Single Frequency Precise Point Positioning Using GPS and Galileo Observables

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Outline

- Introduction
- System Noise Test
- Results and Analysis
- Discussion
- Conclusions

Introduction

- Precise Point Positioning (PPP) technique is more attractive to users due to its lower cost and comparable precision to the differential technique
- Currently, GPS system measurements provide a continues for users by supporting them with the legacy signals L1 and L2 and even by the modernized signals L2c and L5
- Galileo satellite system provides users of Open Service with three frequencies, namely E1, E5a, and E5b
- After launching the Galileo satellite system, it is important to have an integrated PPP solution for GPS/Galileo
- The integrated system of GPS/Galileo offers more visible satellites to users, which is expected to enhance the GDOP and the overall solution

Introduction

- In order to take full advantage of the new Galileo signals, it is essential that its stochastic characteristics are rigorously determined
- In this research, sessions of Galileo measurements were used to study the stochastic characteristics of the new Galileo signal E1
- As a by-product, the stochastic characteristic of the legacy GPS signal P1 is also determined which were used to verify the developed stochastic model of Galileo signals
- Integrated L1/E1 signals of GPS and Galileo, respectively, were used to verify the stochastic model
- This research aims to improve the PPP solution by modeling the stochastic characteristics of Galileo E1 signal

Introduction

- A receiver system noise test is performed to determine the stochastic characteristics of GPS L1 and Galileo E1 signals, respectively
- In addition, this research studies the effect of the satellite elevation angle on the stochastic characteristics
- To verify the obtained results, we implemented the new stochastic model to assess the effect of the stochastic characteristics on the PPP solution precision and convergence time

System Noise Test

- In this research, L1 and E1 signals of GPS and Galileo, respectively, are used to produce a single-frequency PPP integrated solution.

$$\mathrm{P_S} = \rho_S + \mathrm{c}[\mathrm{dt_r} - \mathrm{dt^s}]_\mathrm{S} + c[d_r + d^s]_S + T_S + I_S + e_{PS}$$

$$\Phi_\mathrm{S} = \rho_S + \mathrm{c}[\mathrm{dt_r} - \mathrm{dt^s}]_\mathrm{S} + T_S - I_S + c[\delta_r + \delta^s]_S + \lambda[N + \phi_r(t_0) - \phi^s(t_0)] + \varepsilon_{\varphi G}$$

where s refers to the satellite system

- Both transmitting and reception times are estimated according to each satellite system time frame.

System Noise Test

- Receiver measurement noise results from the limitation of the receiver's electronics
- Two tests are usually used to determine the receiver noise level, namely zero and short baselines
- Zero baseline test uses one antenna followed by a signal splitter that feeds two or more GPS receivers
- Short baseline test, on the other hand, uses two receiver systems of a few meters apart
- In this research, a short base line test is used to determine the stochastic characteristics of Galileo E1 and GPS L1 signals

System Noise Test

- Usually, this test is performed using the same type of receivers
- Unfortunately, two different receivers (Septentrio and Trimple) were available with access to Galileo measurements. This, however, were considered when processing the data
- Taking between-receiver single difference for pseudorange and carrier-phase measurements and assuming no multipath, we get:

$$\Delta \mathrm{P} = P_{\mathrm{R1}} - P_{\mathrm{R2}} = \mathrm{cdt}_{\mathrm{r1}} - \mathrm{cdt}_{\mathrm{r2}} + c[d_{r1} - d_{r2}]_P + e_P$$

$$\Delta\Phi = \Phi_{R1} - \Phi_{R2} = \mathrm{cdt}_{\mathrm{r1}} - \mathrm{cdt}_{\mathrm{r2}} + c[\delta_{r1} - \delta_{r2}]_{\Phi} + \lambda \hat{N}$$

- where the phase measurement noise has been neglected due to its small size compared with the pseudorange counterpart

System Noise Test

- The remaining terms include the hardware delay, the ambiguity parameter and the system noise

$$\Delta P - \Delta\Phi \;= e_P + c[d_{r1} - d_{r2}]_P - c[d_{r1} - d_{r2}]_\Phi - \lambda\hat{N}$$

- Receiver hardware delay is assumed to be stable over the observation period, while the ambiguity parameters and initial phase bias are constants for a continuous observation session

- As such, they can be removed from the model by differencing with respect to the first value of the series. With these operations, only the differenced system noise remains in the model

System Noise Test

- A least squares regression analysis is performed to obtain the best-fit model of the estimated standard deviations

- Three empirical functions were tested for this purpose, namely an exponential, a polynomial and a rational model

- The best-fit model is selected based on the goodness of fit test, i.e., the one with the largest R^2 (R-squared) statistic

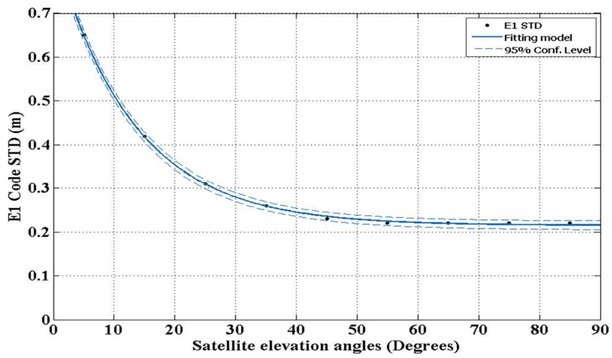
- Regression analysis was done using 95% confidence level limits

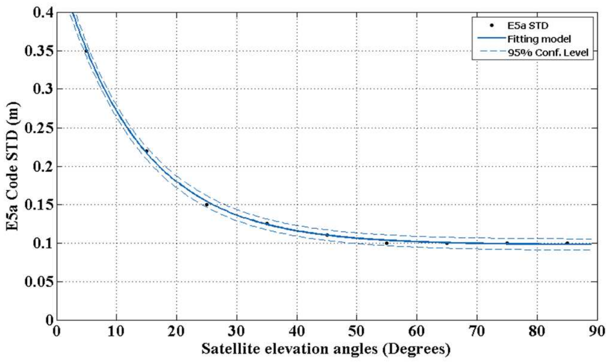
System Noise Test

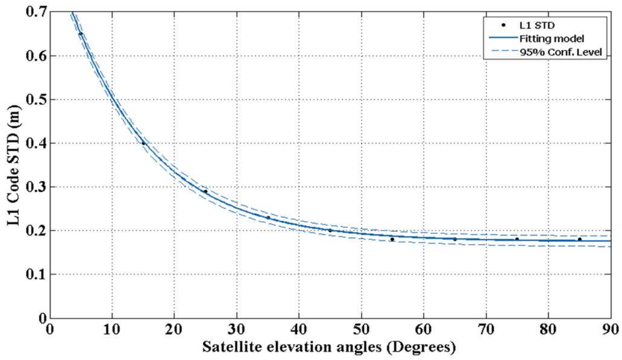
- By applying the last equations to GPS L1 and Galileo E1 signals, we can get the stochastic characteristics
- The differenced measurements are divided into nine bins depending on the satellite elevation angle, starting from 0º to 90º with increments of 10º (i.e., 0º to 10º, 10º to 20º, etc.)

	Exponential function			**Polynomial function**			**Rational function**		
	$STD = a \times e^{(-b \times ELE)} + c$			$STD = -a \times ELE^3 + b \times ELE^2 - c \times ELE + d$			$STD = \frac{(a \times ELE^2 - b \times ELE + c)}{(ELE + d)}$		
	E1	E5a	L1	E1	E5a	L1	E1	E5a	L1
a	0.6383	0.3692	0.6830	1.835e-6	5.892e-6	1.473e-6	3.5e-3	4.315e-3	6.087e-3
b	0.0763	0.0753	0.0730	3.688e-4	1.445e-4	3.195e-4	0.2703	0.5155	0.6533
c	0.2150	0.0974	0.1751	0.02443	0.01556	0.0228	22.93	28.36	36.57
d	-	-	-	0.7557	0.4014	0.7156	28.35	69.29	49.69
R^2	**0.9995**	**0.9993**	**0.9994**	0.9988	0.9977	0.9990	0.9990	0.9977	0.9984
where ELE is the satellite elevation angle in degrees; STD is the observation standard deviation									

System Noise Test



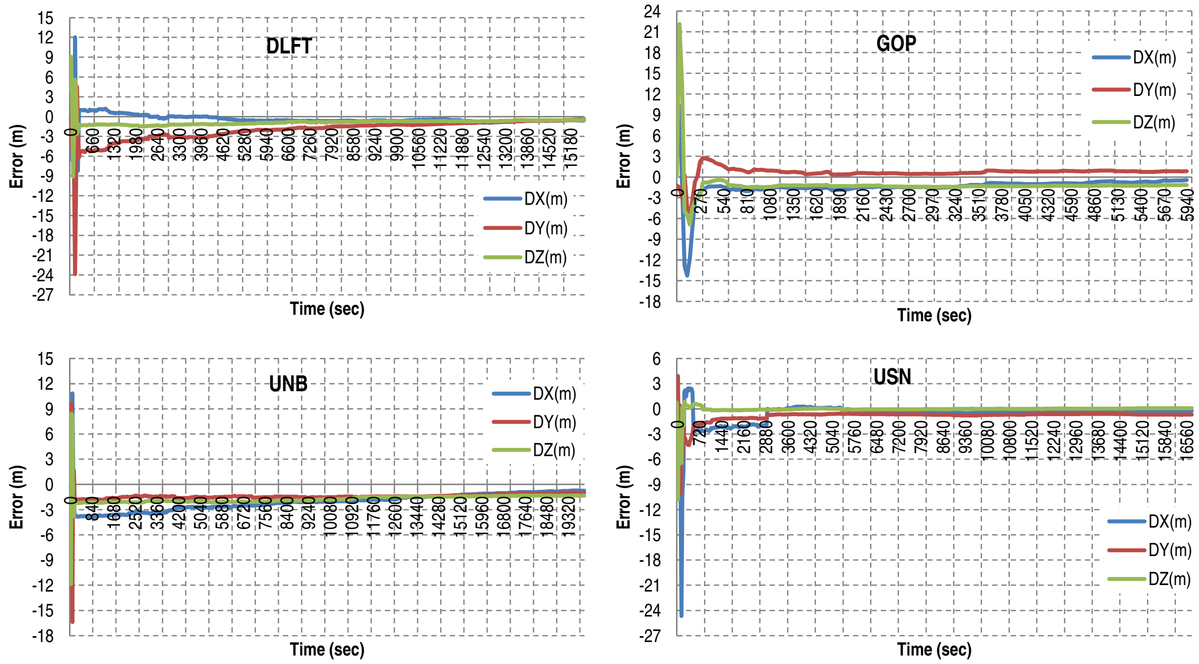




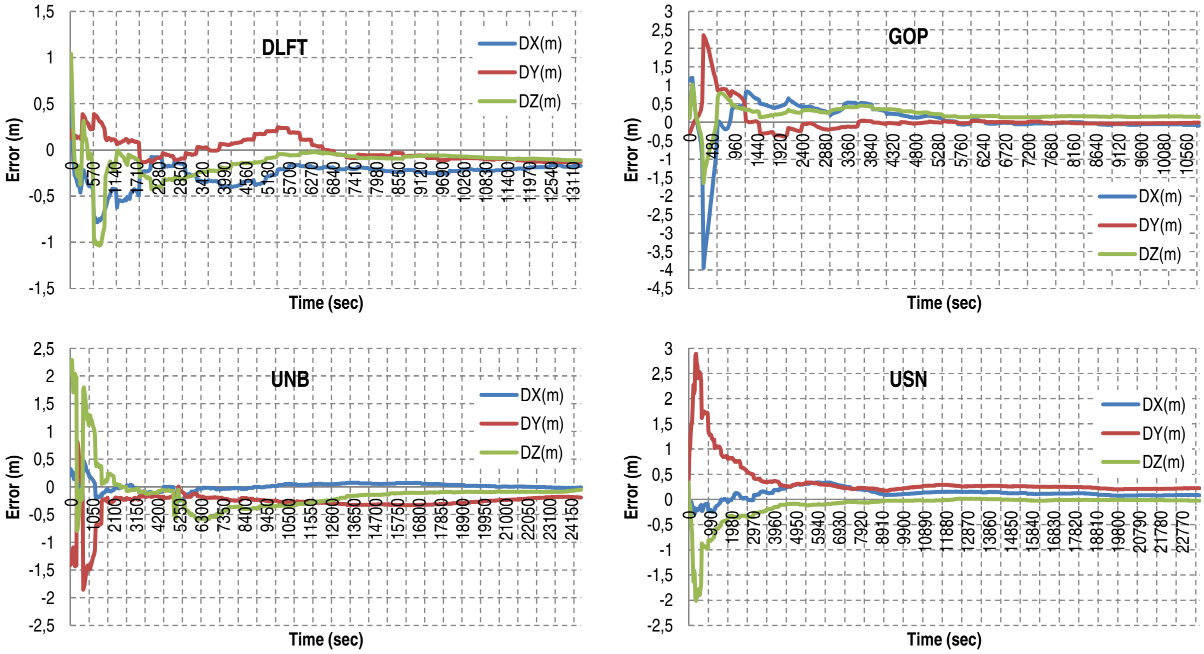
Results and Analysis

- Four stations were used to verify our model. Of them, two stations are located in North America (UNB and USA naval Observatory) and two are located in Europe (Delft and GOP)
- Analysis was performed using the four stations for both the existing stochastic model and the new stochastic model
- IGS GPS precise orbit and clock corrections were used for GPS satellites.
- For Galileo, we used the CONGO network precise satellite orbit and clock corrections
- GIM ionosphere correction model is used to correct the ionosphere delay error

Results and Analysis – Existing model (OCT 16, 2012)



Results and Analysis – New model (OCT 16, 2012)



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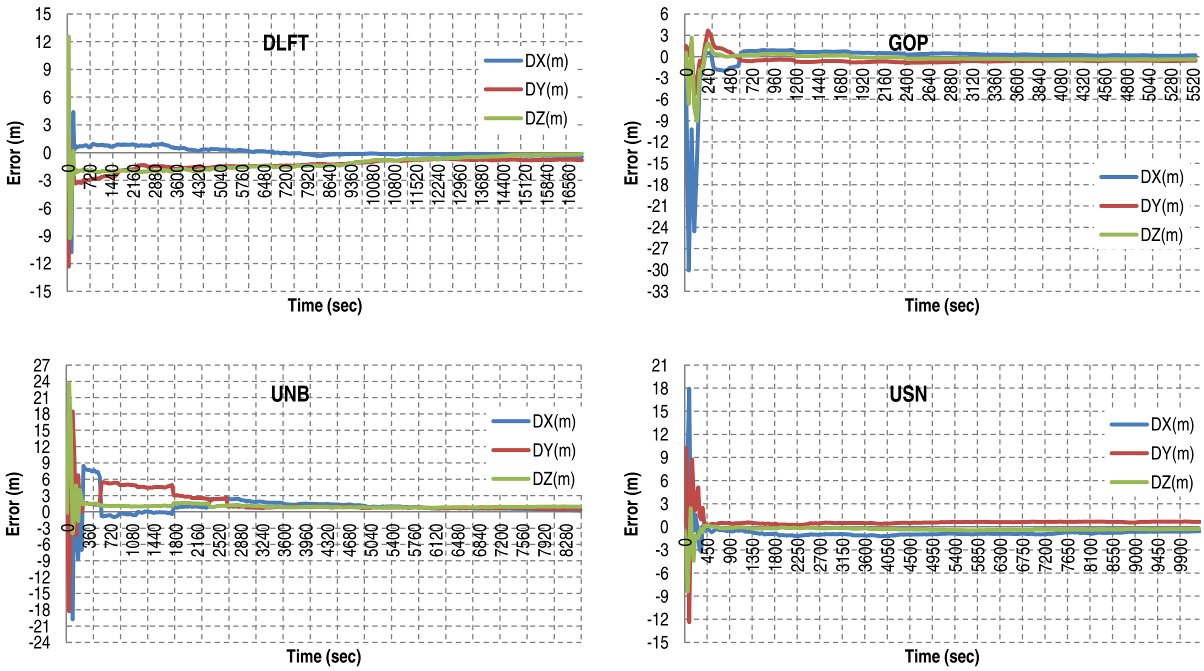

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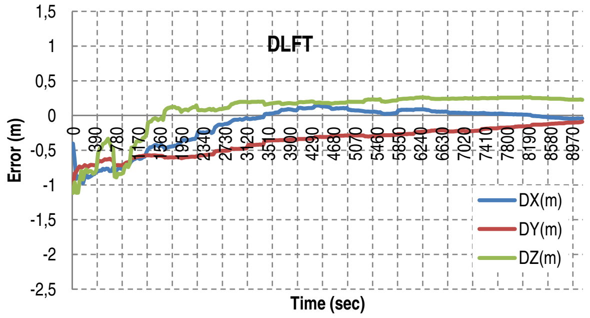

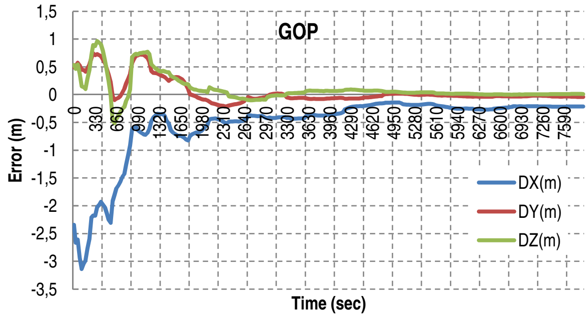

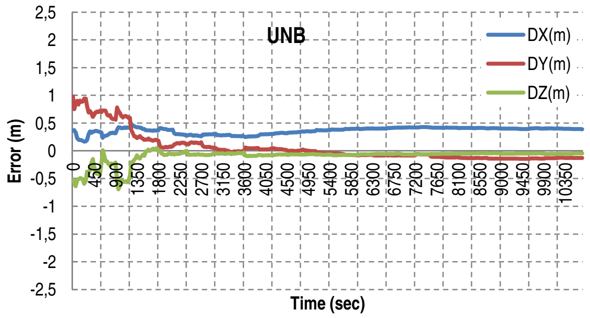

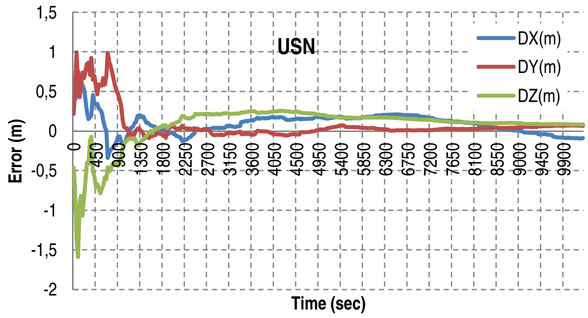

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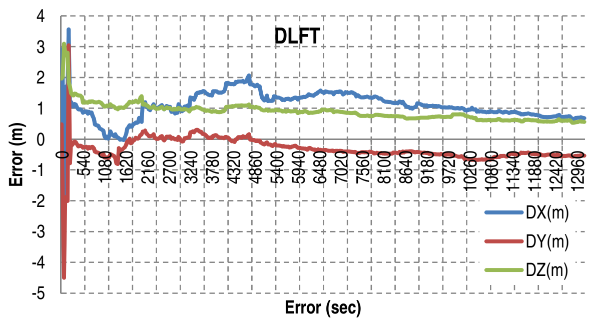

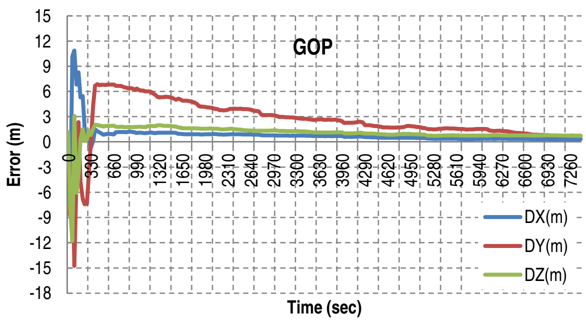

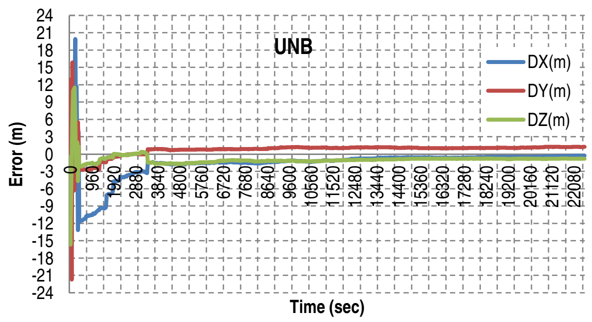

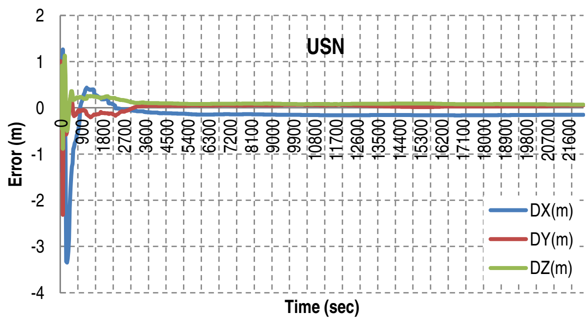

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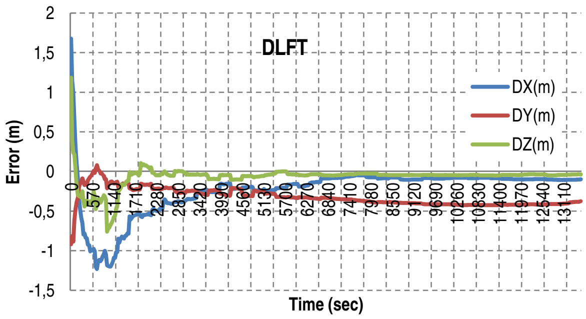
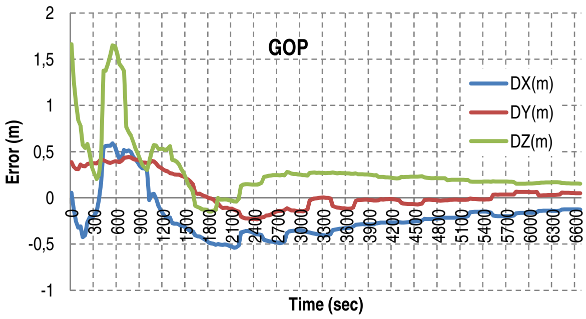
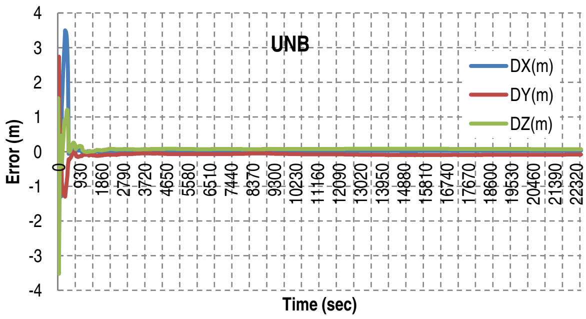
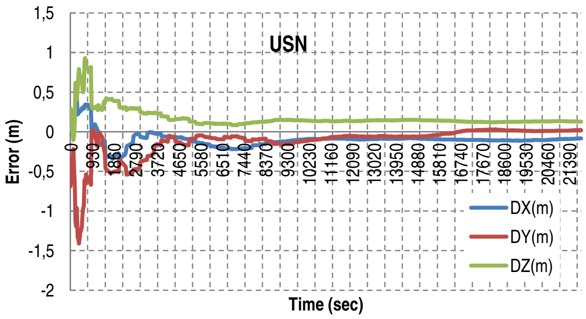
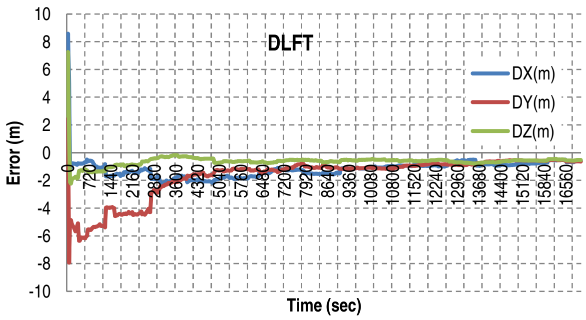


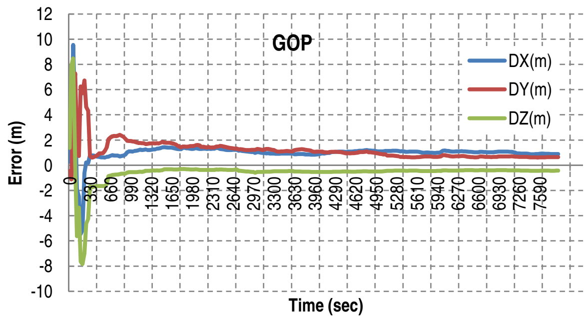


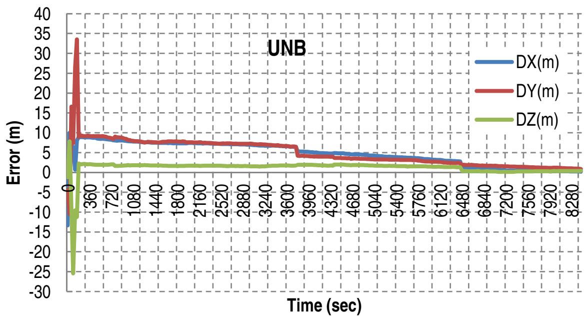


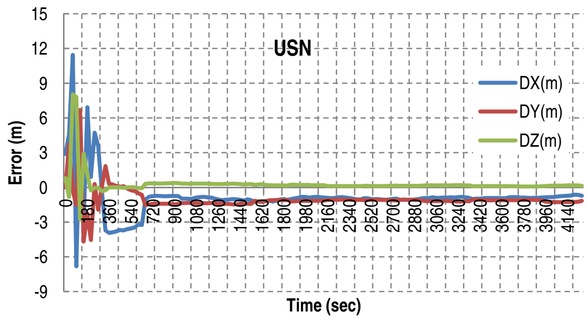


Results and Analysis – Existing model (OCT 24, 2012)

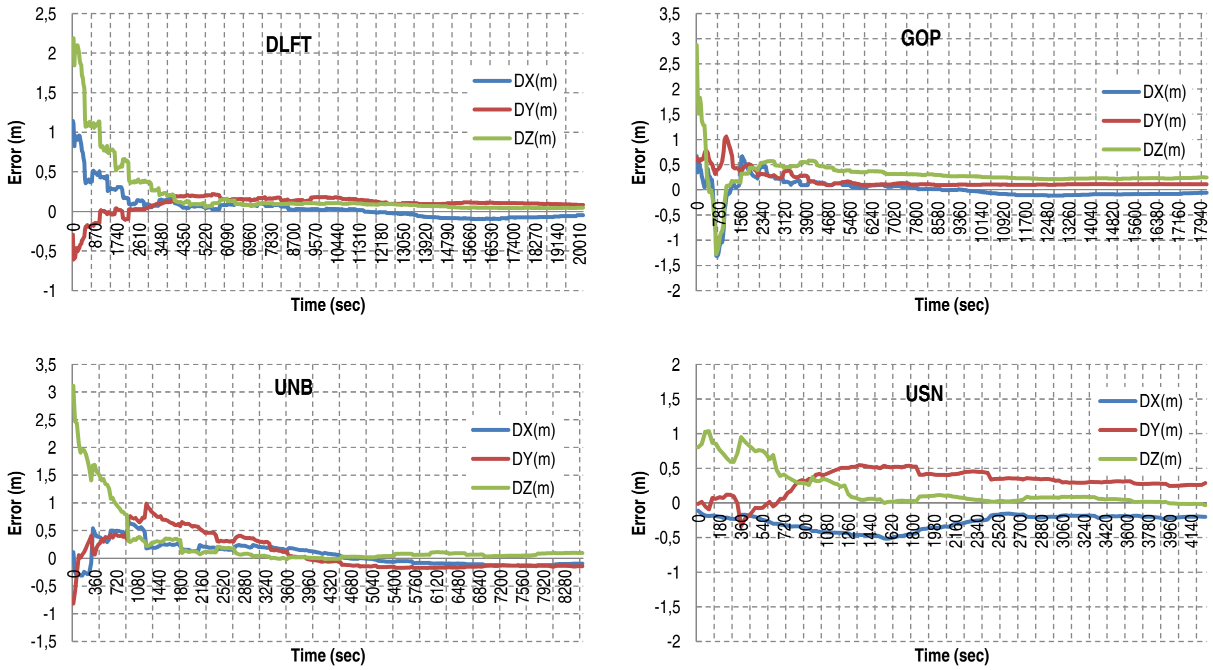








Results and Analysis – New model (OCT 24, 2012)



Discussion

- The results show a significant improvement in the PPP solution in terms of precision and convergence time
- The results of the new stochastic model show faster convergence time without any solution jumps at the beginning
- In addition, the results show a sub-decimeter level of accuracy which is comparable to the dual frequency solution
- As well, a solution convergence time improvement in the order of 60-80% is attained through single-frequency GPS/Galileo PPP, in comparison with single-frequency using the traditional stochastic model

Conclusions

- A short base-line test was performed to determine the stochastic characteristic of the E1 Galileo signal

- As a by-product, the stochastic characteristic of the GPS L1 signal was determined using the same short base line test

- The results showed that precise single-frequency GPS/Galileo PPP solution, comparable to that of dual-frequency GPS, is possible through rigorous modelling of stochastic characteristics of the signals

- Significant improvements in the precision and convergence time (Up to 30 minutes) of the integrated single-frequency GPS/Galileo solution are achieved when the newly developed stochastic model is used

Thank you

Q&A