CENTRE NATIONAL D'ÉTUDES SPATIALES

Real-time PPP with undifferenced integer ambiguity resolution, experimental results

D. Laurichesse, F. Mercier
CNES Orbitography

Undifferenced ambiguity resolution background

- **Identification of differential satellites biases**
  - Gabor & Nerem (1999), Ge & Al (2007)
- **CNES Method (ION GNSS 2007, ENC-GNSS 2008, ION ITM 2008/2009, Navigation 2009)**
  - Satellites biases are absorbed in the clocks
  - Applications to PPP, LEO POD, Real Time 'integer' PPP, CNES/CLS IGS analysis center (GRG)
- **Collins (NrCan, ION ITM 2008) proposes a similar approach**
  - The 'decoupled clock model', generalization of the CNES method
- **Geng method (University of Nottingham, ION GNSS 2008)**
  - Identification of UHD (undifferenced hardware delays)
- **Similar concepts (Mervart, Rocken, GPS Solutions, ION GNSS 2008)**
  - Single difference hardware delays and measurements
- **Blewitt (AGU 2009, NBMG & JPL)**
  - 'carrier range' concept, biases are estimated after a double differenced network solution

CNES method overview

■ **Wide-Lane (ionosphere-free, geometry-free combination, 70 cm wavelength)**

$$\boxed{f\left(L_2 - L_1, P_1, P_2\right)} = -N_w + \Delta h_w$$

phase

pseudo-range

integer widelane

receiver - emitter 'Integer' widelane clocks

■ **Narrow-Lane, ionosphere-free combinations**

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

$$P_c = D_c + \Delta h_p$$

$$Q_c = \underbrace{D_c + \lambda_c W}_{\text{propagation model}} + \Delta h_c - \lambda_c N_1$$

receiver - emitter pseudo-range clocks

integer ambiguity

10.7 cm

propagation model

receiver - emitter 'Integer' phase clocks

Single frequency ionosphere free system with a wavelength of 10.7 cm

Resulting phase clocks have "integer nature"
zero-difference ambiguity resolution at receiver level becomes possible
=> ambiguity fixed PPP for isolated receivers

Benefits of separate phase and pseudo-range clocks

- **SP3 clocks: combine pseudo-range and phase observations**
  - **Pseudo-range clocks smoothed by phase = phase clocks aligned on pseudo-range**

$$\bar{h}_P, \mathrm{cov}\left(\bar{h}_P\right) \approx 5cm$$

- **Integer ambiguity model : separate phase and pseudo-range clocks**

$$h_c, h_p - h_c \qquad \begin{array}{ll} \mathrm{cov}\left(h_c\right) & \approx 1\,\mathrm{cm}, \\ \mathrm{cov}\left(h_p - h_c\right) & \approx 5\,\mathrm{cm} \end{array}$$

- **Reconstruction of SP3 clocks from separate clocks is possible (backward compatibility)**
  - **The error on the reconstructed clock is not better than the SP3 one**

$$\bar{h}_p = h_c + \left(h_p - h_c\right)$$

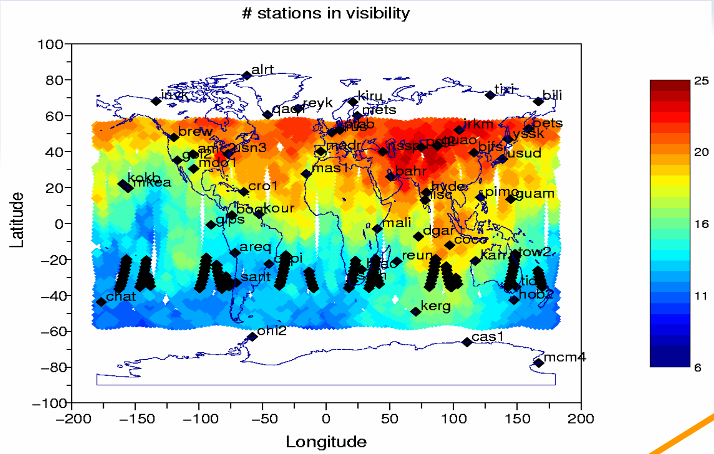
We use the phase clock as the reference

- more accurate (pseudo-range measurements are not involved in their computation)

- phase models are better known

- ‘integer’ property

Application to real-time integer-PPP
Test in replay mode



PPP-like compact representation

h_w clock

GPS orbits

h_p, h_c clocks

Receiver

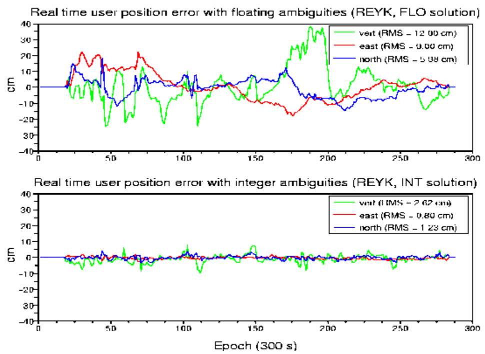
Raw measurements

widelane fixing (sliding window)

Raw measurements (Nw fixed)

Kalman filter
N_1 fixing and position estimation

Precise trajectory



Network raw data flow

widelane fixing (sliding window)

Raw measurements (Nw fixed)

Kalman filter
(mixed float/integer for N_1 fixing)
clocks/orbits corrections computation

- ambiguity fixing strategy based on network connectivity
- 1200 parameters for a network of 60 stations and 32 satellites
- 1000 measurements per epoch

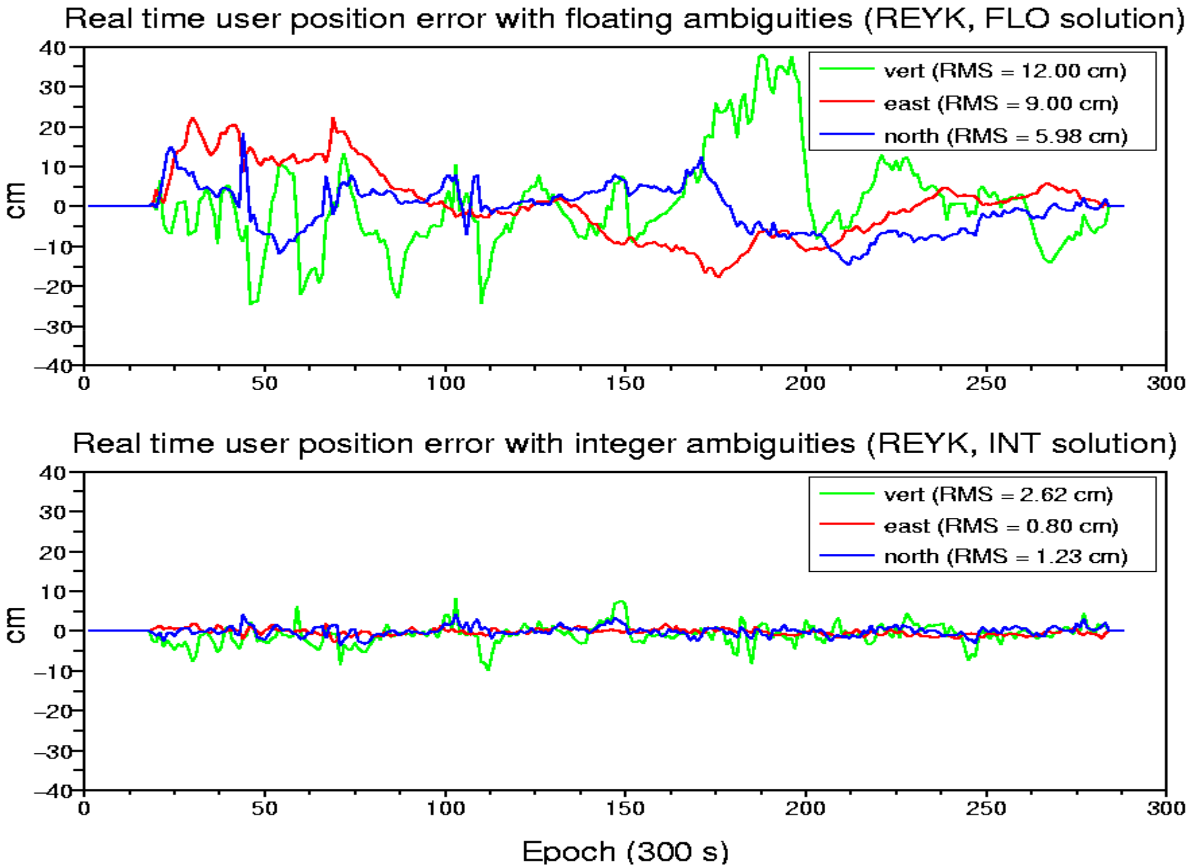
Network side (orbit and clock estimation)

User side (PPP trajectory)

Impact of fixed ambiguities (Kinematic positioning, replay mode) ION ITM 2009

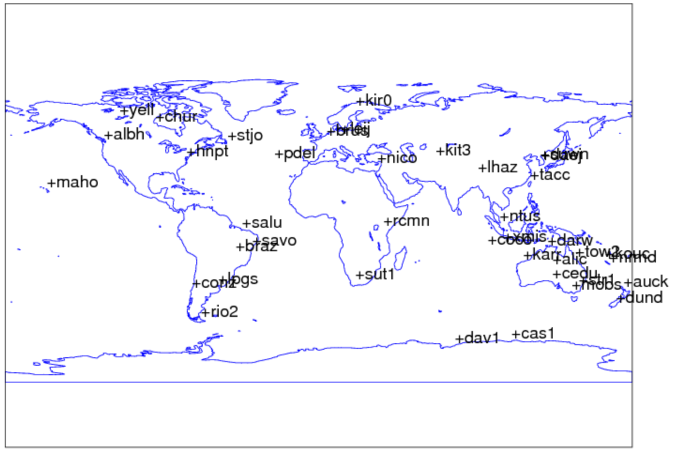
standard PPP with floating ambiguities ~10 cm RMS

PPP with integer fixed orbits and clocks ~2 cm RMS

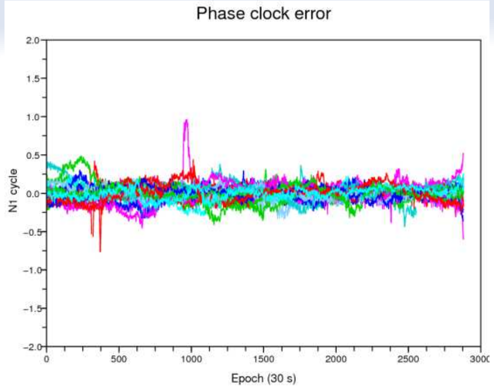


Real-time experiment architecture (network side)

cnes



Network



Analysis

IGS

FTP

NTRIP CASTERS

WEB SERVER

Dissemination
(2-3 sec latency)

BNC

X, Y, Z, Hc, Hw, Hp-Hc

C1, C2, P1, P2, L1, L2

Real-time
(2-3 sec latency)

Daily

WideLane Clock Computation

Hw

GNSS engine
(Kalman filter)

Overall latency
6-8 sec

Real-time continuous orbit construction

X, Y, Z, H

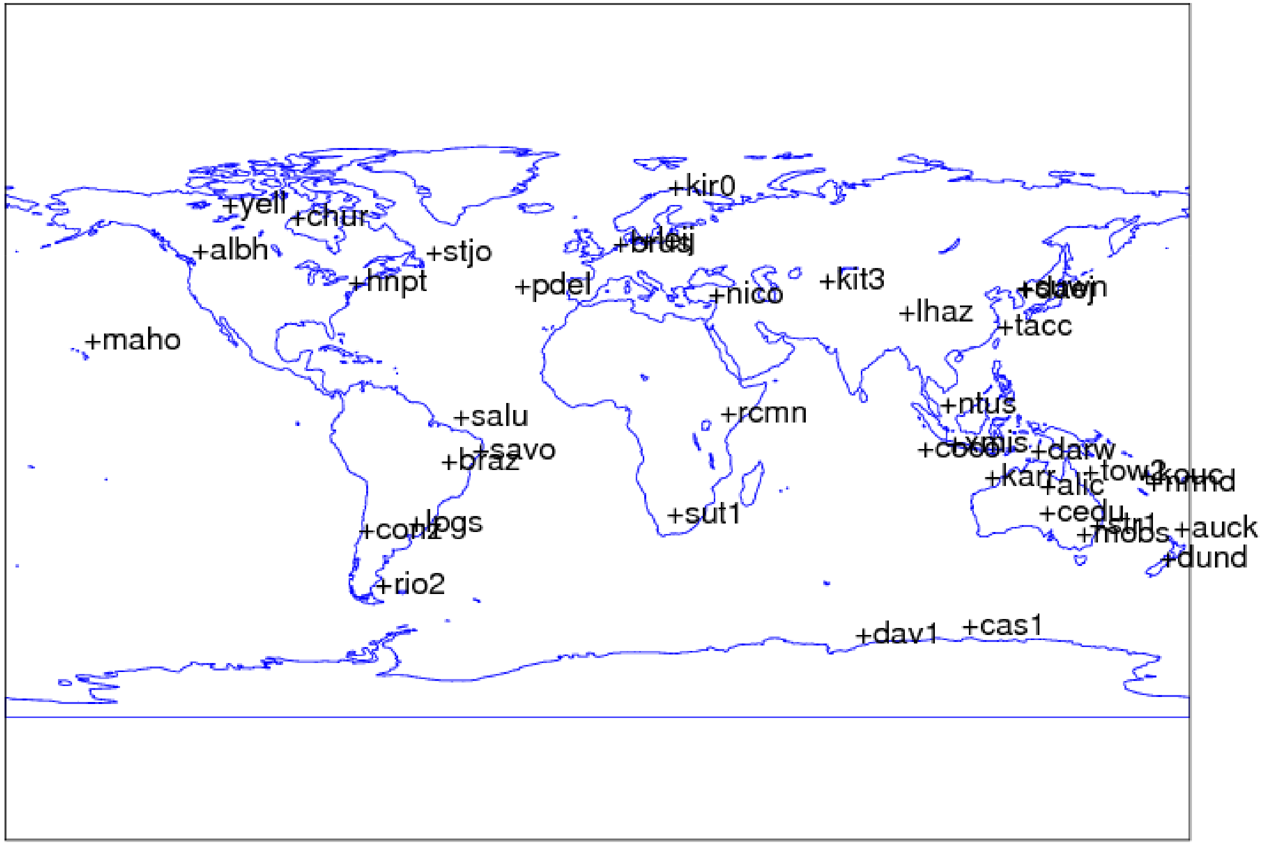
6 hours

Computation: 2 sec

stations/
satellites
configuration

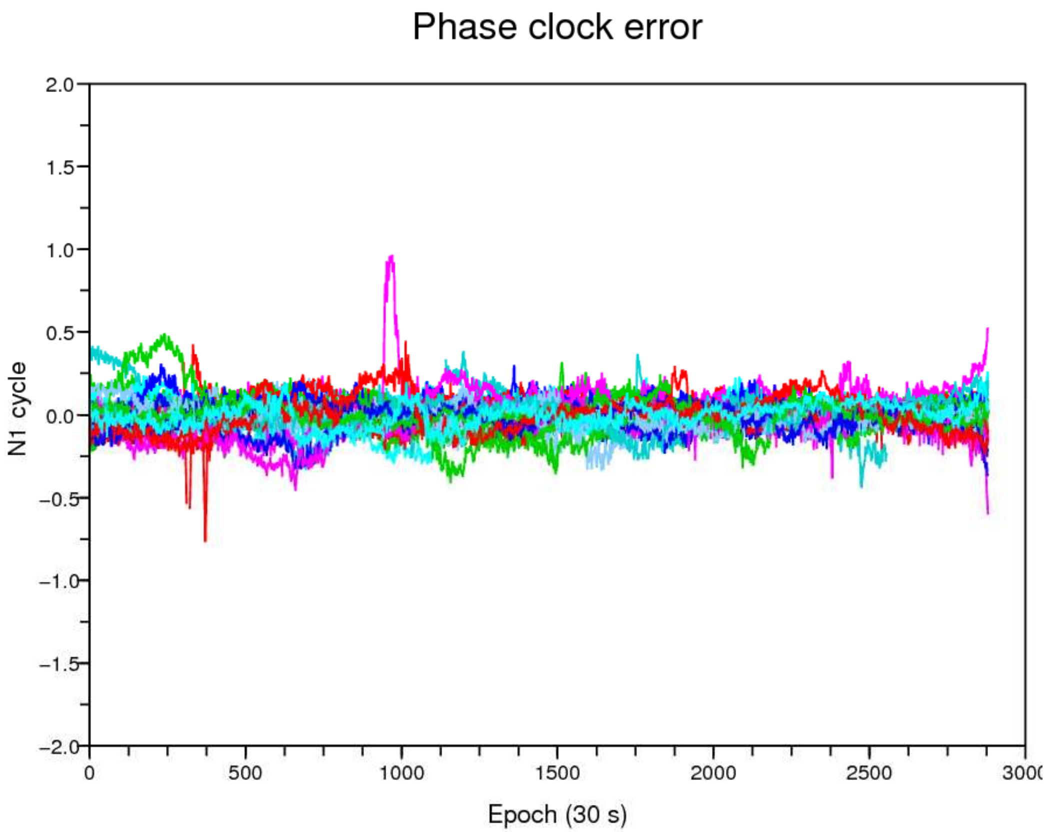
Real-time network of stations

- NTRIP (use of GFZ caster, Courtesy Georg Weber)
- 40 stations
- 1 day of measurements



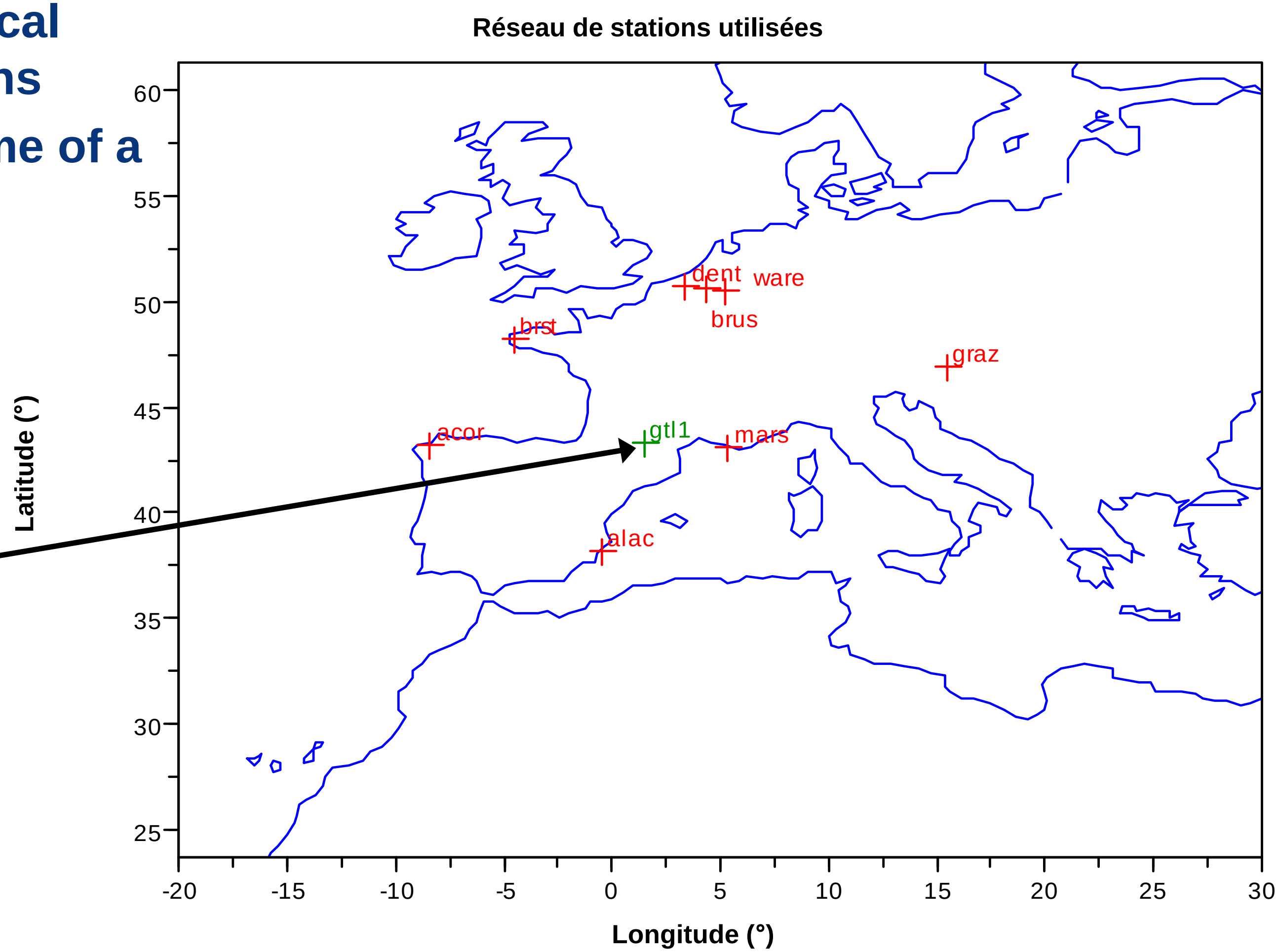
Real-time phase clock solution accuracy

- **Pure phase clocks**
  - h_c
- **Comparison with IGS finals:**
  - **One common offset removed per epoch**
  - **One constant offset removed per continuous clock segment (user-side phase ambiguity estimation)**
  - **Corrected from radial orbits differences**
- **Errors ~ 1 cm (0.03 ns)**
  - **Much better than SP3-like clocks**
  - **Clocks have integer property**
- **Availability 95 %**
- **Global orbits/clocks computation is feasible with current Real Time IGS measurements streams**



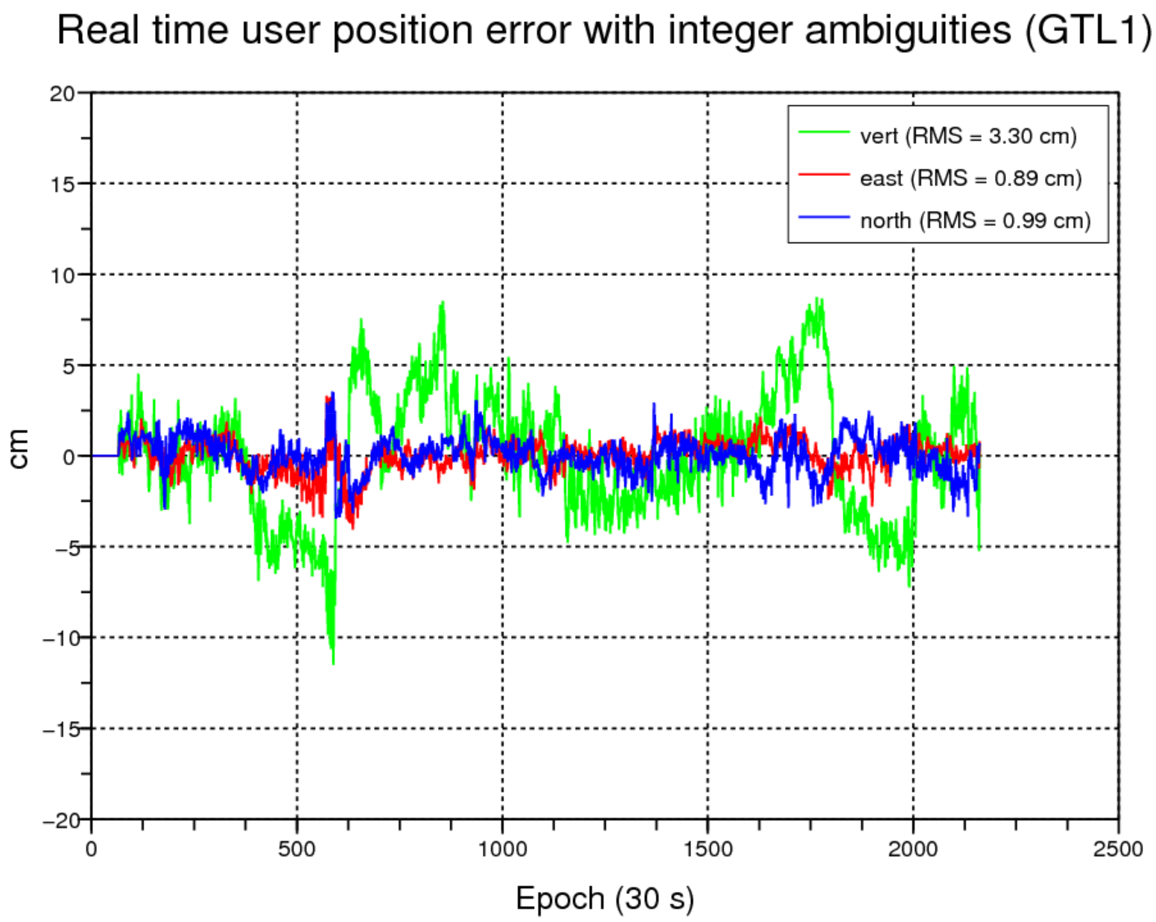
Real-time PPP with local network demonstrator

- System operational since December 2009
- Processes data from a local network of 8 Euref stations
- Adjust position in real-time of a fixed user station GTL1 (Septentrio GeneRx)



GTL1 positioning error

- **Comparisons to a reference position**
- **1 cm RMS horizontal accuracy**
- **3 cm RMS vertical accuracy**



Advantages and drawbacks of the method

	PPP 2-frequencies	RTK 1 or 2 frequencies	CNES Integer PPP 2-frequencies
Geometry	Global	Local (< 50 km)	Global
Convergence time (TTFF)	Convergence : < 30 cm Kick start: 1 mn static: 15 mn dynamic: 30 mn	Convergence : ~ 1 cm 1-5 mn	Convergence : ~ 1 cm Kick start: 1 mn static: 30 mn dynamic: 90 mn
Horizontal precision	10-50 cm	~ 1 cm	~ 1 cm

- The method is operationally equivalent to PPP but with the precision of RTK (1 cm vs. 10 cm)
- Potential application to earthquake monitoring, oil rigs positioning, RTK base station positioning …

Conclusion and future work

- Worldwide orbits and clocks has been computed in real-time using the current RTIGS network and NTRIP tools, results are promising

- A demonstrator has been working since December 2009 in ‘limited’ mode
  - Server side: works on a regional network (European-wide)
  - User side: static receiver (but processed in Kinematic mode)
  - Centimeter accuracy positioning precision

- Perspectives for 2010
  - Extension to the global network
  - Proposal to contribute to the RTIGS project
    - As a real-time provider of measurements from CNES stations
    - As a real-time analysis center
  - Improvements of the user-side algorithms
    - Full Kinematic mode processing
    - Robustness enhancements (for moving receivers in constrained environments for example)