Precise Point Positioning: Recent Developments at UNB

Richard B. Langley

on behalf of the
GNSS Research Group
Department of Geodesy and Geomatics Engineering
University of New Brunswick, Fredericton, Canada

13 July 2010
Technische Universität München

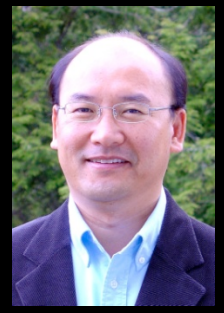
GNSS Research Group

Faculty members:

Dr. Richard Langley

Dr. Peter Dare

Dr. Marcelo Santos



Dr. Don Kim

Students:

Liliana Sukeova
Yong-Won Ahn
Hui Tang
Wei Zhang
Alexandre Garcia
Gozde Akay

Hyunho Rho
Luis Serrano
Simon Banville
Landon Urquhart
Wei Cao
Chaochao Wang

What's Our Research All About?

Research topics of the group aim to a better understanding of the transmitted signals as well as all effects which should be considered in GNSS (Global Navigation Satellite Systems) measurements. The general ultimate goal of our research is the development of tools and methods to improve positioning and navigation with GPS as well the Russian GLONASS system and the future European Galileo system. We work with topics such as:

Development of algorithms for GNSS positioning and navigation applications

Development of models to reduce the effect of the atmosphere on GNSS signals

Using GNSS as a sensor of the atmosphere

Testing GNSS performance in challenging environments

Quality control and analysis of current and new GNSS signals and their augmentations

Presentation Outline

- Beginning of PPP Research at UNB
- GAPS
  - Atmospheric modelling
- The Precise Point Positioning Software Centre
- Some PPP Applications at UNB
  - Earthquake motion
  - Phase wind-up
  - Geometry-free vs. geometric TEC determination (the Cycle Slip Problem)
  - GPS + GIOVE PPP
  - GPS + GLONASS PPP

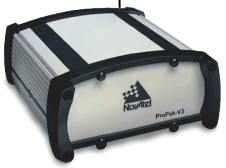
Some UNB 24/7 Receivers

Javad
RegAnt

UNBJ
Javad
Legacy

UNB3
Trimble
NetR5

UNBT
Topcon
NET-G3



UNBN
NovAtel
ProPak-V3

GAPS History

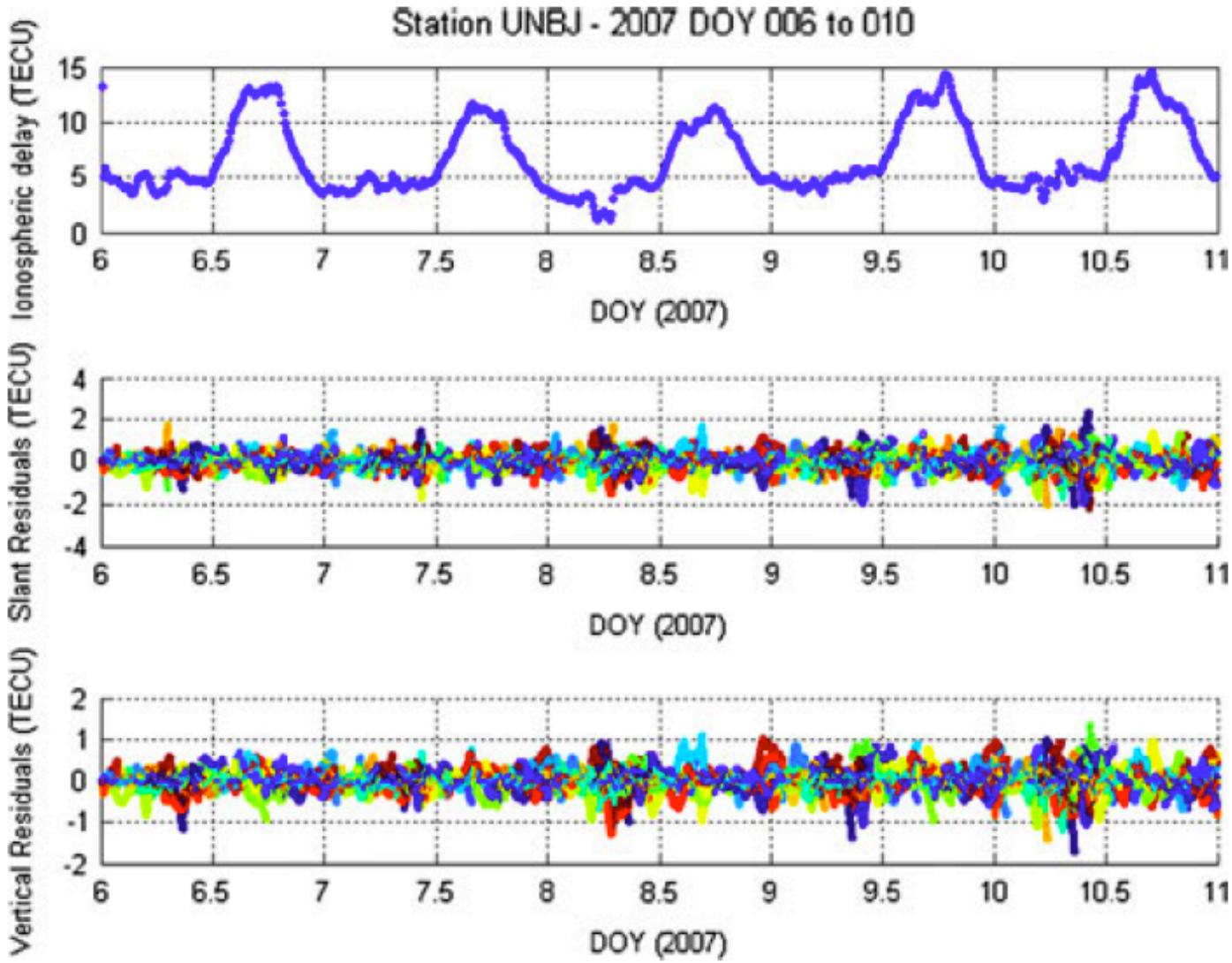
- Work on the *GPS Analysis and Positioning Software* (GAPS) began in 2006
- Initially developed by Rodrigo Leandro and Marcelo Santos
- Developed not just for positioning but also signal analysis and quality control
- Other PPP engines have been developed at UNB by various students; collaborative effort

GAPS Novel Features

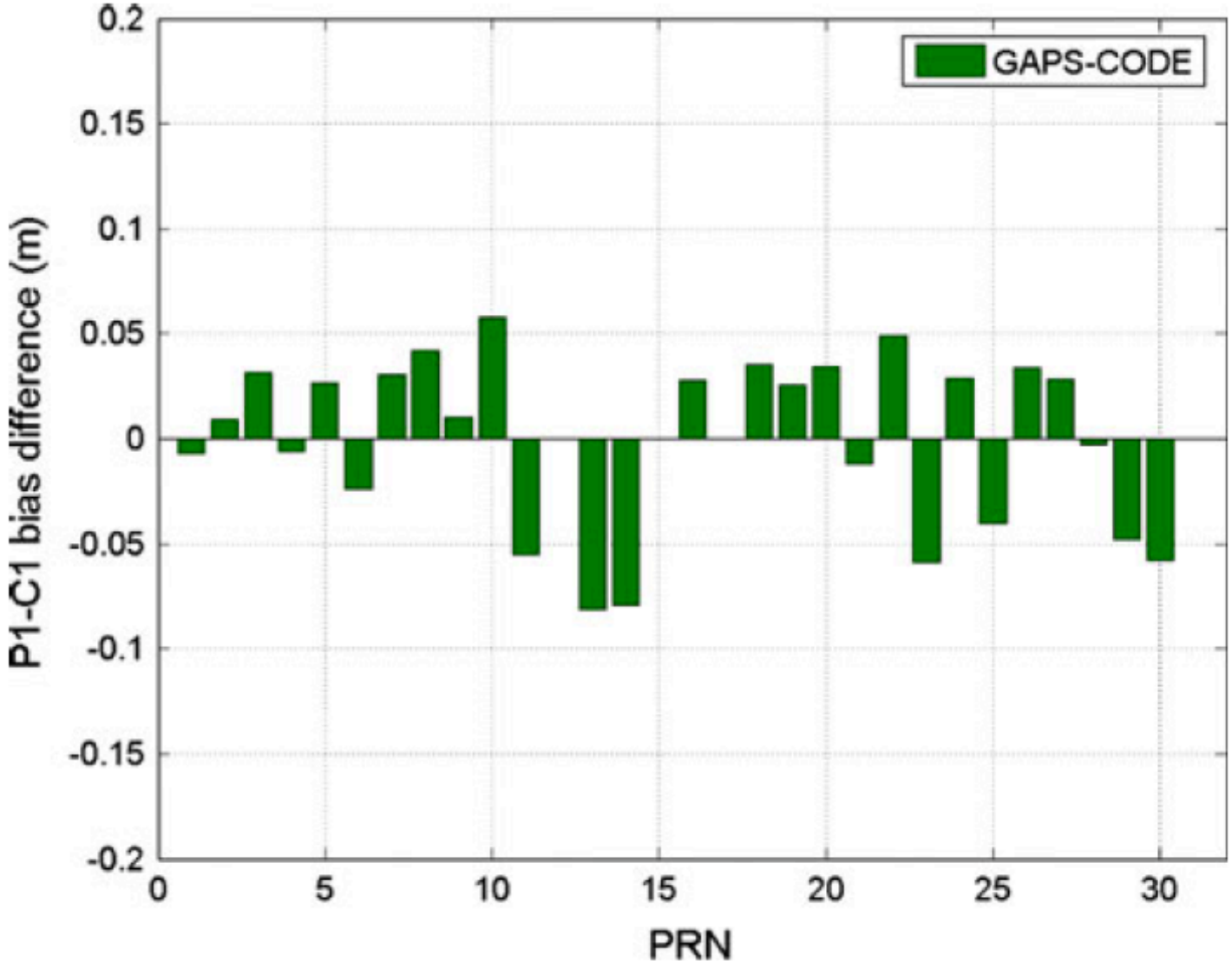
- Estimates ionospheric delay
  - Uses shell model; uses carrier-phase measurements
- Estimates code biases
  - Based on a positioning observation model rather than satellite clock estimation model
- Estimates satellite clock errors
  - So-called pseudo-clock since other effects are present
- Estimates code multipath
  - Carrier-phase not directly used, unlike procedure in TEQC

(For details, see Leandro et al., "Analyzing GNSS Data in Precise Point Positioning Software" now on line at the GPS Solutions website.)

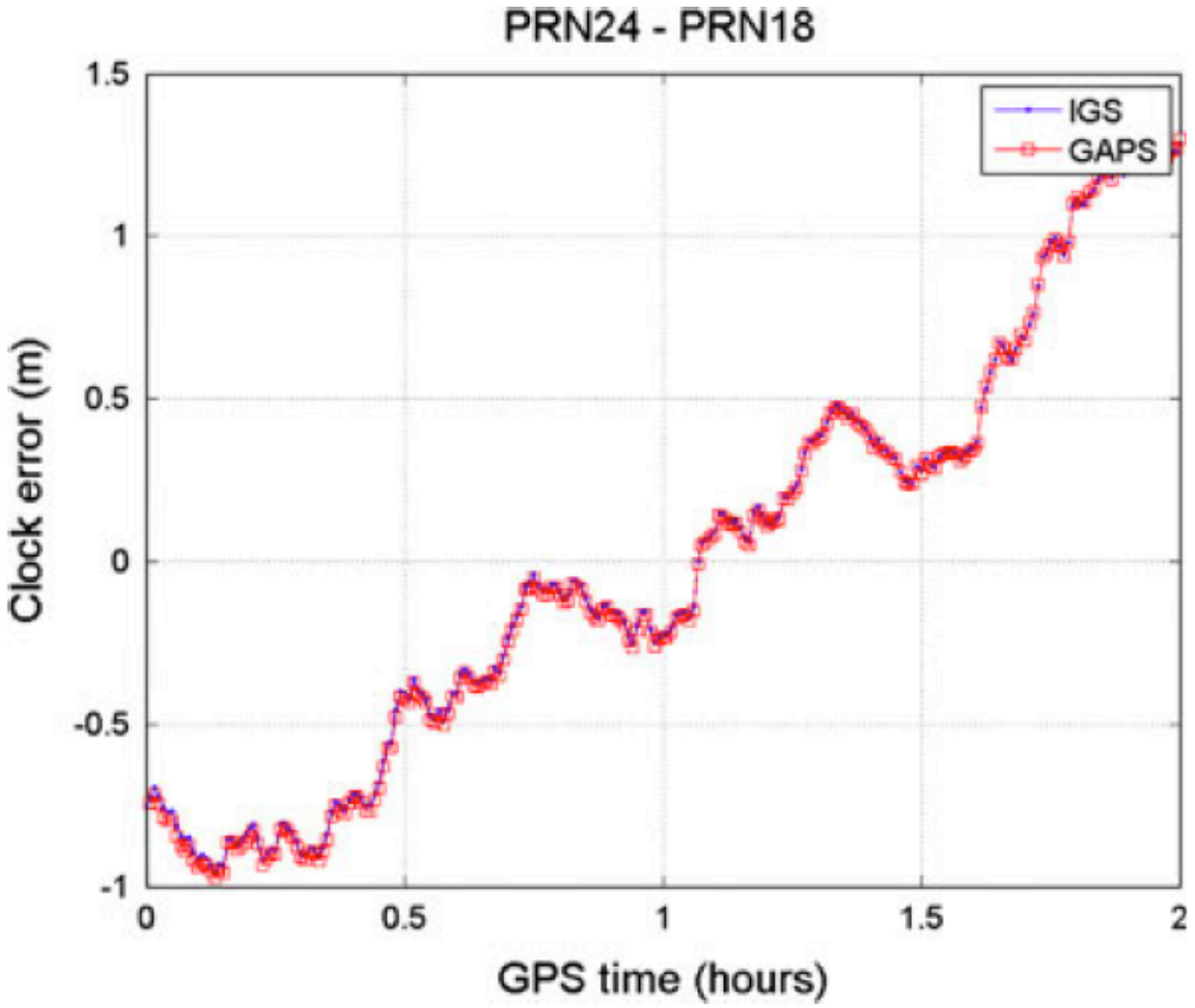
Ionospheric Delays Estimated by GAPS



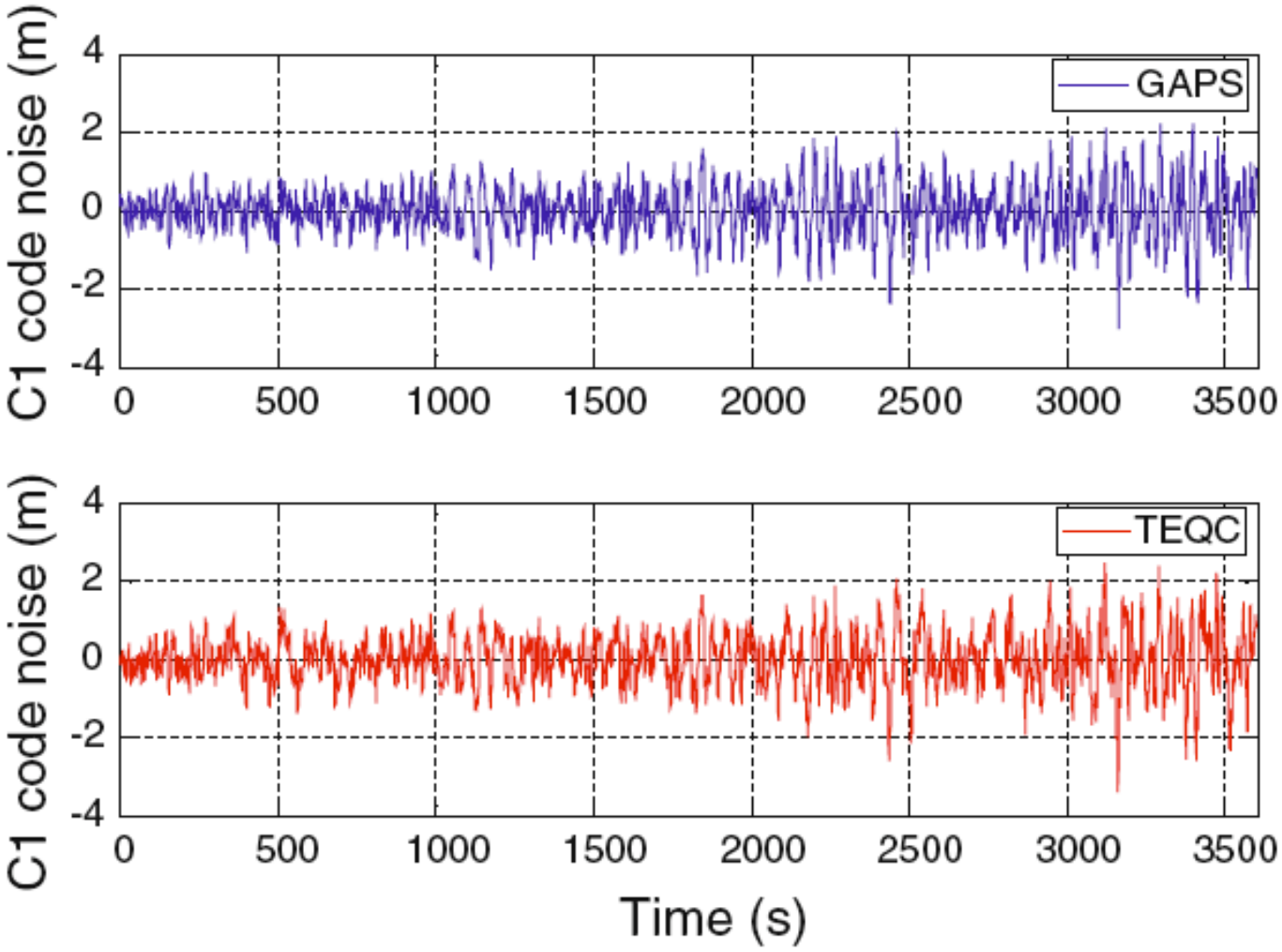
Code Biases Estimated by GAPS



Pseudo-clocks Estimated by GAPS



Code Multipath Estimated by GAPS

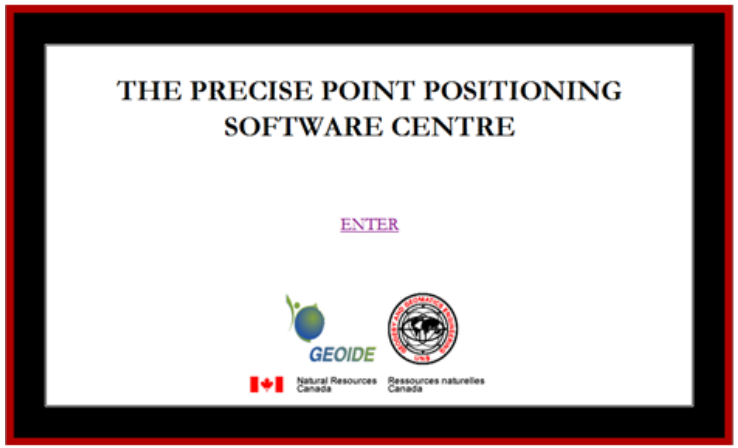


(PRN06 observed at ALGO on 8 January 2007)

Atmospheric Modelling at UNB

- Although a separate initiative, relevant to PPP
- GAPS uses UNB3m as the *a priori* model, then estimates a residual zenith delay as a random-walk process with process noise of 5 mm/h$^{0.5}$
- UNB3m is an improvement on UNB3, the basis of the WAAS MOPS model, present in most GPS receivers
- UNBw.na is an improved climatic ("blind") model for North America

Precise Point Positioning Software Centre



PRECISE POINT POSITIONING SOFTWARE CENTRE

THE PRECISE POINT POSITIONING SOFTWARE CENTRE:
http://gge.unb.ce/Resources/PPP/

RINEX OBSERVATION FILE PROCESSED: algo1500.08o.Z

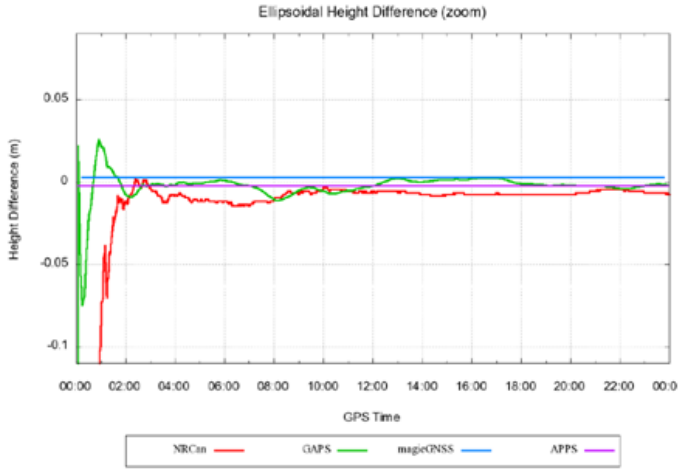
REPORT CREATED ON: Tue Feb 09 12:38:05 2010 (UTC Time)

PROCESSING MODE: Static

PPP RESULTS ARE PROVIDED BY:
CSRS-PPP: http://www.geod.nrcan.gc.ca/online_data_e.php
GAPS: http://gaps.gge.unb.ca
APPS: http://apps.gdgps.net/
magicGNSS: http://magicgnss.gmv.com/ppp

ERROR MESSAGES: none

COMMENTS:
- Refer to http://gge.unb.ca/Resources/PPP/OnlinePPPs.html for more details regarding the processing characteristics of each software.
- For acknowledging the PPP Software Centre, please use the following reference:
Banville, S., R.B. Langley and M.C. Santos (2009). "The Precise Point Positioning Software Centre: An Insight Into Online PPP Services", Poster presented at the IAG 2009 Meeting, Buenos Aires, Argentina, August 31.



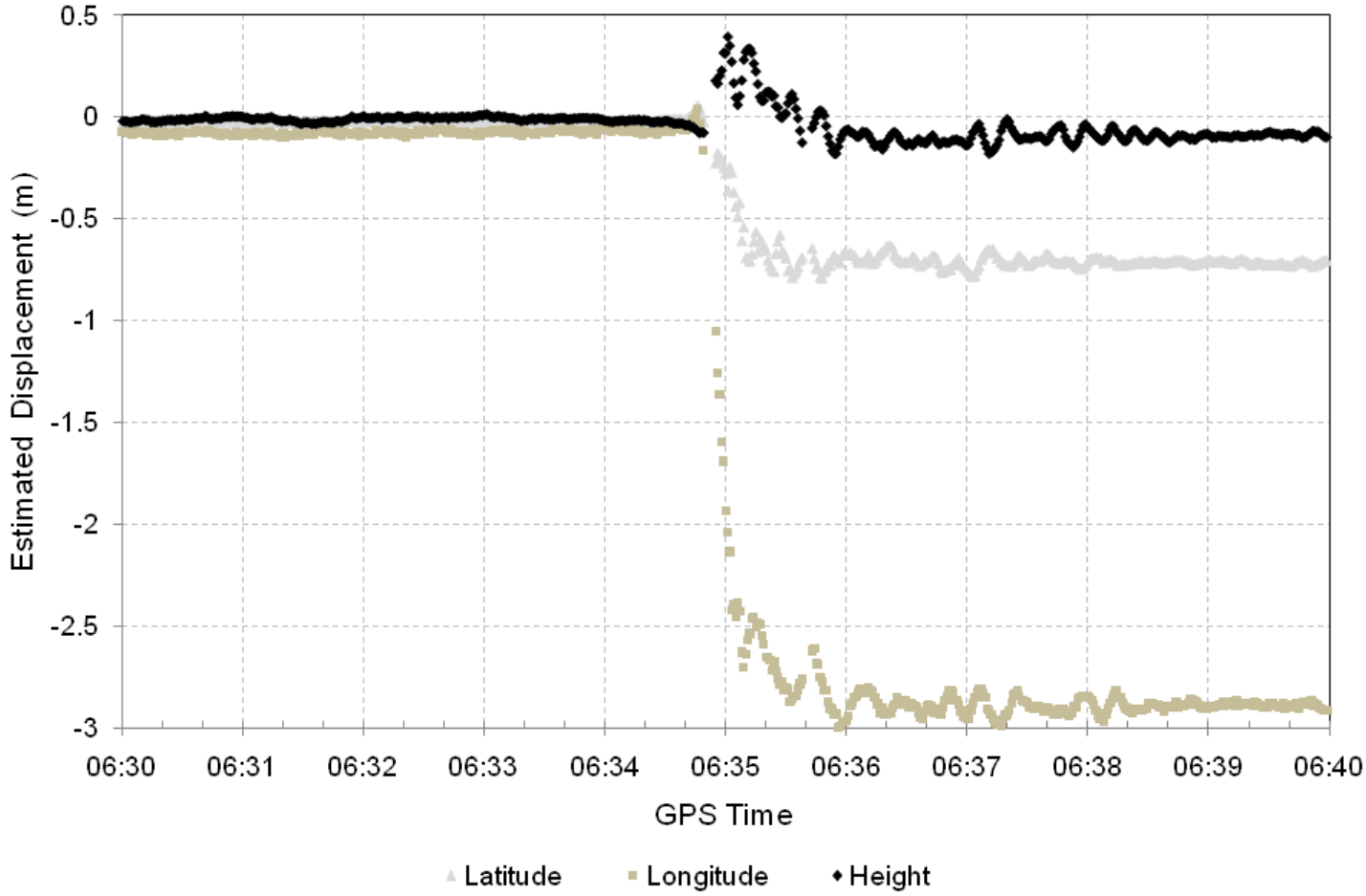
Software Characteristics

	NRCan	GAPS	APPS	magicGNSS
Static Processing	All epochs / Forward only	5-min epochs / Forward only	5-min epochs / Smoothed	5-min epochs / Batch solution
Kinematic Processing	All epochs / Smoothed	All epochs / Forward only	5-min epochs / Smoothed	N/A

Precise Point Positioning Software Centre

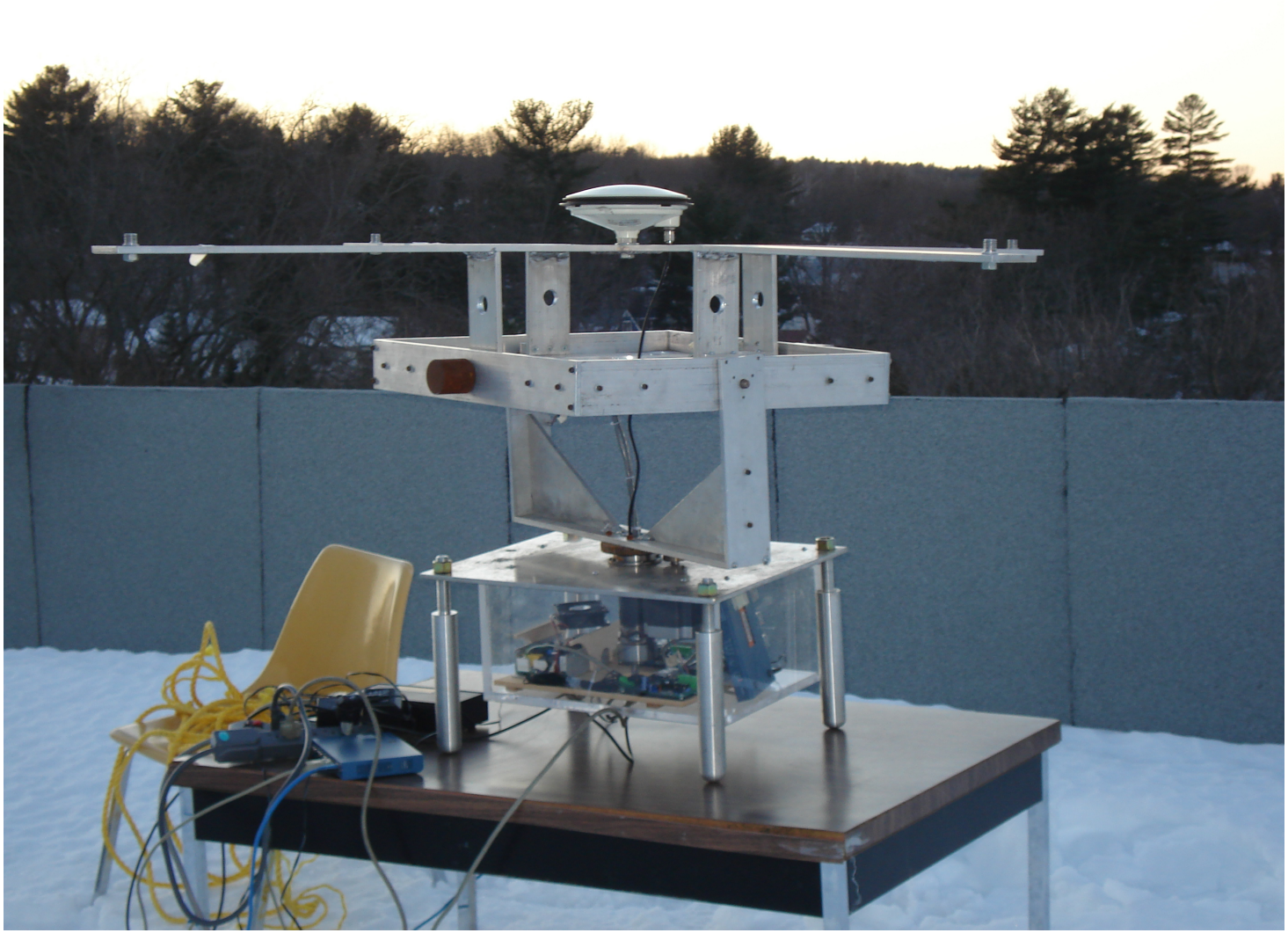
- Website: http://gge.unb.ca/Resources/PPP
- Submit RINEX file by e-mail to ppp@unb.ca

Estimate of Earthquake Displacement

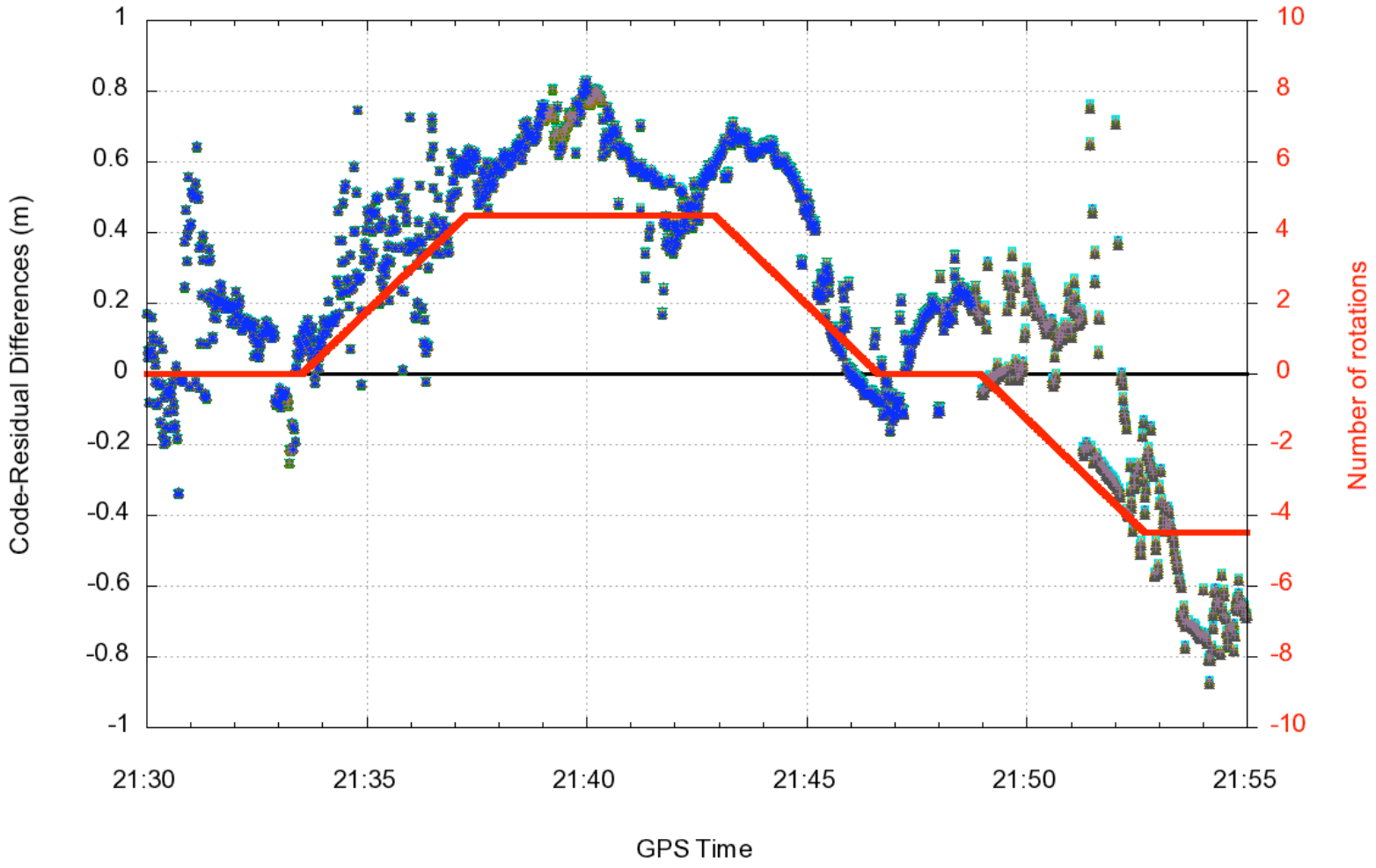


(Estimate of CONZ co-seismic motion following Chilean earthquake of 27 February 2010)

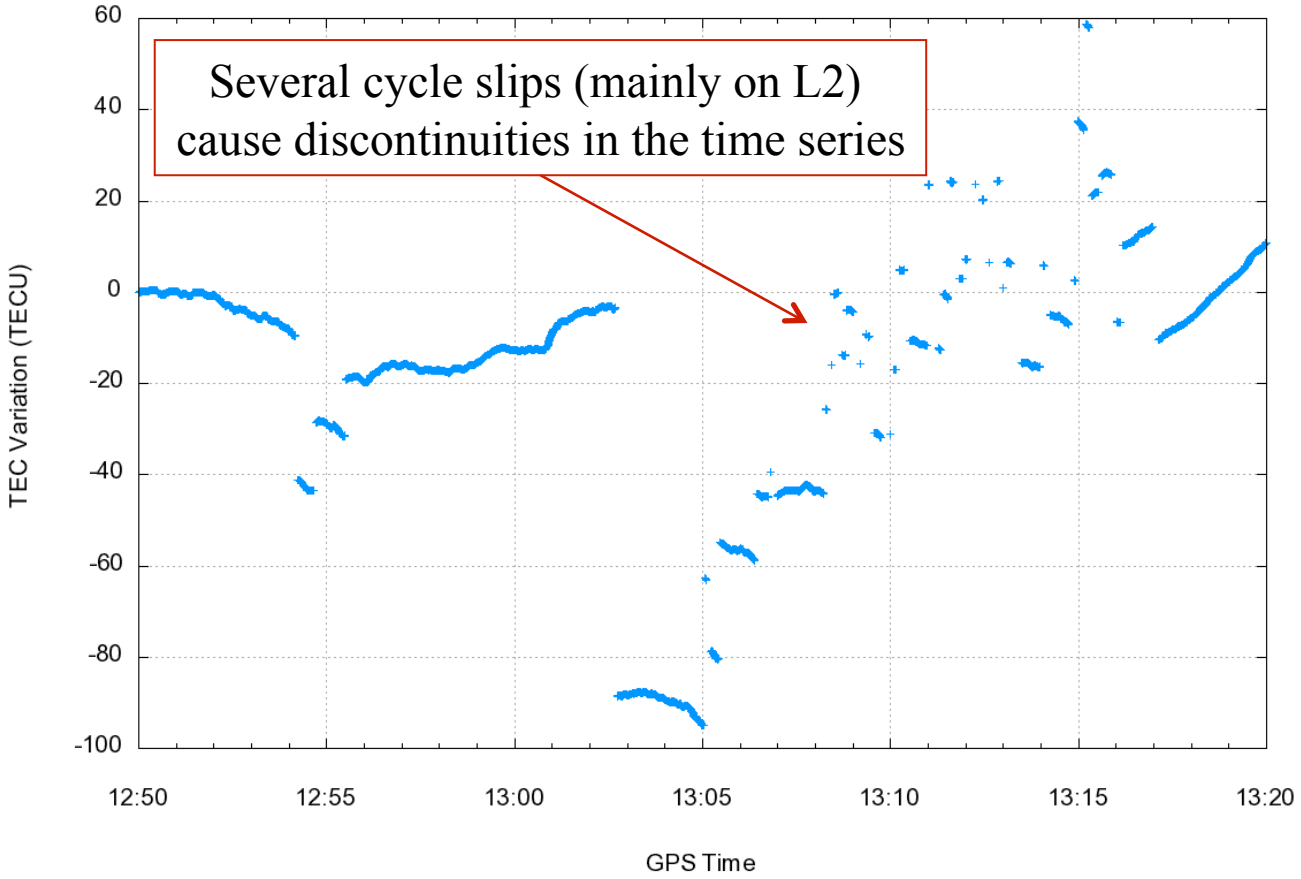
Phase Wind-up Studies



Phase Wind-up Studies



TEC Determination: Problem Statement



Total Electron Content (TEC) variation computed using the geometry-free linear combination of carrier-phase measurements for PRN21 on 23 March 2004, Okinawa, Japan.

Problem Statement -> Solution

- Correcting for cycle slips would allow to:

  - Minimize the impact of cycle slips on TEC-variation monitoring.

  - Improve the continuity/integrity of ionospheric corrections for augmentation systems (e.g., SBAS and GBAS).

  - Expand the study of ionospheric structures using GPS.

Geometry-free vs Geometric Model

- Geometry-free model

  - Explicitly combines measurements on both frequencies.

  - A cycle slip on any frequency = discontinuity.

  - No means of easily accounting for cycle slips.

Geometry-free vs Geometric Model

- Geometric model
  - Estimate the quantities in red in a least-squares adjustment:

Variation of carrier-phase observations corrected for known effects.

The ionospheric delay variation is estimated for each satellite.

Noise and unmodelled errors.

$$\delta\tilde{\Phi}_1^i = \delta dT - \delta I^i + \lambda_1 \delta N_1^i + \varepsilon_{\delta\Phi_1}$$

$$\delta\tilde{\Phi}_2^i = \delta dT - \alpha\delta I^i + \lambda_2 \delta N_2^i + \varepsilon_{\delta\Phi_2}$$

The variation of the receiver clock offset is common to measurements from all satellites.

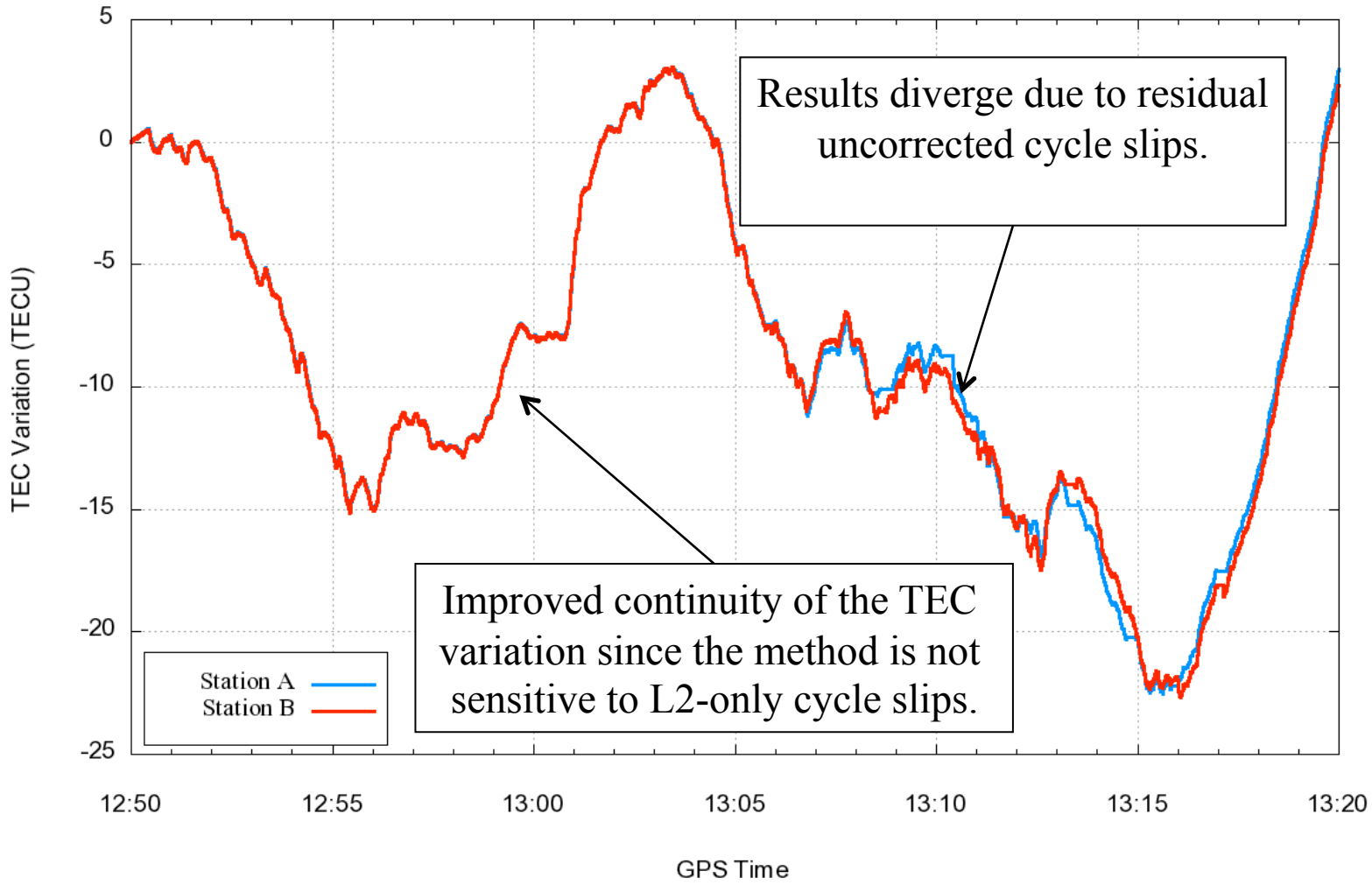
The size of the cycle slip is 0 for continuous carrier-phase measurements, while it is an integer value otherwise.

Geometry-free vs. Geometric Model

- Benefits of the geometric model
  - Ionospheric delay variation can be estimated using L1-only observations during short data gaps on L2.
  - The size of cycle slips can be estimated in the filter and fixed to integers.

- Drawbacks of the geometric model
  - Sensitive to geometric errors.
  - Not as computationally efficient as the geometry-free model.

Geometry-free vs. Geometric Model



Cycle-Slip Correction

- The size of the detected cycle slips can be estimated in the least-squares filter.

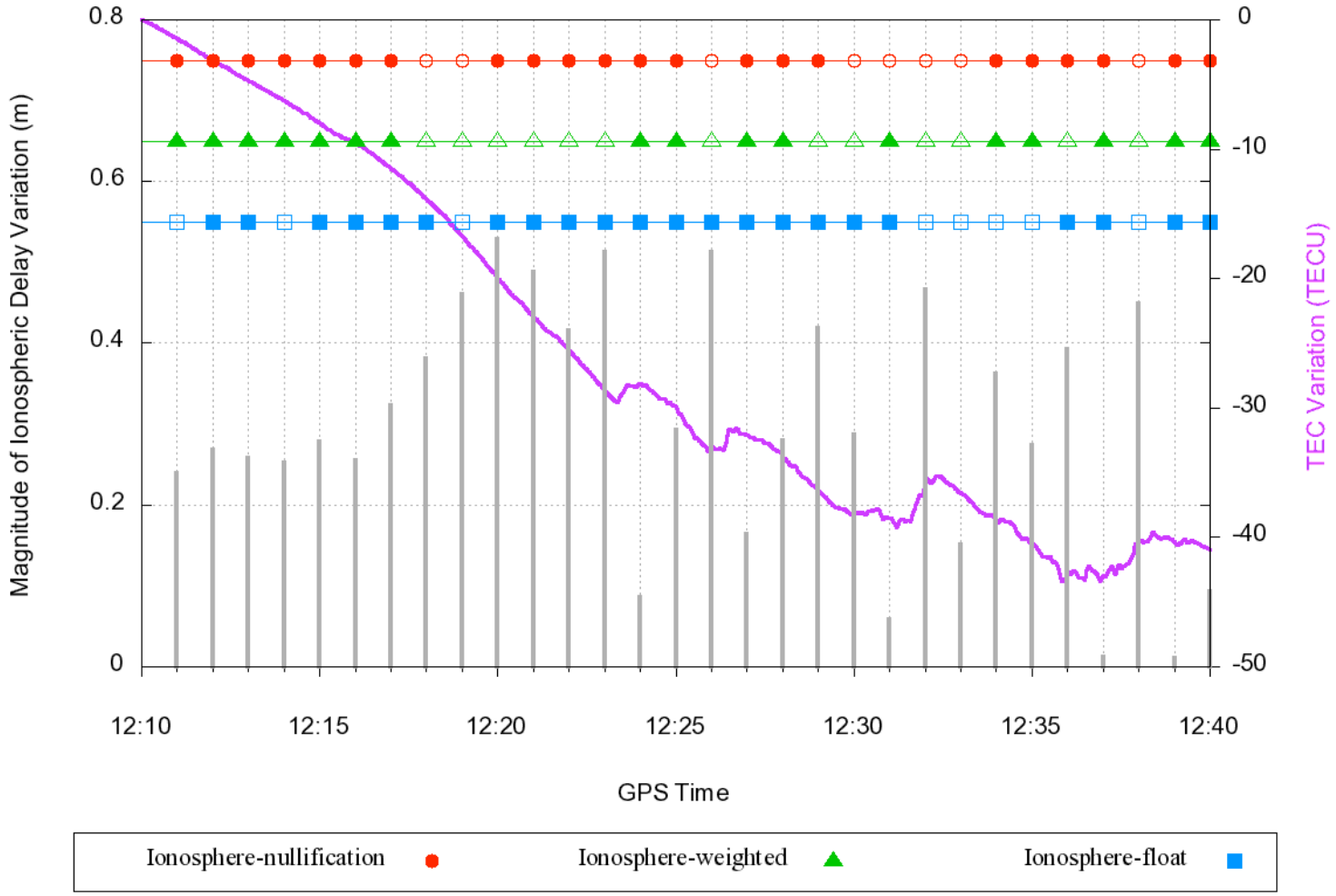
- The float estimates of cycle-slip parameters and their covariance matrix can then be used to fix cycle slips to integers.

Cycle-Slip Correction

- Characteristics of cycle-slip correction methods:
  - Ionosphere nullification (searching for L1 & L2 candidates that minimize the ionosphere-free variation of phase measurements)
  - Ionosphere-weighted model + LAMBDA
  - Ionosphere-float model + LAMBDA

Model	Benefits	Drawbacks
Nullification	Removes all ionospheric effects.	Sensitive to geometric errors and noise.
Weighted	More tolerant to geometric errors for short data gaps.	A guesstimate of the ionospheric delay variation is required.
Float	No guesstimate of the ionospheric delay variation is required.	Code noise and multipath propagate in the cycle-slip parameters.

Cycle-Slip Correction

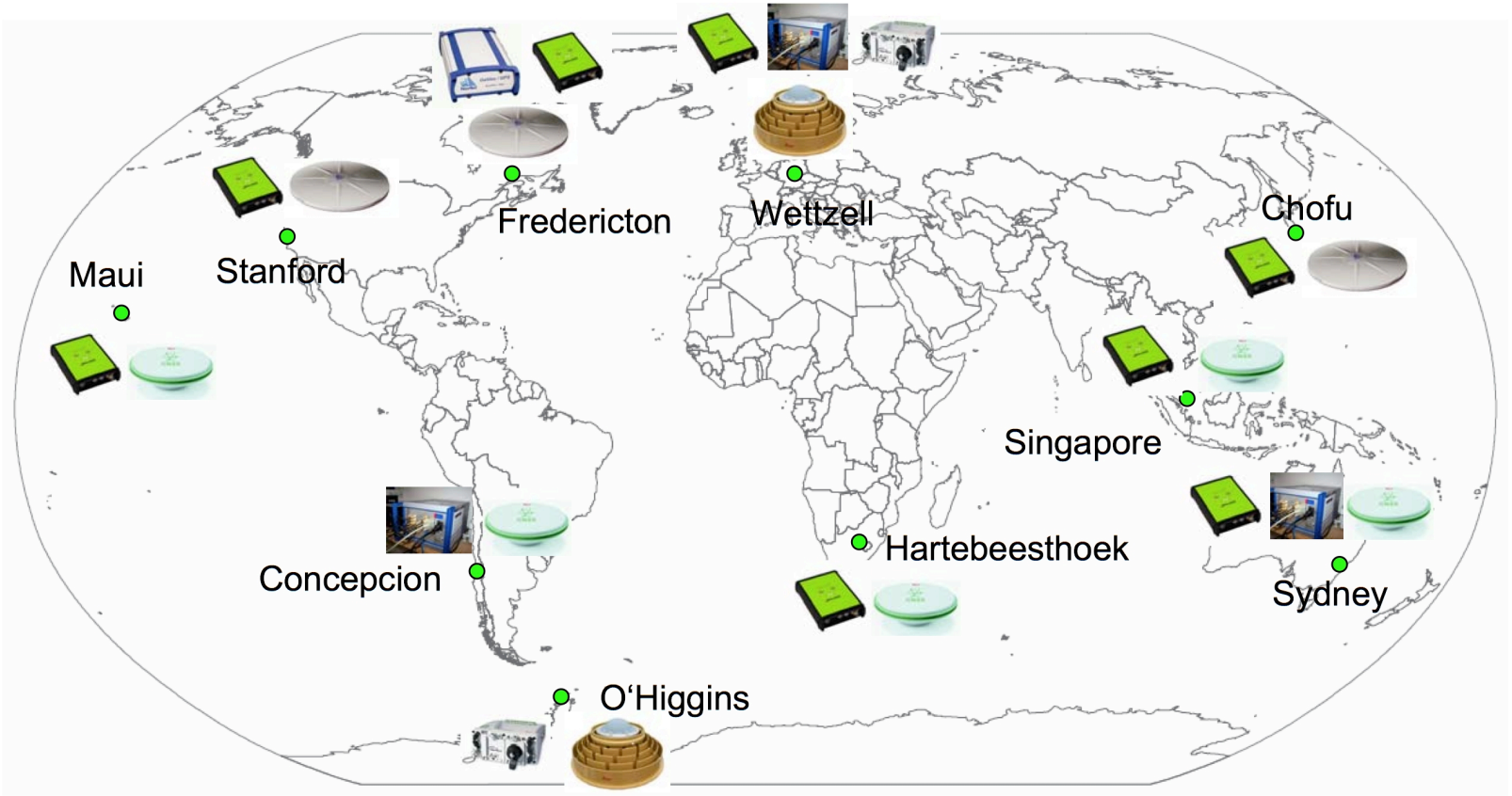


PRN05 on 23 March 2004, Okinawa, Japan.

GPS+GIOVE PPP

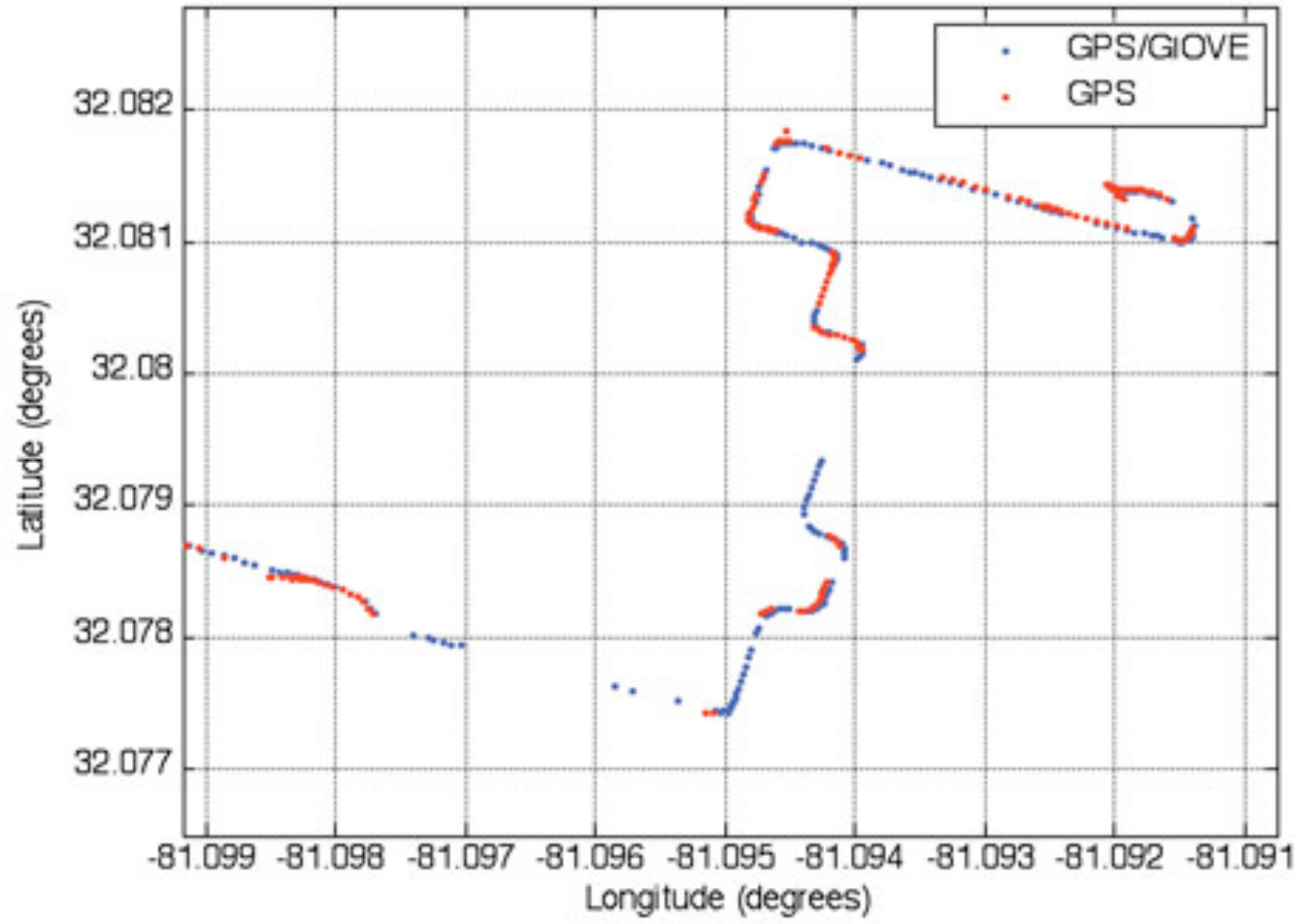
- Collaborative effort between UNB and DLR
- GAPS modified to process both GPS and GIOVE observations simultaneously
- RETICLE products used
- Kinematic test carried out in Savannah, Georgia, U.S.A., on occasion of ION GNSS 2009 meeting
- Results presented at ION ITM 2010 and in GPS World Tech Talk article

GPS+GIOVE PPP - CONGO Network

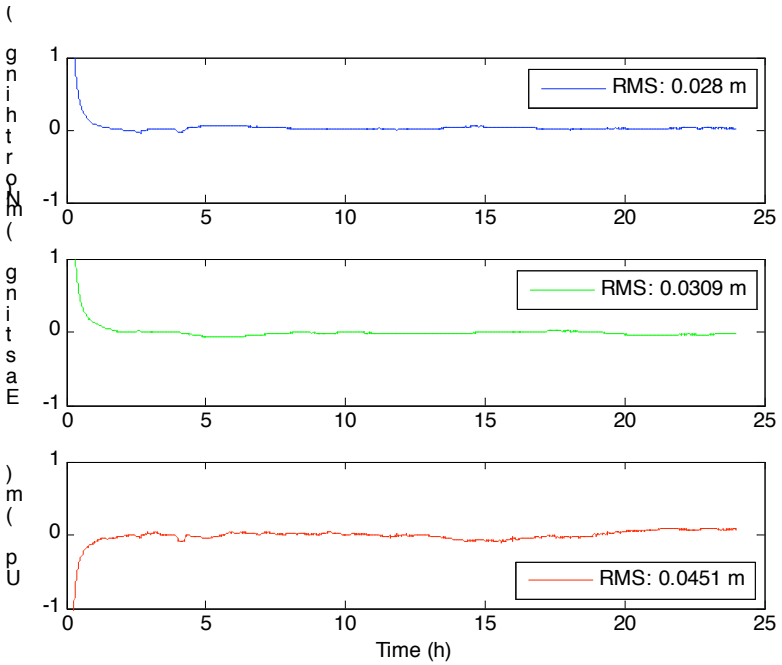


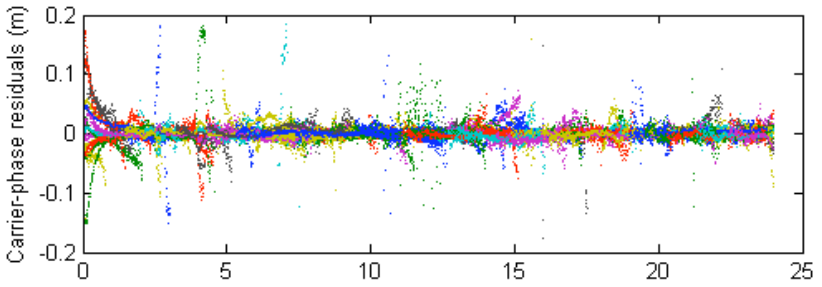
GPS+GIOVE PPP - Savannah

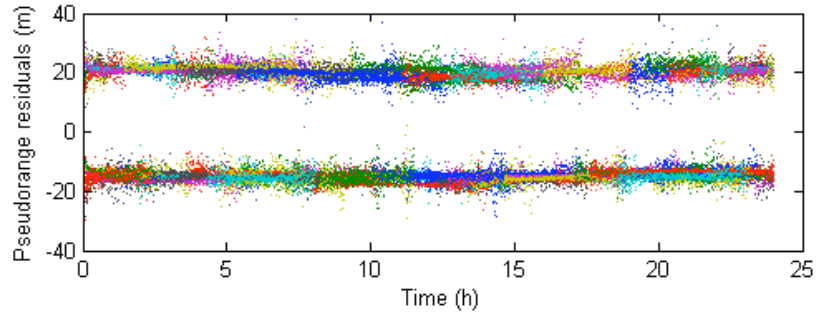
GPS+GIOVE PPP - Savannah

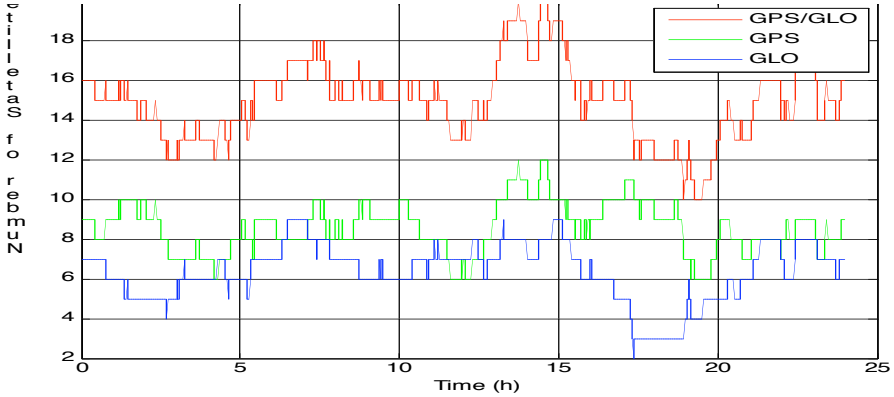


GPS+GLONASS PPP - First Results





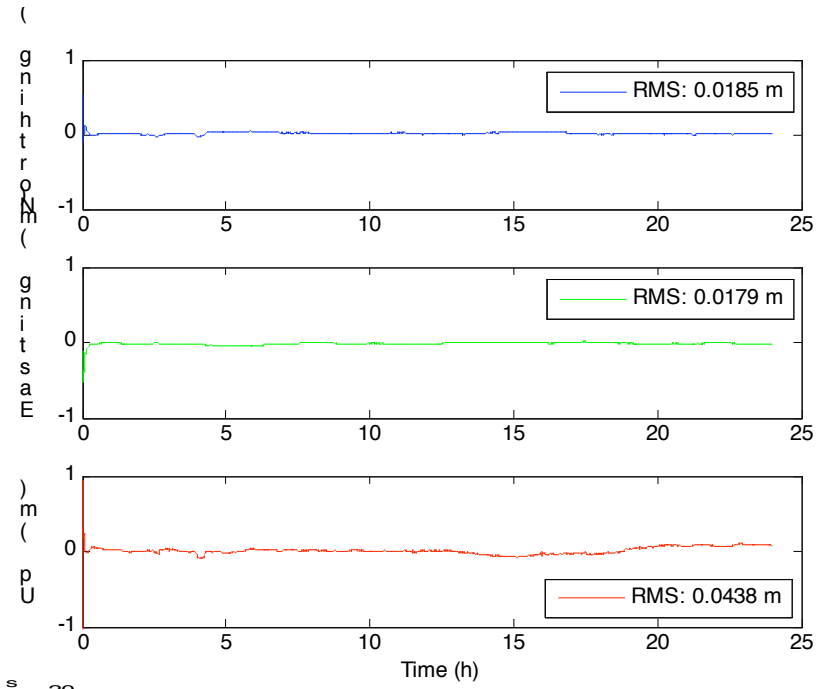


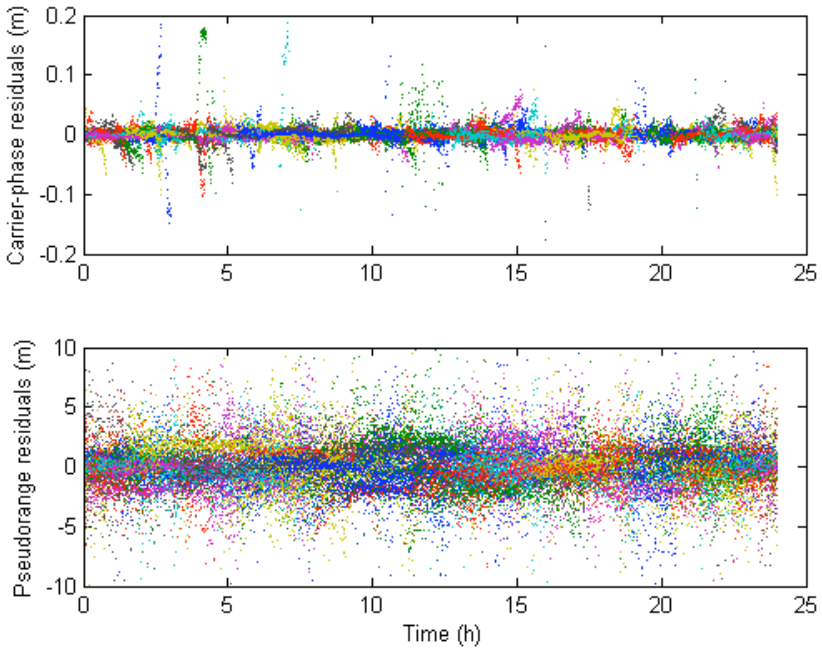


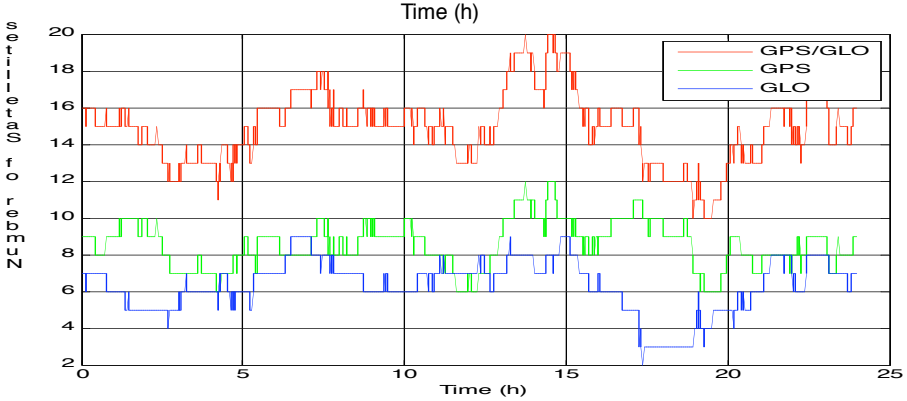
GPS/GLO PPP solution without inter-system bias correction

Station UNBJ, 30 April 2010

GPS+GLONASS PPP - First Results







GPS/GLO PPP with inter-system bias correction

Station UNBJ, 30 April 2010

Acknowledgements

- UNB GGE faculty members and past and present graduate students who have contributed to PPP development over the past few years.
- The global community of PPP researchers including those at TUM and DLR. PPP is truly a collaborative effort.