Zero difference integer ambiguities, Integer phase clocks

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Introduction

How is zero difference ambiguity fixing possible ?

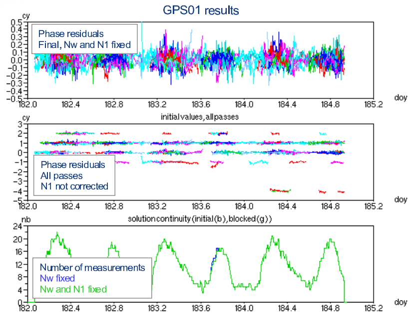
Single difference integer ambiguities between stations have shown very good performances for time transfer applications (continuous solutions on very long durations, no frequency error)
Zero difference ambiguity fixing brings improvement to the overall observability, and to the constellation clock solutions, for time transfer, PPP and LEO orbit determination.

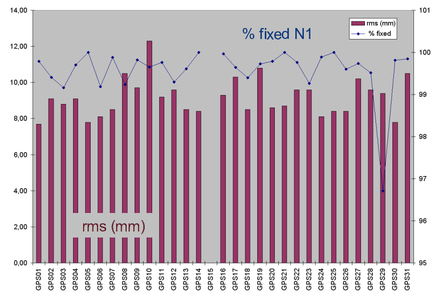
Observation shows that the mean widelane per pass on good receivers is nearly constant for each pair of receiver and satellite. Fluctuations of these parameters are small enough to identify integer widelane ambiguities.

Then with these fixed Nw ambiguities a solution over a global station network provides N1 integer ambiguities and all clocks.
The resulting integer phase clocks are free from frequency bias error, they allow exact reconstruction of overlapping solutions, and they can be used for integer PPP.

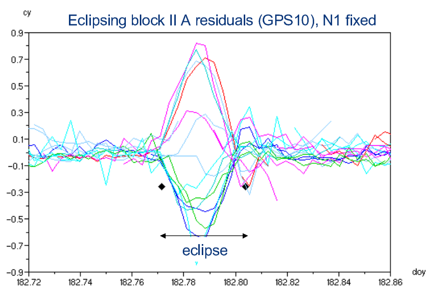
Some results

Complete zero-difference integer clock solution with ambiguity fixing on a 54 stations global network, three days, IGS precise orbits





* : eclipsing GPS IIA
GPS 29 : ephemeris with bad quality index on the third day

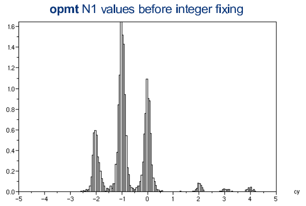


Complete observed rotation 360 ° around radial axis
Relaxation after the end of the eclipse

Integer PPP property

Example : phase ionosphere-free residuals for station **opmt** (not in the reference network) after widelane ambiguity fixing using the identified satellite reference biases, and troposphere correction obtained with floating PPP

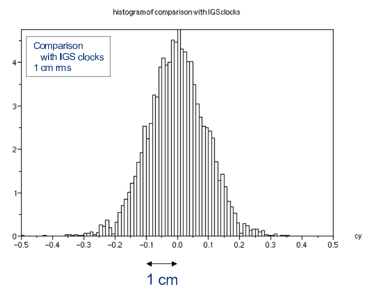
opmt N1 values before integer fixing



Comparison with IGS clocks

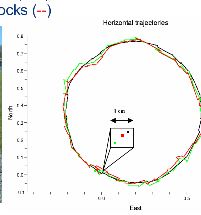
Statistics : excluding eclipsing GPS IIA
alignment with one global bias for each clock

Solution is very close to IGS precise clock solution
but in addition, integer phase clocks allow **integer PPP**



Stochastic positioning

Roving receiver, kinematic solutions
- short baseline L1 or Lc (--,--)
- with integer phase clocks (--)



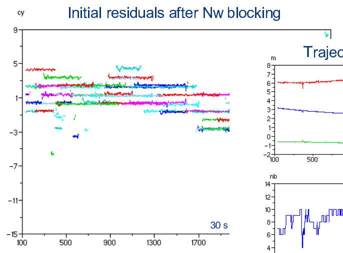
Receivers on a floating glacier, one stable reference station
Single baseline solutions 250 km, one day, 30 s

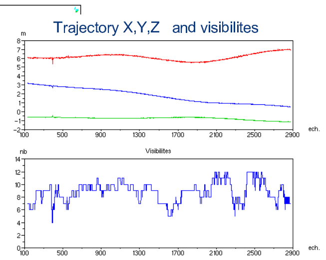
Zero-difference widelane ambiguity blocking
possible because no model is needed (trajectories are unknown)

Floating absolute kinematic solution,
mainly to obtain the troposphere propagation effects

Floating relative kinematic solution, with constrained troposphere

N1 blocking and stochastic position with unambiguous phase measurements





Formulation

Dual frequency semi-codeless receiver, rinex notations, one GPS, one receiver

observables

$$
\begin{array}{ll|lllllll}
\text{pseudo range} & P_1 = & D_1 & +e & +\Delta h_p & +\Delta\tau_p & \\
 & P_2 = & D_2 & +\gamma e & +\Delta h_p & +\gamma\Delta\tau_p & \\
\text{phase} & \lambda_1 L_1 = & D_1+\lambda_1 d_{windup} & -e & +\Delta h & +\Delta\tau & -\lambda_1 N_1 \\
 & \lambda_2 L_2 = & D_2+\lambda_2 d_{windup} & -\gamma e & +\Delta h & +\gamma\Delta\tau & -\lambda_2 N_2
\end{array}
$$

Clocks (ionosphere-free pseudo-range one value per epoch)

tgd

integer ambiguities

Four independent clock like parameters

wavelength

phase centre to phase centre distance including troposphere effects

ionosphere

Clocks (ionosphere-free phase one value per epoch)

4 independent equations

Ionosphere free pseudo-range

$$P_c = D_c + \Delta h_p$$

Widelane

integer ambiguity (per pass)

receiver widelane bias (per epoch)

emitter widelane bias (per epoch)

$$f(L_2 - L_1, P_1, P_2) = -N_w + \mu_j - \mu^i$$

for all measurements on a pass between receiver *j* and emitter *i*

Ionosphere free phase

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 L_2}{\gamma - 1} = D_c + \lambda_c d_{windup} + \Delta h - \lambda_w N_w - \lambda_c N_1$$

Ionosphere estimation

....

with identified integer N_w

integer phase clocks (per epoch)

integer (per pass)

Ionosphere free phase

$$Q_c = D_c + \lambda_c d_{windup} + \Delta h - \lambda_c N_1 \qquad \lambda_c = \frac{\gamma\lambda_1 - \lambda_2}{\gamma - 1} \approx 10.7cm$$

Clock, satellite *i*

Clock, receiver *j*

notation : $\Delta h = h_j - h^i$

Zero-difference widelane solution

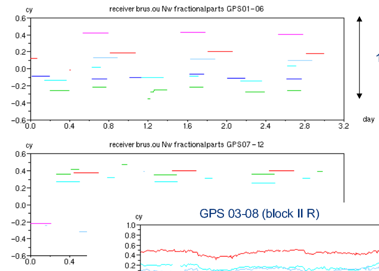
Two steps :

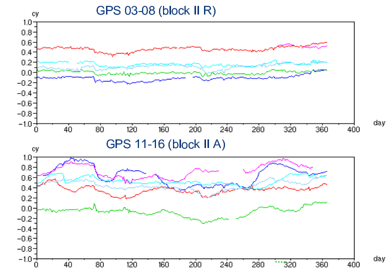
- identification of satellites widelane delays (μ^j fractional part) with a few stable receivers

satellite delays can be assumed constant over few days (variations<0.1 cy)

Example : receiver brus, three days, mean Nw fractional part
$< f(L_2 - L_1, P_1, P_2) >_{pass}$ (mean value over a pass)

In this case, μ_i, μ^j can be taken as constant up to 0.1 cy over three days
First guess for μ^j by taking average values

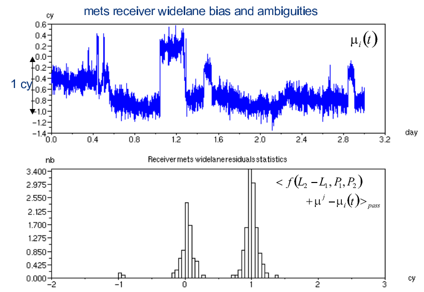




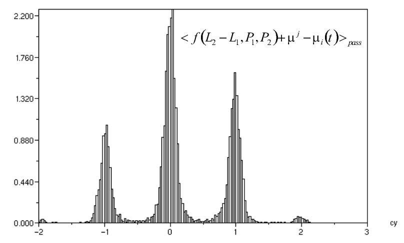
Satellite daily widelane fractional biases (2007)

- independent solution for each receiver by applying the satellite μ^j values

solution, for all passes of each receiver
$$f(L_2 - L_1, P_1, P_2) + \mu^j = -N_w + \mu_i(t)$$



Complete network widelane ambiguities



Example : Application on a 54 stations global network, three days (182-184 year 2007)
Consistent set of integer Nw for all passes
More than 99 % of the measurements are in a pass with fixed widelane

Solution of the ionosphere free phase equation

Construction of the residuals

Reference geometry using floating PPP solution
and precise constellation ephemeris (mainly for troposphere effects)

Ionosphere-free phase equations, with integer widelane corrected :

$$R_c = \Delta h - \lambda_c N_1$$

Simultaneous solution for N_1 and h^i, h_j

Sequential solution using alternatively clock expansion or ambiguity expansion, with a sliding reference epoch :

Clocks defined partially on a pass : estimation of the integer ambiguity by mean over the pass, elimination of passes with too important fractional residuals
$x = -\frac{1}{\lambda_c}\langle R_c - \Delta h \rangle_{pass}$ and $N_1 = round(x)$

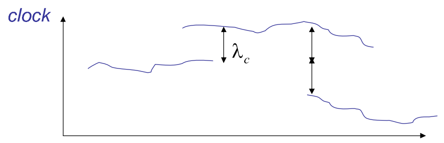
For a receiver without any clock value, initialization procedure (similar for satellite)
Find for all passes corresponding to the current epoch, the integer ambiguities *N1* and the receiver clock values which verify : $R_c - h^i = \lambda_c N_1 + h_j$
(also used for initialization, and integer PPP)

clocks estimation using the passes with fixed ambiguities (similar to a standard pseudo-range clock solution) $(R_c - \lambda_c N_1) = \Delta h$

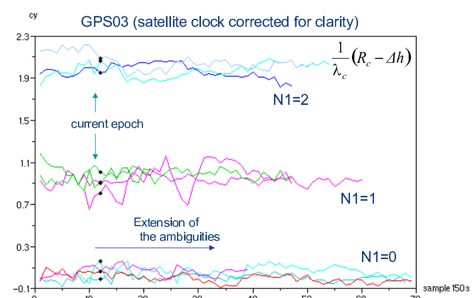
Properties

compatible with double differences methods (by taking the double difference of the ionosphere-free phase equations)
use of satellite integer phase clocks (improve GPS orbits precision, integer PPP)

clocks are defined modulo 1 cy (10.7 cm) for a given set of widelane biases
allows exact reconstruction of overlapping clocks solutions (time transfer applications)



Processing of overlapping solutions
using common widelane biases values
No long term drifts in the clocks, the frequency is perfectly determined



Example : processed passes on a GPS satellite, initialisation step
(stations clocks are defined, estimation of consistent ambiguities and satellite clock)

References

Formulation

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