Real Time PPP: From clock to position estimation

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Introduction

- The Real Time PPP (RTPPP) method requires the availability of real time precise orbits and satellite clock corrections
- Currently, it is possible to use:
  - Predicted IGU ephemerides for satellite position
  - Clocks available in the IGU do not provide suffice accuracy (3 ns ≅ 0.9 m) to accomplish real time PPP with the centimeter level accuracy
- Nowadays there are already available real time orbits and satellite clock corrections inside the RTIGS Pilot project context
  - BNC and BNS software packages from BKG
  - Clocks from combined real-time GNSS data through RTNet software

Introduction

- The main aim of this project is to further research and develop appropriate methodologies for estimating the satellite clock corrections in real time and also to accomplish RTPPP
- The estimation of satellite clock corrections can be performed based on a GNSS network of reference stations
- Some investigations have been proposed for the estimation of the satellite clock corrections by:
  - Using GNSS code and phase observable at the double difference level between satellites and epochs (WEBER; MERVAT; DOUSA, 2007)
  - Kalman Filter in the network PPP mode to estimate the satellite clock corrections together with other parameters such as phase ambiguities (HAUSCHILD, 2010)
  - Integration of both methods, using network PPP and observables at double difference level in specific time intervals (ZHANG; LI; GUO, 2010)

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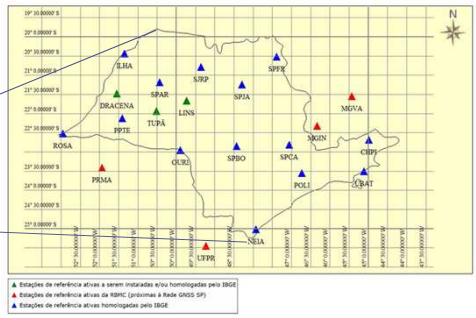
Brazilian GNSS Network

Brazilian Network transmitting GNSS real time data via NTRIP protocol

Infrastructure available in Brazil

Sao Paulo State Network



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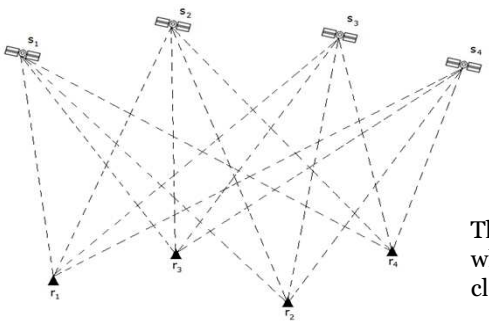
Methodology

- The methodology adopted in this work consists in the estimation of the satellite clock corrections based on the adjustment of data in the PPP mode for a network of GNSS stations, the so called 'network PPP'



Linearized Mathematical Model

$$E\left\{\begin{bmatrix}\Delta PR_{IF_f}^{s_i}\\ \Delta\lambda_{IF}\phi_{IF_f}^{s_i}\end{bmatrix}\right\} = AX = \begin{bmatrix}-1 & 1 & m_f & 0\\ -1 & 1 & m_f & \lambda_{IF}\end{bmatrix}\begin{bmatrix}cdt^{si}\\ cdt_r\\ T_{zw}\\ N_{IF}^{s_i}\end{bmatrix}$$

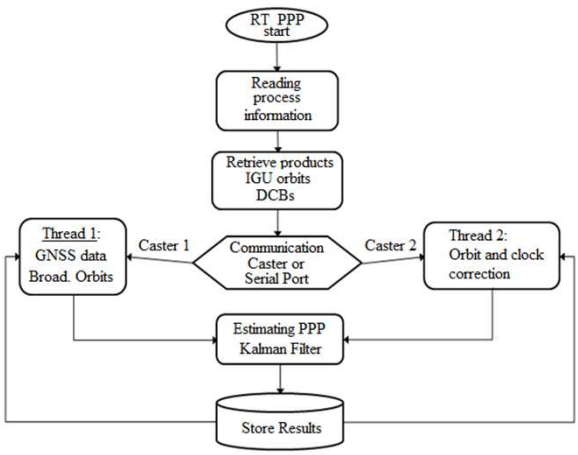
The model presents rank deficiency, what can be solved by constraining clocks with known values from IGU

Developments

- To estimate satellite clock correction and to accomplish real time PPP two pieces of software have been developed, respectively,
  - "RT_SAT_CLOCK"
    - To estimate satellite clocks based on a GNSS network
  - "RT_PPP"
    - To accomplish Real Time PPP
- Software developed in C++ and running under linux
- Network internet communication has been adapted from
  - RTCM3ToRINEX and BNC (BKG NTRIP Client)

RT_PPP Implementation

- Flowchart of RT_PPP software



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Mathematical models implemented in the RT_PPP

Effect	Strategy
Ionosphere – 1st order	•Ionosphere free combination or •Estimating Ionosphere as stochastic process (L1)
Troposphere	•Hopfield Model only •BNWFM (Brazilian Numerical Weather Forecast Model) •VMF1 with ZTD from ECMWF (European Centre for Medium-range Weather Forecasts) •All above as a-priori value plus ZWD Estimating (random walk)
Ocean Tide Loading and Earth Body Tides	Models proposed by IERS convention
Receiver and Satellite Phase Centre Variation	Absolute Phase Centre Variation correction
Precise Ephemeris	Predicted IGU or RTIGS
Satellite clock correction	From Network PPP estimation
Differential Code Bias	Estimated values from CODE
Ambiguities	Float solution
Phase windup	Applied

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Software – RT_Sat_Clock

- **RT_Sat_Clock** - Network PPP
  - Kalman Filter
  - All corrections described before for each station
  - Process GPS data using two types of observables: code smoothed by carrier phase or undifferenced code together with carrier phase
  - **Troposphere**
    - BNWFM (Brazilian Numerical Weather Forecast Model)
    - ECMWF (European Centre for Medium-Range Weather Forecasts)
    - VMF - Vienna Mapping Function
    - Estimating troposphere
  - **Receiver clock correction (dtr)**
    - White Noise
  - **Satellite clock correction (dts)**
    - Linear prediction model or a second degree polynomial
    - Treated as an integrated Random Walk/White noise
  - **Ambiguities**
    - Estimated for each satellite in each station with float solution

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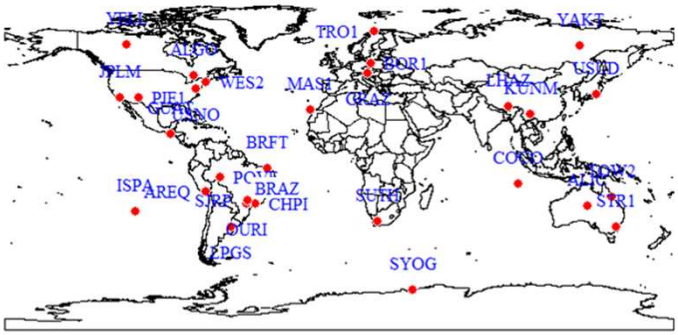
Experiments

- Global Network



- In this case were processed data from GNSS stations around the world using RT-PPP
- The results of this processing will be used in the network configuration for the clock estimation

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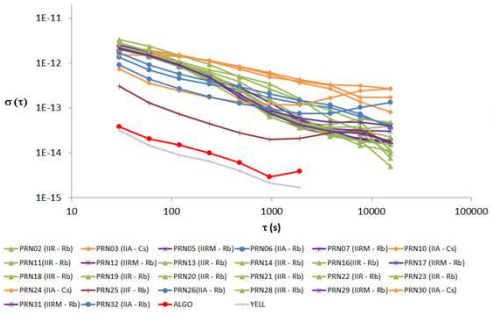
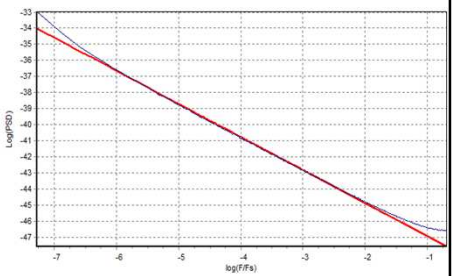
Analysis of clocks stability

- Modified Allan Variance



Power Spectral Density



Source: AllaVar software - http://www.alamath.com/index.php?option=com_content&task=view&id=12&Itemid=9

The PSD was adjusted to a coefficient α = -2.1, what means that the clocks have a strong random walk behavior – PRN03

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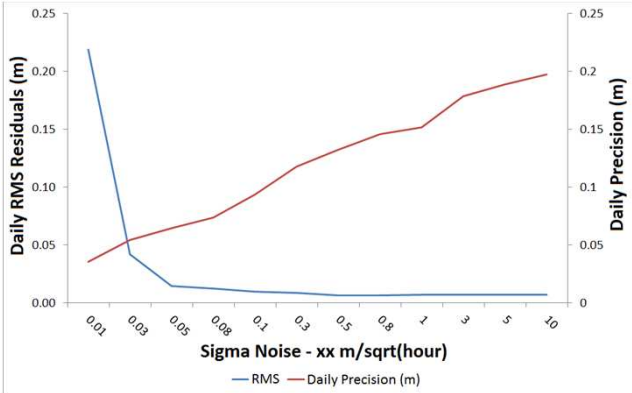
Noise precision in the Kalman filter

- Clocks estimated by using around 30 global stations with different sigma noise for clocks in the Kalman filter in order to tune the values for precision of noise



Residuals of clocks gets stabilization near 0.03 m/sqrt(hour)

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Configuration

Based on initial experiments we adopted the following values:

Process noise

Parameters	σ_0	Correlation Time t (s)
Receiver clock offset	1.10^{18}	
Satellite clock offset	0.3	600
Troposphere	0.005	3600
Ambiguity	0	

Measurement Precision

Observable	σ (m)
P1 (Code)	0.8
P2 (Code)	1.0
PH1 (phase L1)	0.008
PH2 (phase L2)	0.01
Satellite clock constraint	0.10

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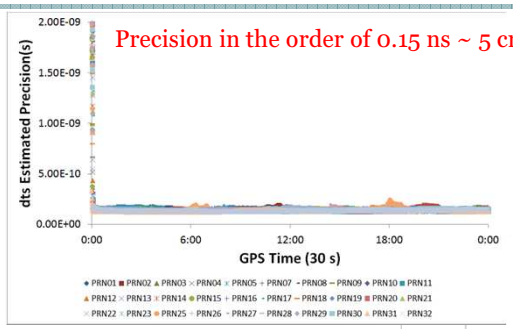
Estimated satellite clocks

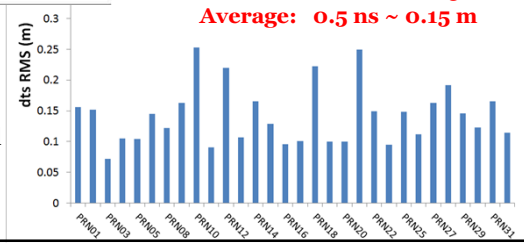


Precision in the order of 0.15 ns ~ 5 cm

By applying code and phase
Day 10 of 2012

Daily RMS
Minimum: 0.2 ns ~ 0.07 m
Maximum: 0.8 ns ~ 0.25 m
Average: 0.5 ns ~ 0.15 m

RMS when compared with IGS final solution



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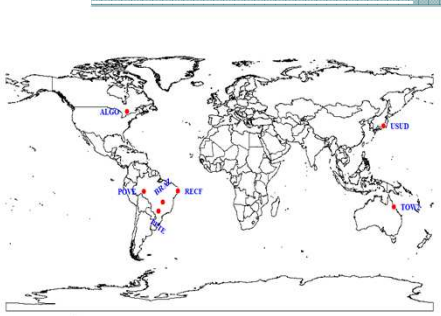
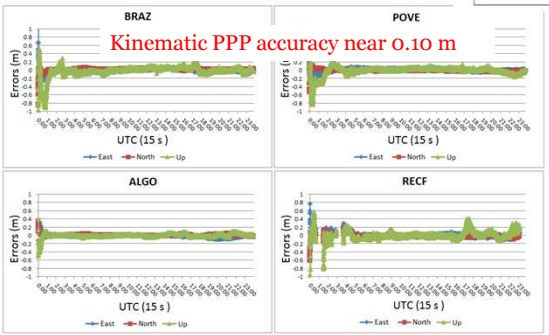
RT_PPP software

- Initial experiments
  - Post processed mode
  - 24 hours of data in the day 244 of 2009

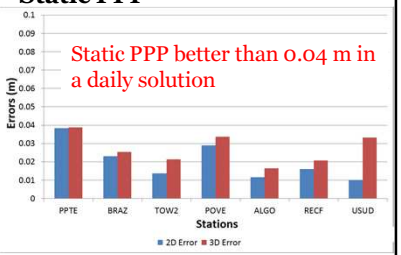


Kinematic PPP



Kinematic PPP accuracy near 0.10 m

Static PPP



Static PPP better than 0.04 m in a daily solution

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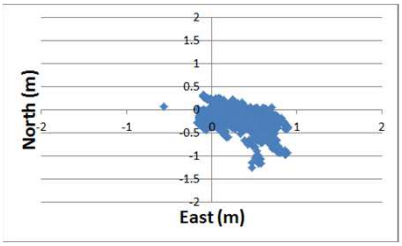
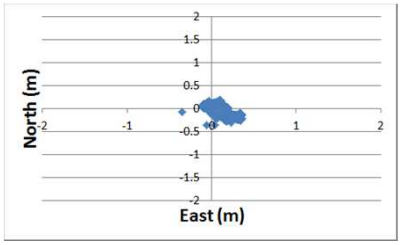
Real Time PPP with clocks from RT_SAT_CLOCK



Brazilian POVE station

IGU orbits and clocks using code smoothed by phase

IGU Orbits and clocks using undiffirenced pseudorange and phase



PPP (IGU + clk from smoothed Pseudorange)			
	DE	DN	DU
Mean Error	0.345	-0.176	0.256
Standard Deviation	0.243	0.215	0.559
RMS	0.422	0.278	0.615
PPP (IGU + clk from code and phase)			
	DE	DN	DU
Mean Error	0.103	-0.031	0.022
Standard Deviation	0.092	0.079	0.254
RMS	0.139	0.085	0.255

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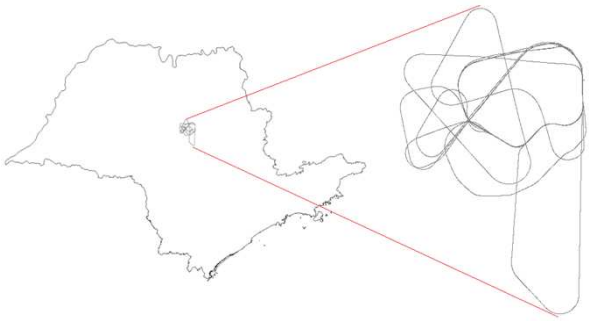
Estimated Clocks and RTPPP for flights

- We have estimated satellite clocks to apply in the RTPPP for flight of airplanes
- Some experiments were accomplished for a test flight data of an EMBRAER aircraft in the day 244 of 2009



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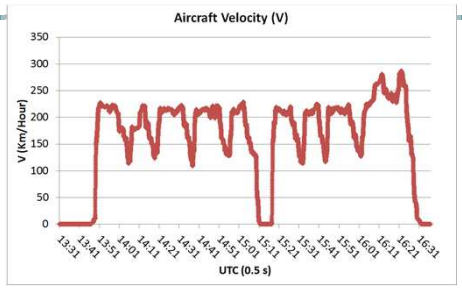
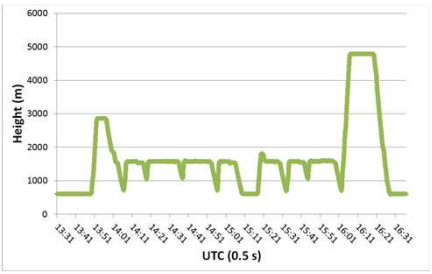
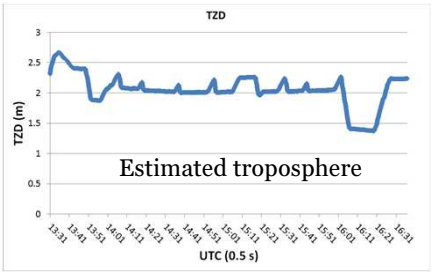
RT_PPP applied for airplanes flight







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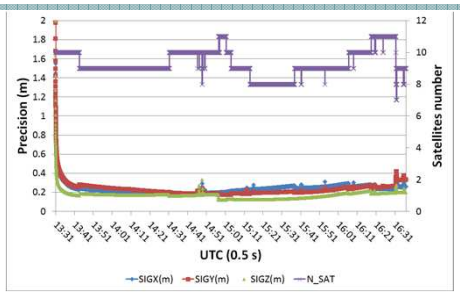
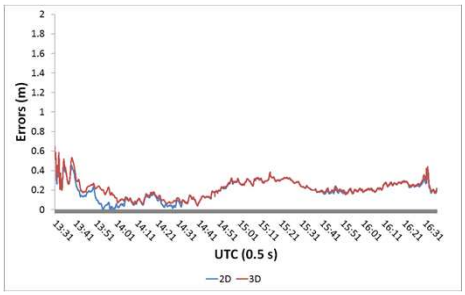
RT_PPP applied for airplanes flight

Estimated Precision of the PPP for the regional airplane flight





PPP for flight was compared with PPP using final IGS products

	2D Error (m)	3D Error (m)
Mean Error	0.173	0.216
St. Deviation	0.072	0.089
RMS	0.187	0.234

Conclusions

- The estimated clocks by using around 30 stations presented accuracy of 0.15 ns (5 cm)
- Application for kinematic RTPPP – accuracy of the order of 20 cm
- Application for regional airplanes flight – horizontal accuracy of the order of 20 cm

Future Works

- Improvements to turn the system completely operational
- Implementation for GLONASS and other systems
- Satellite clocks from local networks (Brazilian network) in order to accomplish RTPPP for more test flights

Actual Status

- Cooperation project among UFPE, UNESP and EMBRAER
- Ambiguity solution is being investigated and will be implemented

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Acknowledgements

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Grupo de Estudos em Geodésia Espacial

FAPESP

Universidade Federal de Pernambuco

EMBRAER

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Thanks for your Attention!

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