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Investigation on the performance of a low-cost single frequency GNSS receiver for PPP application

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ABSTRACT

During the "United Nations/Russian Federation Workshop on the Applications of Global Navigation Satellite Systems (GNSS)" (Krasnoyarsk - 2015, May 18th-22nd), a joint project between the Laboratory for Application and Innovation in Aerospace Science (LAICA) of the University of Brasilia (UnB), Brazil, and the Telecommunications/ICT for Development Laboratory (T/ICT4D) of the Abdus Salam International Centre for Theoretical Physics (ICTP) has been started. The main activities carried out in this cooperation frame consist of Precise Point Positioning (PPP) studies, single frequency mass-market receiver positioning and related ionospheric research in the region of Brasilia. [1]

1. Introduction

This work compares the performance of different absolute positioning techniques using a single-frequency mass-market low-cost Global Navigation Satellite System (GNSS) receiver. [2] The receiver is a multi-constellation u-blox NEO-M8T GNSS timing module (NEO-M8T). [3] This kind of receivers provides different types of information such as L1 pseudorange and carrier-phase measurements in a proprietary u-blox format, that a posteriori is converted into RINEX format at 1Hz sampling rate. Different sessions of surveys using two of these u-blox receivers have been carried out in Trieste and in Brasilia from the beginning of the collaboration. The objective of this research is to assess the performance of such type of GNSS low-cost single frequency receivers in order to use it for preliminary positioning tests in the LAICAnSat high altitude platform for tracking and high-precision applications, as well as for attitude control and determination in space applications which requires the knowledge of the precise position of the spacecraft in the orbit for the correct behavior of the sensors and actuators. An open source program package [4] has been used to process single-frequency GNSS data. GNSS radio waves transmitted from satellites to users are affected by the Earth's atmosphere resulting in a degradation of the position accuracy. For single-frequency receivers the ionosphere is the main error source that causes this accuracy degradation.

2. Data and Results

It is well known that in case of multi-frequency receivers no modeling of the ionosphere is required because the first order ionospheric delay can be subtracted. [2] Meanwhile observations from single-frequency receivers need to be corrected using an external model in order to remove the first order ionospheric error contribution. In this research GNSS data has been corrected using the Klobuchar Ionospheric Model, the NeQuick 2 Ionospheric Model [5] and the Global Ionospheric Maps (GIMs) corrections [6]. NeQuick 2 is the latest version of the NeQuick ionosphere electron density model. It is a climatological model that uses monthly average values of solar activity expressed by the 12-month running mean sunspot number R12 as a driver. However in this work, to switch from ionospheric climatology to weather and with the aim to apply NeQuick 2 model corrections in real-time, the solar flux of the day before is used as a model input [7]. The open source program package RTKLIB has been used to calculate the PPP solution in static mode applying the ionospheric corrections mentioned above. Table 1 and 2 include positioning error statistics obtained after processing u-blox EVK-M8T data in the two locations representative of middle (Trieste) and low latitude (Brasilia) regions. In order to evaluate the performance of the three selected ionospheric corrections in the positioning accuracy, measurements were taken in both sites at the same local time using the same receiver kinematics. The reference coordinates for the u-blox were calculated in post processing mode applying standard RTK technique with respect to TRIESTE permanent station TRIE (Regional Network Marussi [8]) and BRASILIA permanent station BRAJ (GLONASS Ground Station Network [1]). This hourly test was performed on 27th January 2016 (quiet day, Kp=1, Dst=12 nT) at 14h local time. Other tests have been carried out as well, but this case was preferred to evaluate the correction algorithms when facing the maximum ionospheric delay possible along the day. Moreover, at this stage, measurements from the night periods were discarded to avoid the effects of ionospheric irregularities [9] usually present after sunset hours at the Brazilian location. [10]

Trieste u-blox	Positioning Errors	GIM	Klobuchar	NeQuick
GPS	East (m)	-0.064 ± 0.040	-0.155 ± 0.039	-0.144 ± 0.048
	North (m)	-0.018 ± 0.042	0.082 ± 0.099	0.456 ± 0.071
	Up (m)	-0.910 ± 0.363	-4.438 ± 0.199	-2.111 ± 0.124
GPS + GLO	East (m)	0.065 ± 0.051	-0.085 ± 0.091	-0.173 ± 0.084
	North (m)	-0.566 ± 0.126	-0.718 ± 0.105	-1.033 ± 0.159
	Up (m)	0.171 ± 0.473	-2.803 ± 0.547	-0.007 ± 0.127

Table 1. Statistical (average and standard deviation) comparison of the GPS-only and multi-constellation (GPS+GLONASS) solutions with the GIMs, Klobuchar and NeQuick ionospheric model corrections for the receiver situated in Trieste on 27th January 2016.

Brasilia u-blox	Positioning Errors	GIM	Klobuchar	NeQuick
GPS	East (m)	-1.544 ± 0.019	-1.962 ± 0.074	-1.151 ± 0.060
	North (m)	0.261 ± 0.009	0.853 ± 0.038	0.249 ± 0.042
	Up (m)	0.702 ± 0.308	2.274 ± 0.517	2.597 ± 0.657
GPS + GLO	East (m)	-1.138 ± 0.034	-1.402 ± 0.047	-0.647 ± 0.066
	North (m)	0.562 ± 0.026	1.229 ± 0.058	0.449 ± 0.029
	Up (m)	-2.178 ± 0.672	-0.326 ± 0.174	1.144 ± 0.719

Table 2. Statistical (average and standard deviation) comparison of the GPS-only and multi-constellation (GPS+GLONASS) solutions with the GIMs, Klobuchar and NeQuick ionospheric model corrections for the receiver situated in Brasilia on 27th January 2016.

Figure 1 includes the root-mean square (RMS) values computed at the two locations. It is clearly observed that in mid-latitude GIMs maps and NeQuick corrections outperform Klobuchar model particularly in the vertical component. In the three cases the 3D error slightly decreases when including GLONASS in the PPP solution with a notable improvement in vertical and some degradation in the North direction. The GPS horizontal accuracy is degraded for the low-latitude scenario in the three cases (particularly the East component). When adding GLONASS the error using the GIM maps increases (particularly the average as shown in the Table 2); while the other two models slightly improve the 3D error of the GPS standalone solution.

3. Summary

This study aims at testing the applicability and accuracy of different ionospheric correction algorithms upon mass-market receiver solutions with the perspective of a future use in real-time kinematic positioning applications. Preliminary results were obtained from a surveying campaign conducted with mass-market receivers under different ionospheric scenarios. These test confirm that in mid-latitude GIM maps are reliable and outperform the other alternatives whereas in low-latitude the error still includes a notable bias which is comparable to the other two alternatives (particularly it is degraded when adding GLONASS). Moreover, NeQuick and Klobuchar solutions improve in a 3D basis when adding GLONASS (with a small degradation in the North dimension). This research is a preliminary step to test the accuracy of mass market receivers situated at middle and low latitudes for different positioning purposes such high altitude platform for tracking and high-precision applications, attitude control and determination for space applications.

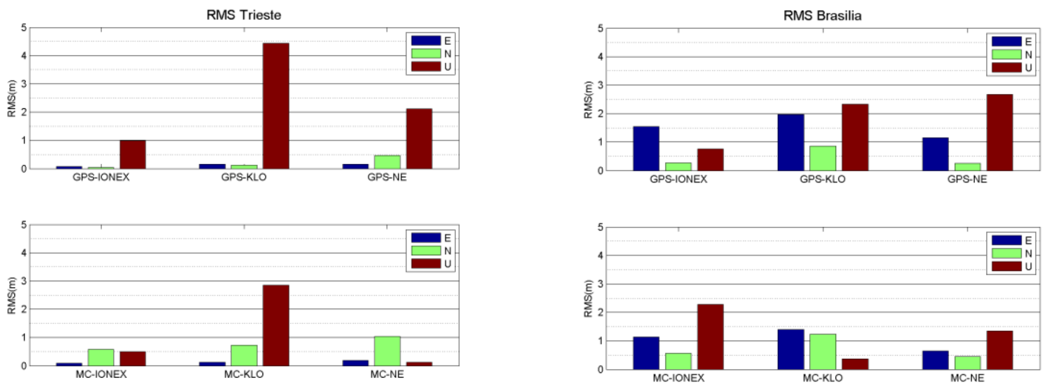

Figure 1**.** Root-mean square (RMS) of the positioning solution errors computed with GIMs, Klobuchar and NeQuick ionospheric model corrections at Trieste (left column) and Brasilia (right column). For both columns first line is referred to the GPS only solution, while the second one to multi-constellation solution (GPS and GLONASS).

4. References

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