A review of “integer” PPP applications

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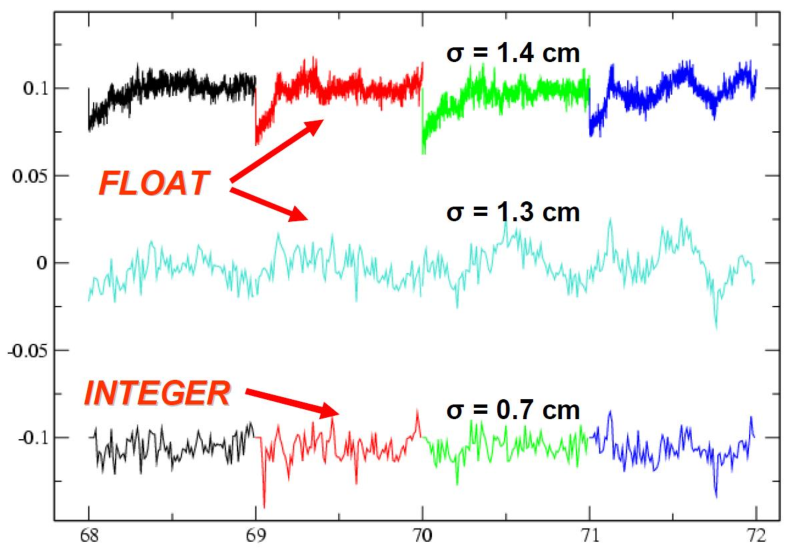
Introduction

The possibility of fixing GNSS phase observations to integer values in PPP mode has been demonstrated by several authors.
This so called Integer-PPP mode (IPPP) has a better accuracy than classical float PPP.
However, additional satellite phase delays products are needed to fix the wide-lane and narrow-lane ambiguities.
GRG IGS final products from the CNES-CLS Analysis Center provide such products (Loyer et al. 2012). www.igsac-cnes.cls.fr/
This poster reviews various examples of IPPP processing at different frequencies from multi-day down to 1 Hz. The GINS CNES/GRGS software and the GRG products were used to get most of these results.



These curves represent the repeatability of the 30 second East solution of a fixed station for 4 consecutive days of 2010 (Perosanz et al. 2010). The upper plot is a PPP classical series. The middle curves are obtained from a single 7 days batch. The midnight discontinuities mostly disappear
The lower curve is derived from IPPP solutions. Both « midnight jumps » and high frequency spurious oscillations mostly disappear when ambiguities are fixed to integer values. The superiority of IPPP fundamentally arises from both a drastic diminution of the correlations between estimated parameters and the capability to guaranty the continuity of the parameters between successive batches (Petit et al. 2015)

Decennial surveying of geodetic benchmarks
S. Loyer et al. 2014

As soon as station coordinates are averaged over daily batches, the improvement brought by ambiguity fixing becomes limited. Nevertheless, IPPP remains an efficient technique for massive processing of huge number of stations and long time span:

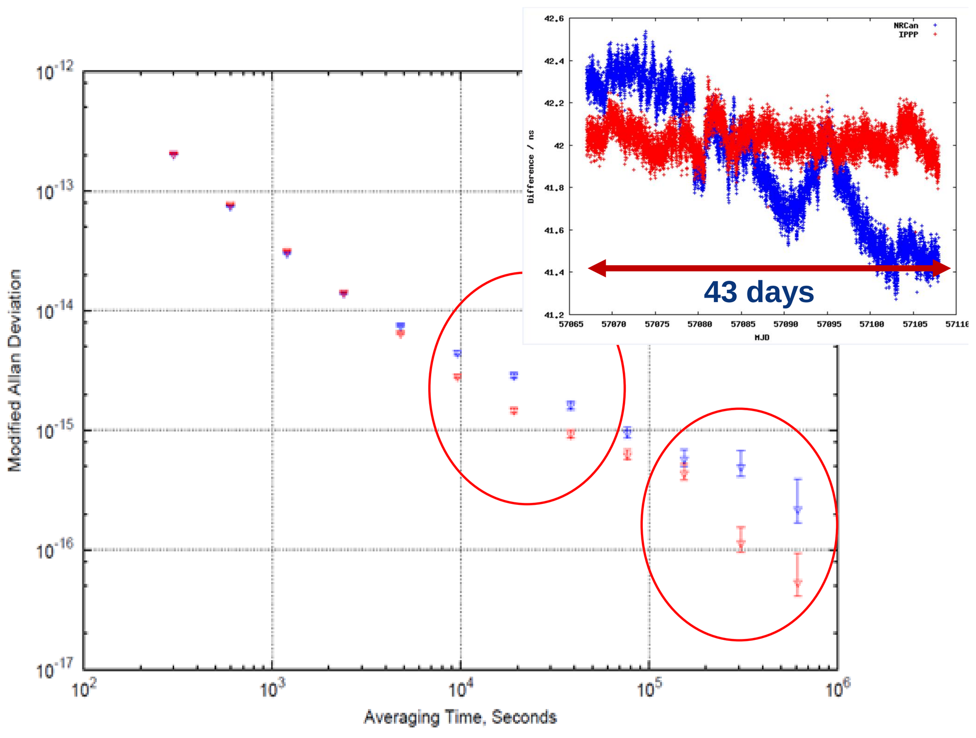
- Small CPU and parallel processing
- Decorrelation of station specific problems

This figure compares Thule (Greenland) station coordinates derived from 10 years of GPS daily IPPP solutions (blues plot) with weekly DORIS solutions (red plot). A sub-centimeter 3D RMS accuracy level is reached by the IPPP technique. Various geophysical signals (tectonic, isostatic, hydrologic loading,…) obviously appear on these series and can be analyzed.

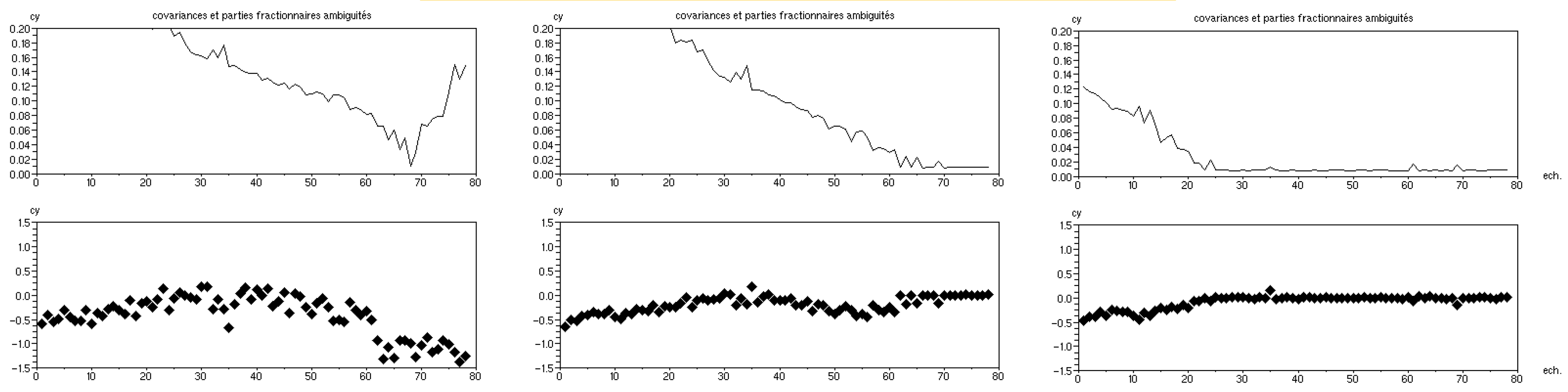
Frequency transfer between atomic clocks over decades
G. Petit et al. 2015

IPPP receiver clock offsets solutions from consecutive batches can easily be “aligned” as they are shifted by integer number of cycles. As soon as no signal interruption occur, accurate and continuous clock solutions become accessible over decades.

These plots compare IPPP (red plot) and PPP (blue plot) performance in terms of frequency transfer. The clock difference between two GNSS stations connected by a fiber link and separated by 420 km is used as reference.
Stability of IPPP is better at few hours and at long term : 5.3x10-17 @ 7.1 days
In addition, IPPP has no significant slope.



LEO Precise Orbit Determination
F. Mercier et al. 2012



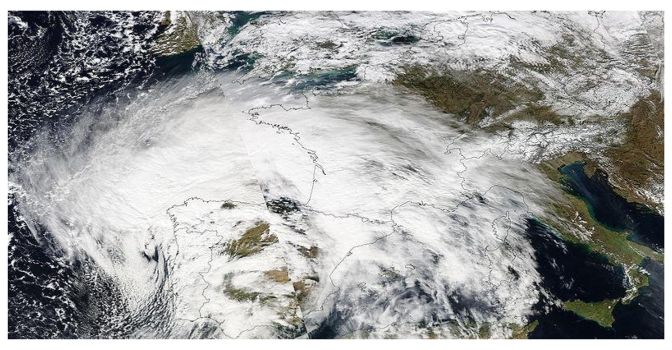
The fixed ambiguities improve the observability of the orbit determination process, which allows to significantly reduce the dynamic constraint of the solutions. The short duration of the passes on LEO satellites makes the use of zero difference ambiguity fixing a very attractive technique to improve the accuracy of POD solutions.

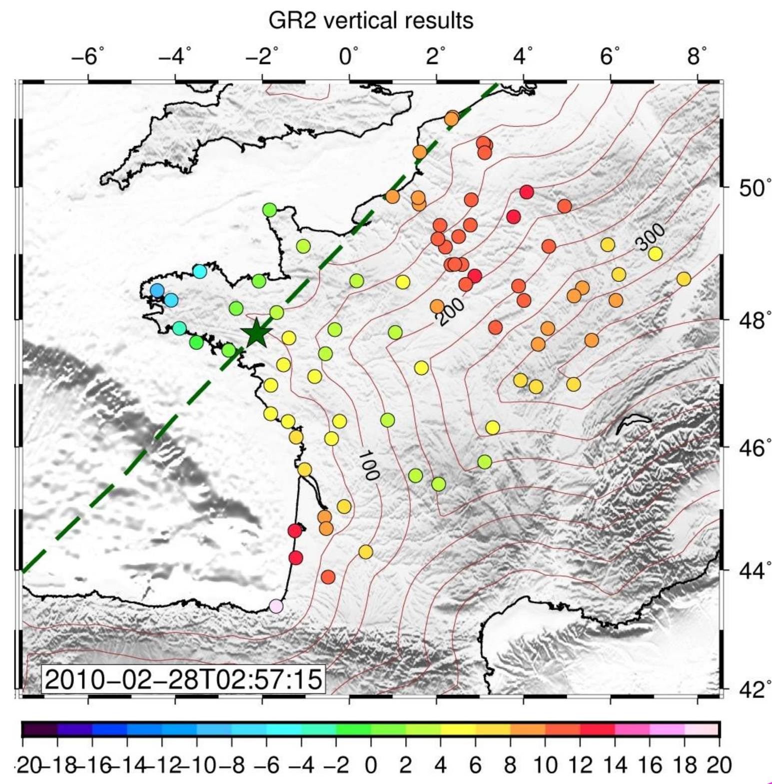
In this example, HY2 satellite GPS ambiguity have been fixed. The figures illustrate 3 steps of the bootstrapping process where respectively, from the left to the right, none, 30 and 77 ambiguities of the same satellite arc (5 hours) were resolved.

sub-diurnal loading deformation - Xynthia extreme storm
J.Nicolas et al. 2015

The more the sampling of the solutions becomes shorter compared to the duration of satellite passes, the more fixing ambiguities impacts and improves the solution.

In this example, 6 hour IPPP solutions of a dense regional network have been computed during the 2010 February 27-28 extreme Xynthia storm. The colors correspond to the vertical displacements due to the cumulative effect of the atmospheric, oceanic and hydrologic loading (scale in mm)

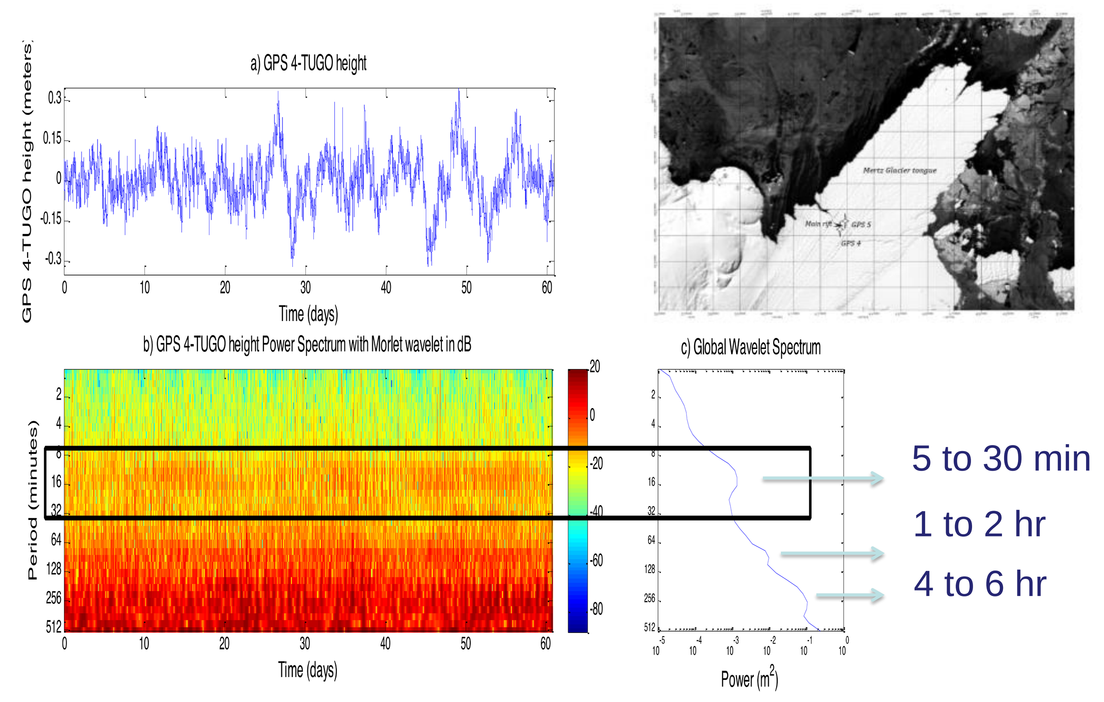




High frequency Antarctic glacier oscillation
L. Lescarmontier et al. 2012

IPPP is a powerful technique to determine hourly and sub-hourly signals especially is areas where no reference station exists.

In this example, a wavelet analysis of GPS IPPP series shown 3 oscillation frequency bands of the Mertz glacier as expected from the theory.

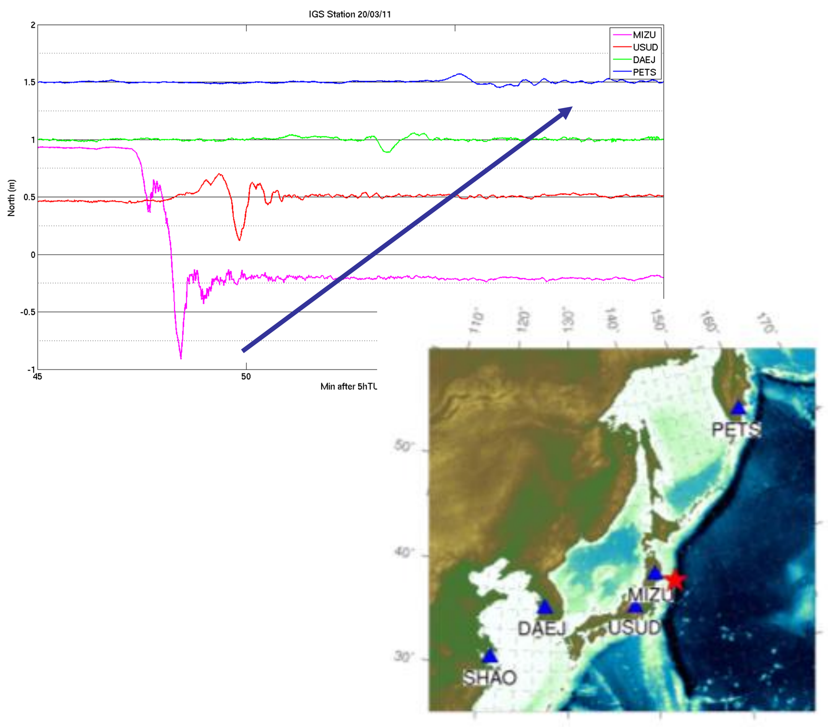


1 Hz co-seismic deformation - Sendaï Earthquake
F. Fund et al. 2012

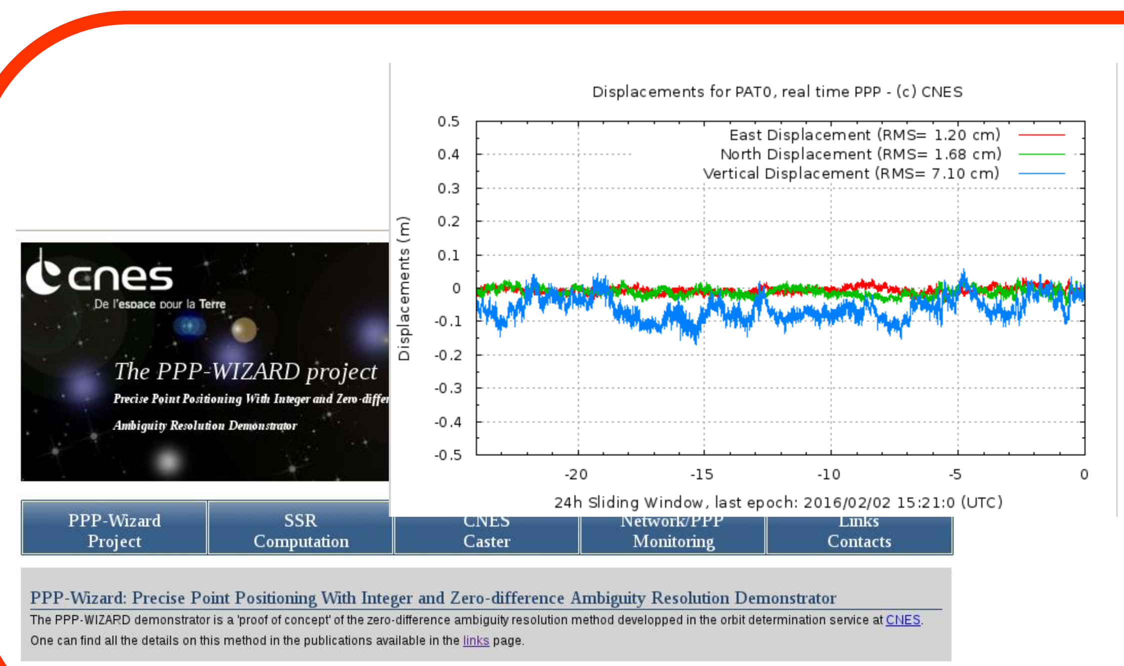
Computing IPPP solutions at a sampling shorter than 30 seconds (= GPS combined clk sampling) needs additional care. Two options are available:

- Interpolating 30s clocks to the desire sampling. In this case, interpolation errors (depending on the satellite clock stability) are directly projected onto the solution
- Using 5s clocks from the CNES-CLS Analysis Center

These plots illustrate the 1 Hz North deformation for 4 stations at various distances from the epicenter during the Sendaï Earthquake in March 11, 2011. The amplitude of the displacement and the arrival time of the seismic wave at the 4 stations behave as expected.



Summary and perspectives



This poster illustrates the interest of the IPPP technique for a variety of applications needing decennial observability down to 1 Hz positioning.
In a close future, IPPP will be available for most of GNSS constellations and will benefit from this hybridization. Hopefully, the IGS will recommend Analysis Centers to adopt a compatible approach to deliver satellite products allowing IPPP for users. Real time IPPP is also on the way as illustrated by the CNES IPPP Wizard demonstrator (D. Laurichesse, www.ppp-wizard.net). This plot, extracted from this web site, shows the IPPP real time coordinate solution of the PAT0 station situated on a active seismic zone in Greece.

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