solution)

This works for long solutions (typically one day)
for shorter solutions, pseudo-range processing must be improved

Example of positioning results

One week solution, station brus , grg solution, 900 seconds

- stochastic solution (one position per epoch)
  - floating ambiguities
  - fixed ambiguities

Weeks 1574, 1575

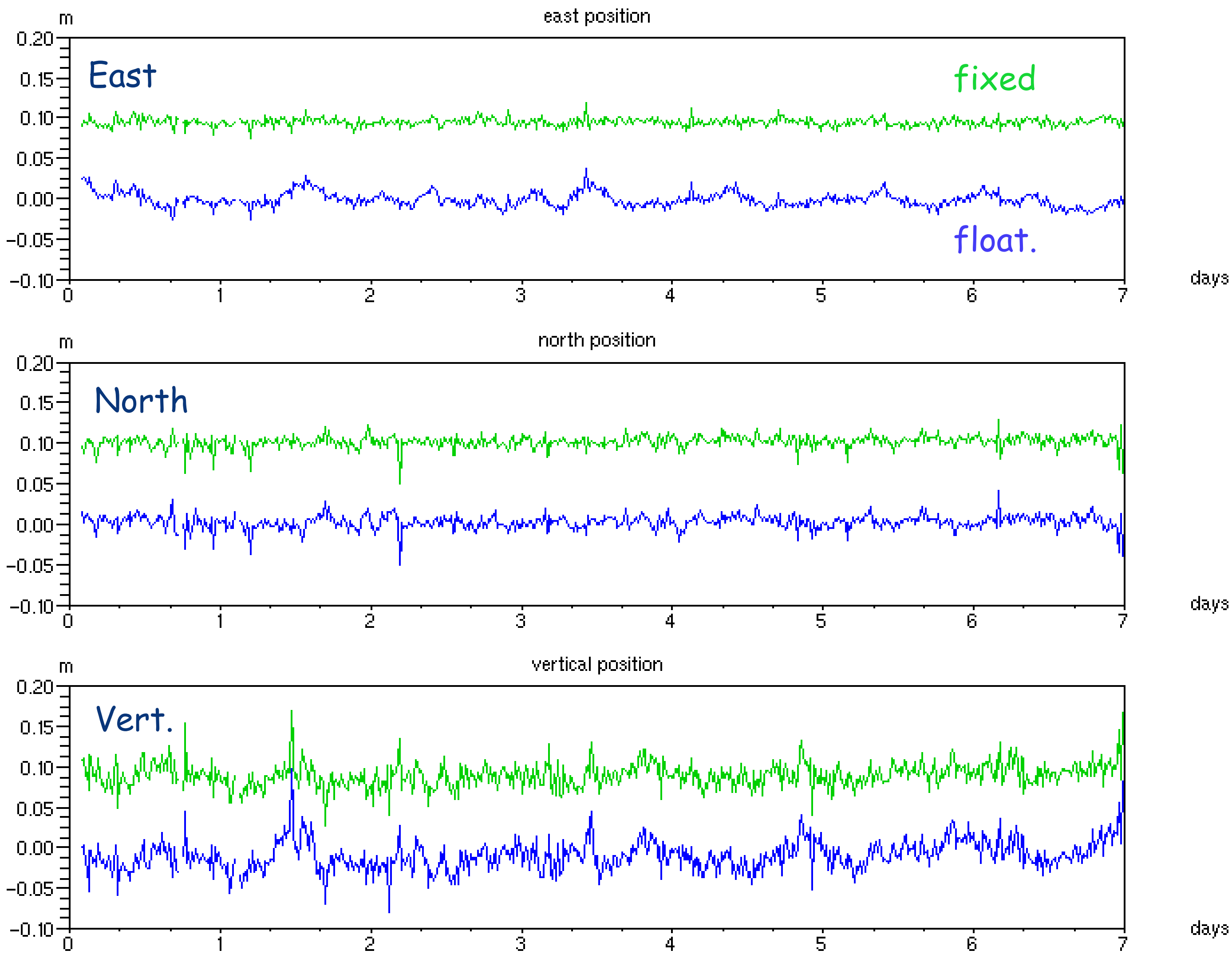
rms results East, North, Vertical in mm

Week	1574 e,n,h			1575 e,n,h		
Float.	9.0	8.5	18.8	11.2	9.9	26.7
Fix.	5.2	7.6	15.4	5.9	8.8	25.4

Time history (brus, week 1574)

Exactly the same measurements for the two solutions

Not sensitive to the pseudo-range errors



- Improvements with fixed ambiguities
- Horizontal signatures are minimized
- Vertical errors improve ZTD models

PPP and biases

	Pseudo-range	Phase	Bias
widelane processing	meas. only	meas. only	daily WSB
geometry modelling	precision ~ 10 m	-	-
ambiguity fixing	-*	iono-free with fixed widelane	daily*

Remark :

* for short data sets, it is necessary to use a precise pseudo-range information to minimize the ambiguity search domain.

This pseudo-range information must be as precise as possible, this means :

- minimize errors (biases) for the pseudo-range clocks, for example : use a specific clock for pseudo-range (daily code-phase bias correction, different clocks for phase and pseudo-range....)
- the pseudo-range processing must be consistent with the solution used for example see the biases present between esa and jpl solutions, more than 1 cycle

Combination of the phase clock solutions

Initial solutions data :

- ephemeris
- phase clocks
- daily WSBs, used in the orbits/clocks solution construction
- daily code-phase bias (or pseudo-range clock)

Solutions combinations :

- ephemeris
- WSBs differences, production of a common set of reference WSBs
- integer part correction on the phase clocks (wavelength $\frac{\lambda_2}{\gamma - 1}$)
- clocks combination with modulo λ_c corrections
- daily code-phase bias construction (only for pseudo-range processing, not critical)

Integer PPP user :

- ephemeris
- daily WSBs for receiver widelane ambiguities fixing
- phase clocks, specific processing to deal with possible λ_c cycle slips
- pseudo-range clocks (for example reconstructed with code-phase biases)
- ambiguity fixing, with precise pseudo-range processing for short durations

Conclusion

Formulation and properties of phase clocks
- grg solution
- satellite widelane biases (WSBs)
- integer number of narrowlane wavelength in the phase clocks

Comparisons of the clock solutions (grg,esa,jpl)
- observation of the iono-free code-phase biases
- a daily code-phase bias value is suited to reconstruct
  a pseudo-range clock equivalent to the present igs clocks convention

Combination of different phase clocks solutions
- WSBs combination
- phase clocks combination

Application to stochastic positioning with ambiguity fixing
- use of orbits/clocks (grg solution)
- kinematic examples without and with ambiguity fixing

Thank you

Widelane

Widelane formulation using satellite daily widelane biases (WSB)

Example of satellite WSBs

Impact of the widelane convention on the phase clock

Widelane solution

$N_w = N_2 - N_1$ is estimated using the pseudo-range and phase equations

(four observable linear widelane combination, Melbourne - Wubenna)

Expression :

$$L_2 - L_1 + \text{l}\left(P_1, P_2\right) = N_w + \tau_{WB,j} - \tau_{WB}^{i}$$

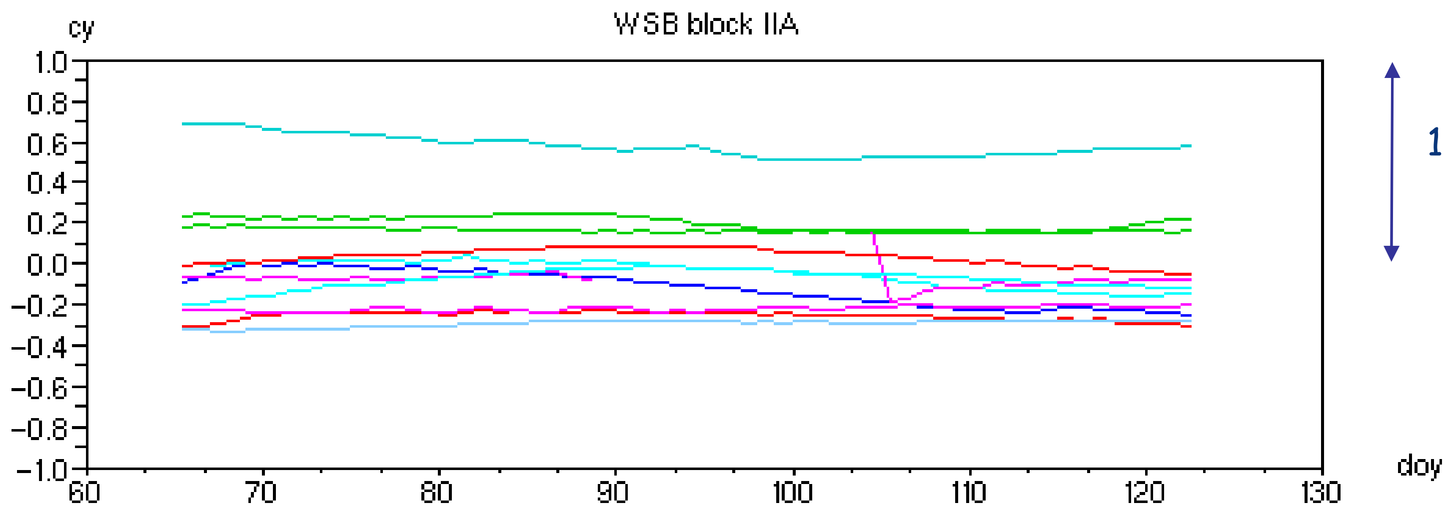
- $L_2 - L_1 + \text{l}\left(P_1, P_2\right)$: measurements
- $\tau_{WB,j}$: receiver widelane bias
- τ_{WB}^{i}: satellite widelane bias

Remarks : no model is needed (cancellation of the windup effect, negligible phase centre relative offsets)

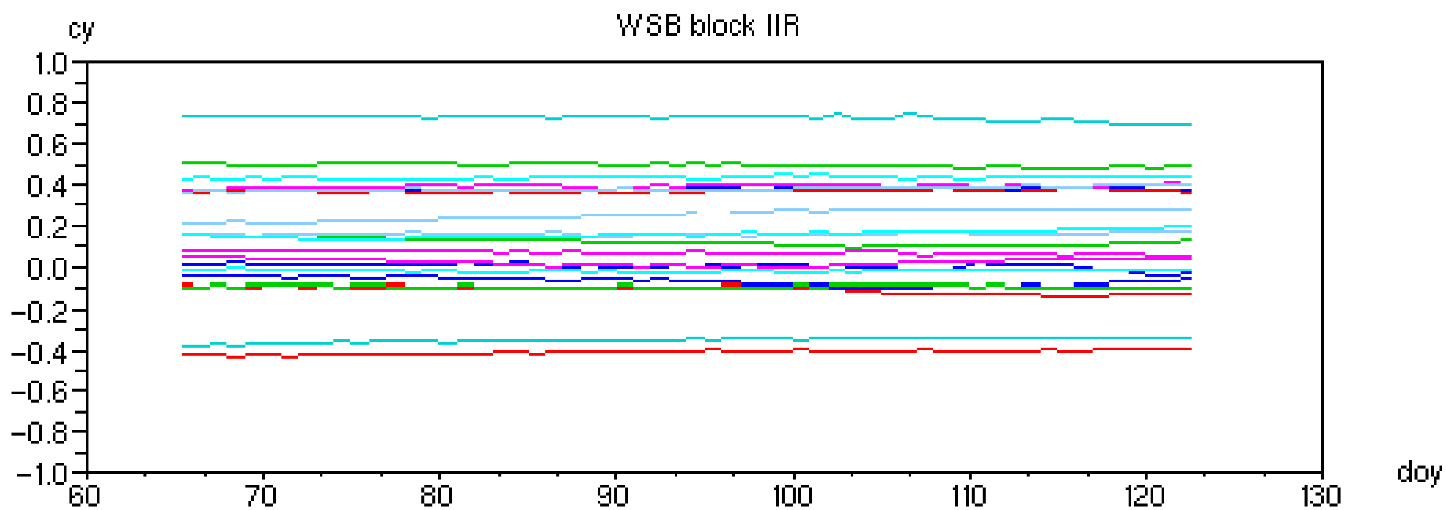
it was shown that the stability of the satellite biases τ_{WB}^{i} is excellent, and can be assumed to be constant over a day, for the purpose of solving integer N_w (Mercier-Laurichesse oct. 2007)

this is also a modulo 1 equation : only the floating part of τ_{WB}^{i} can be observed, and the long term evolution is reconstructed by continuity

Example : satellite widelane bias values



1 cy



Daily values for the Widelane Satellite Biases (see grg solution website http://igsac-cnes.cls.fr)

Effect of the integer part of the widelane biases

Example :

change of τ_{WB}^{i} convention $\longrightarrow$ $\tau_{WB}^{i} + k$ (integer)

all corresponding widelane ambiguities are changed : $N_w \longrightarrow N_w + k$

the phase equation is changed (for all passes with satellite i):

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 (L_2 + N_w + k)}{\gamma - 1} = D + \lambda_c d_{windup} + t_j - t^i - \lambda_c N_1$$

the new satellite clock solution has a bias corresponding to $\frac{k\lambda_2}{\gamma - 1}$ for satellite i

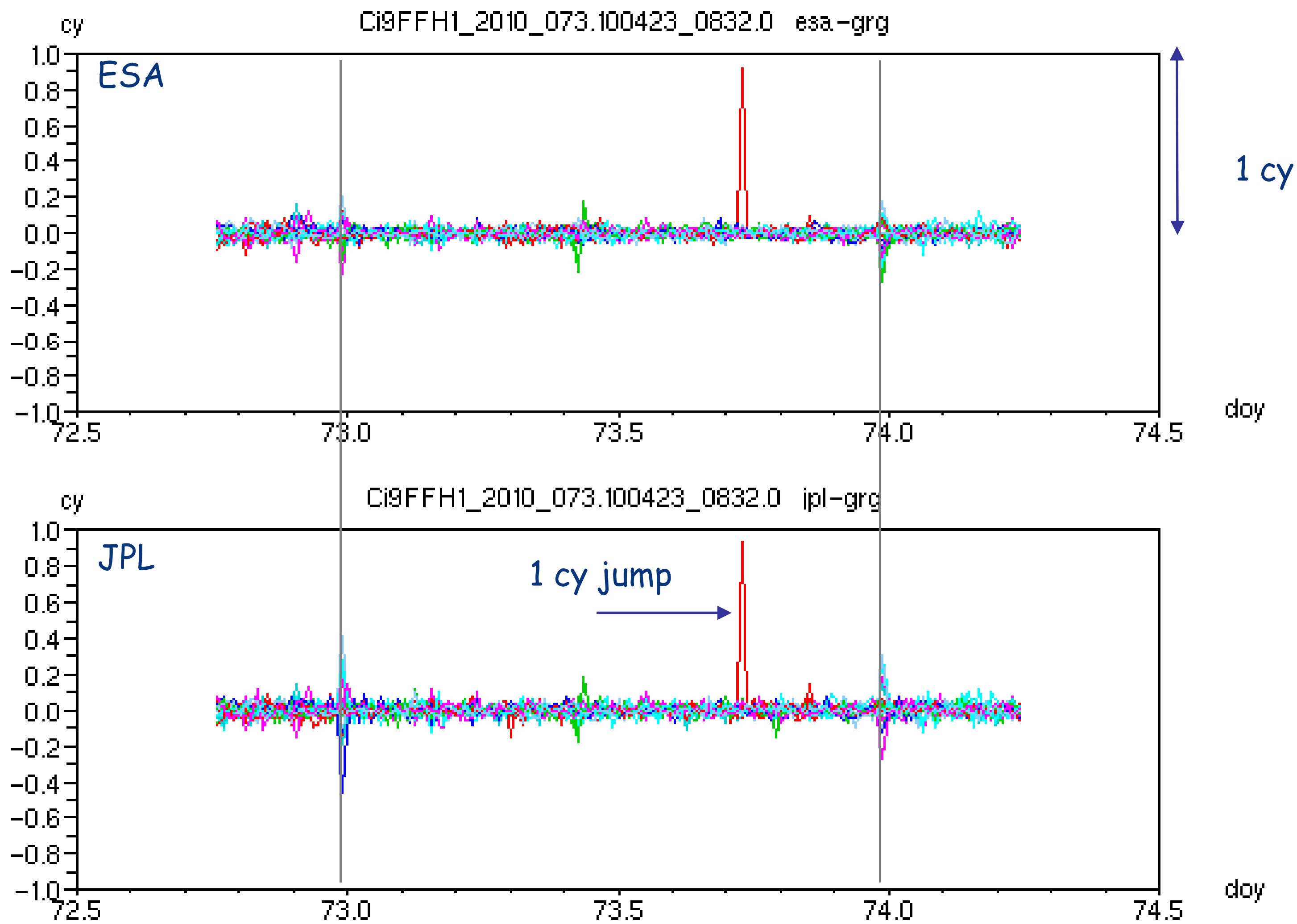
$$t^i \longrightarrow t^i + \frac{k\lambda_2}{\gamma - 1}$$

Conclusion :

phase clock solutions must be corrected with the widelane biases differences before comparison, to observe integer λ_c cycles offsets cnes

Spare

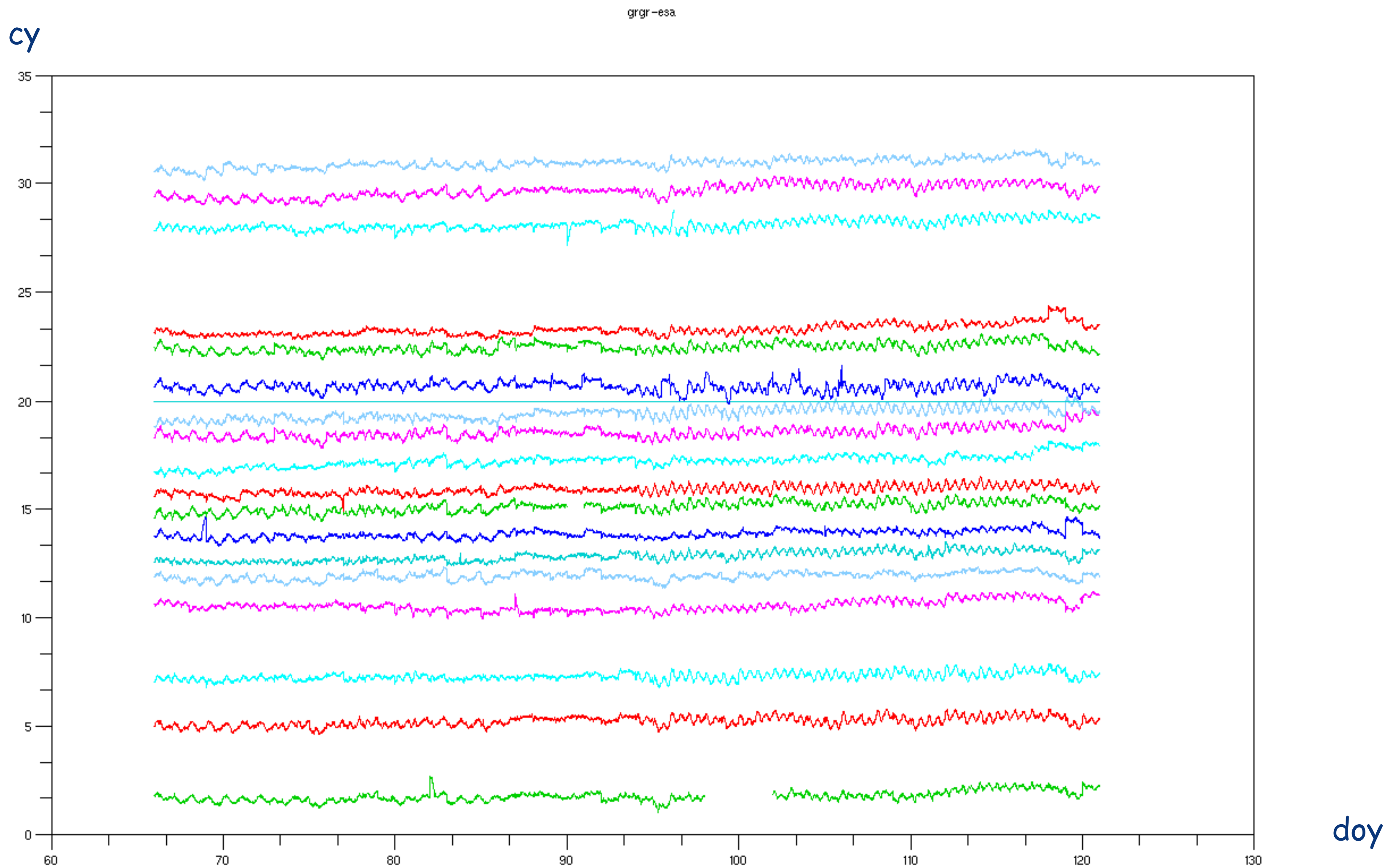
Comparison for a standard grg solution arc (1.5 day)



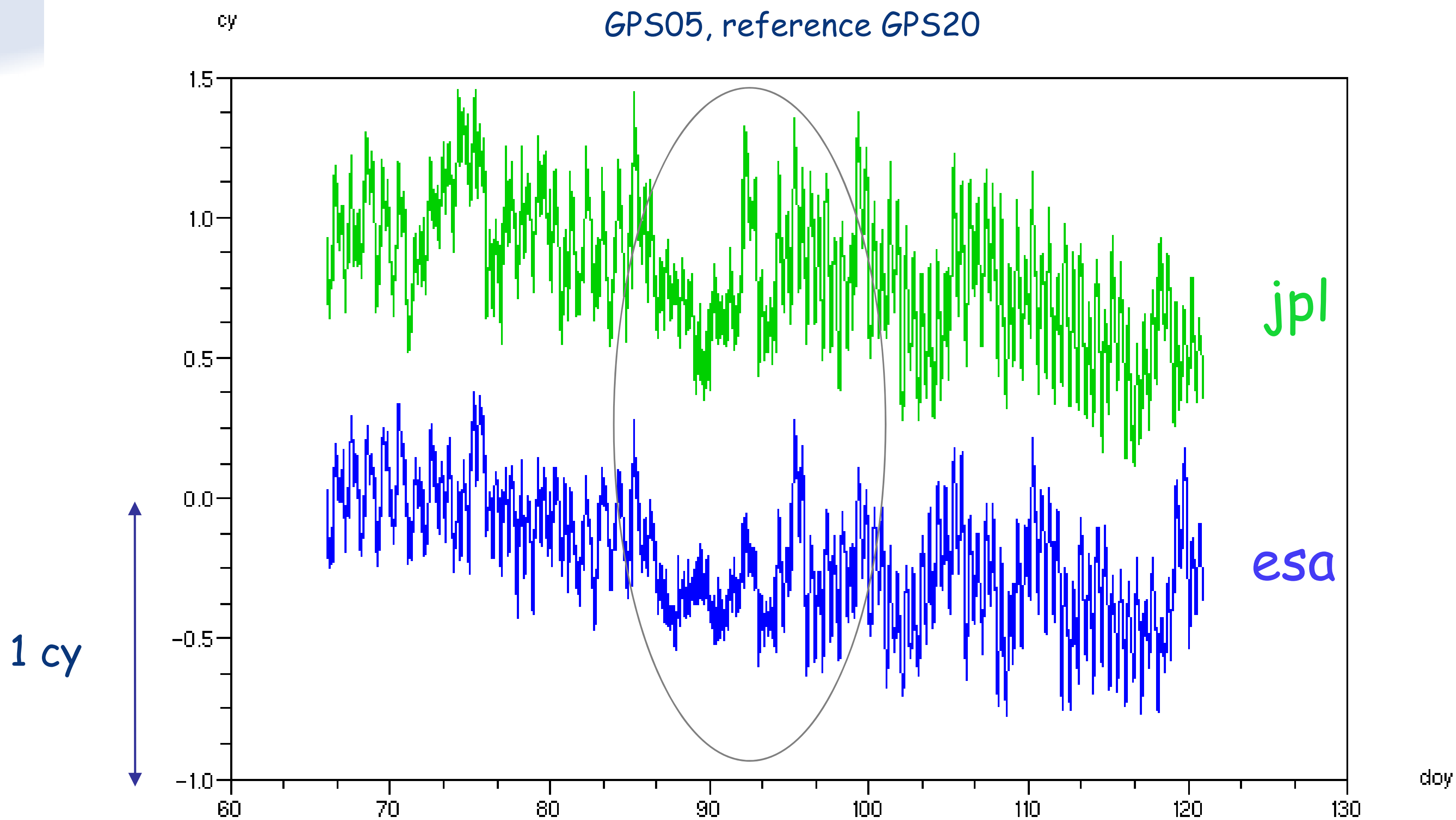
Comparisons esa-grg or jpl-grg, for a complete grg elementary arc (1.5 day, centred, one colour for each GPS)
Clocks variations (900 s sampling) between esa or jpl and the daily grg solution

grg-esa IIR clocks differences

grg-esa, IIR clocks differences after reconstruction

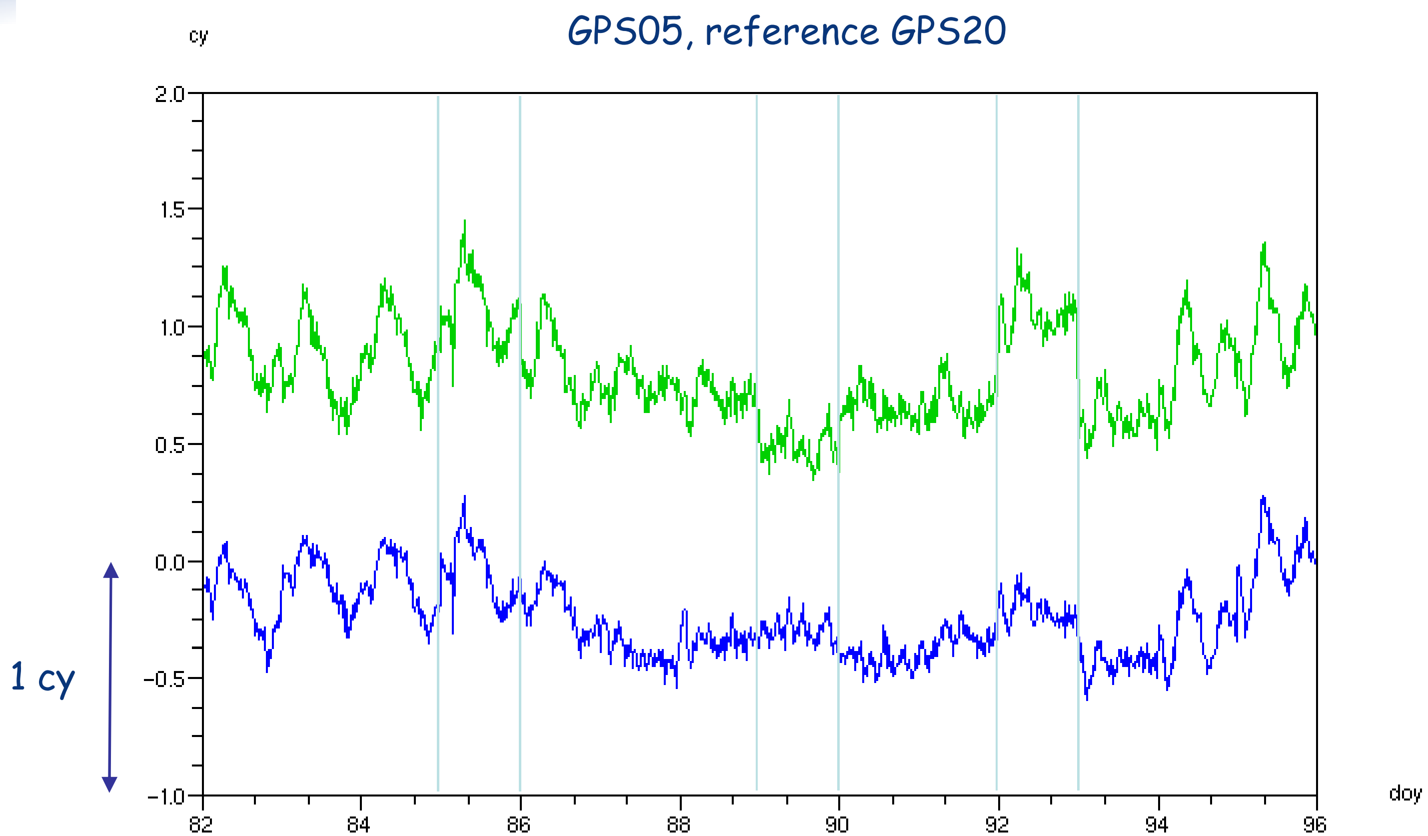


Code-phase bias, esa-grg and jpl-grg



1 cycle offset applied on the jpl result
Long term evolutions are identical (0.5 cy in 3 months)
Oscillations due to the grg solution (to be improved…)
Observation of the local differences at day boundaries →

Code-phase bias, esa-grg and jpl-grg (zoom)



Daily boundaries variations : estimation of the precision of the observed bias, better than 5 cm