GreenLab: autonomous low power system extending multi-constellation GNSS acquisition in Antarctica

L. Mossucca (1), L. Pilosu* (1), P. Ruiu (1,2), G. Giordanengo(1), S. Ciccia (1,2), G. Vecchi (2), O. Terzo (1)
V. Romano (3,4), L.Spogli (3,4), C. Cesaroni (3), I. Hunstad (3) and A. Serratore (3).
(1) Istituto Superiore Mario Boella, Torino, Italy
(2) Politecnico di Torino, Torino, Italy
(3) Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy
(4) SpacEarth Technology, Roma, Italy

Abstract

The opportunity to extend monitoring campaigns in Antarctica, overcoming the limitations of the current fixed installations and getting data directly on-field, becomes increasingly attractive for researchers and scientists. The GreenLab is an energy-efficient and self-sufficient system specifically conceived for critical environments. It is equipped with a multi-constellation GNSS receiver and low power systems for computing and communications. Exploiting an automatically reconfigurable antenna, the GreenLab enables a real-time sharing of received data with the base station while optimizing power consumption. This paper presents the deployment and validation of the first GreenLab prototype, during the XXXII summer campaign in Antarctica. Acquired data have been compared to existing GNSS receivers already installed in Antarctica in fixed observatories, with encouraging results.

1. Introduction

The Antarctic observatories are a great resource for scientific communities of different fields: astrophysics, magnetism, biology adaptation, evolution of the earth's crust and climate change are only some of them. Antarctica is one of the best locations on the Earth for investigating the electromagnetic propagation in the ionosphere and studying phenomena related to the interactions between the Sun and Earth.

The work presented in this paper is focused on the analysis of the ionosphere, which is the largest contributor to the Global Navigation Satellite System (GNSS) error budget. In particular, ionospheric scintillation is one of the most harmful and interesting effects.

At present, critical environmental conditions and logistic difficulties in polar regions (e.g., power supply and network outside the bases) are such that the experimental acquisitions are almost exclusively carried out within the base stations. In the case where remote stations are available, the acquired data are not shared in real time with the base station.

The GreenLab aims to be an alternative to this scenario, acquiring and pre-processing data directly on field (remote stations), and sending them to the base station.

2. GreenLab architecture

The GreenLab is an autonomous, disposable system powered by renewable sources, equipped with low power processing and wireless communication technologies. It is composed of four main blocks, as shown in **Figure 1**: power supply by renewable sources (i.e. photovoltaic panels); GNSS receiver (PolaRxS), low power computing for acquiring and pre-processing data; low power communications for transferring data to the base station.

Solar energy has been chosen as the main power source because, even if in winter the Sun never rises for several months in Antarctica, the solar radiation values are quite high during summer time (24 sun hours per day), which is the addressed season for the on-field experiments.

The first prototype of the GreenLab has been installed and configured in the Italian station “Mario Zucchelli”, in Terra Nova Bay, as an extension of the existing observatory [1]. This is the first attempt to test such type of solution in a harsh environment like Antarctica and **Figure 2** shows the first installation.

The installation is composed by two parts: *(i)* the *receiver module*, composed by the communication and storage devices, placed inside the base station and *(ii)* the GreenLab, hosted in a measurement station, 500 m far away from the base station. While *(i)* does not have particular constraints, *(ii)* is affected by some critical aspects, such as climatic constraints, power supply and management, distances and Line of Sight conditions for wireless communications.

In this area, temperature spans from a minimum of -35°C to a maximum of +8° C: this entails that all involved hardware in the prototype is able to operate in this temperature range, while commercial equipment usually works in standard temperature range from 0°C to +40°C.

The GreenLab is realized to be suitable for the critical environmental conditions of Antarctica, and it aims at being simply deployable on field, leveraging a new antenna technology for automatically discovering the receiver’s position without the need of an accurate pointing. The process flow of the GreenLab is composed by three sequential macro-tasks: (a) 24/7 continuous acquisition of raw data from a Septentrio PolaRxS GNSS receiver, (b) processing of the received data on the low power computing block, and (c) wireless transmission of pre-processed data to the receiver module.

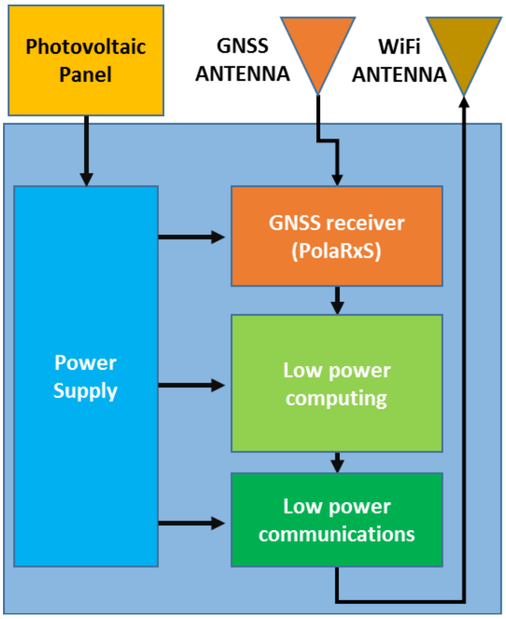

Figure 1. Block diagram of the GreenLab

After the acquisition of raw data from the GNSS receiver, the low power computing block runs a pre-processing algorithm to extract only the most significant information that will be sent to the base station. For this purpose, the this processing block is activated hourly, and powered off immediately after the elaboration in order to optimize power consumption.

The power supply module aims at optimizing power management, both gathering electrical energy from the photovoltaic panels and orchestrating the ON-OFF duty cycles of all the other modules. An *ad-hoc* firmware has been developed to minimize the power consumption of the whole system, using energy saving policies which allow to switch off modules as soon as they finish their tasks.

The low power communications block is devoted to transmit efficiently the pre-processed data coming from the low power computing block. A reconfigurable antenna, controlled by a Software Defined Radio algorithm has been chosen to improve communication link and to reduce power consumption [2].

Figure 3 shows the core components of the first GreenLab prototype.

3. Data acquisition and management

The Septentrio PolaRxS is a receiver capable to sample the GNSS L-band signals from GPS (L1, L2 and L5), GLONASS (L1 and L2) and GALILEO (E1, E5a and E5b) constellations [3]. Starting from raw measurements of the phase and amplitude of the signals taken at 50 Hz sampling rate, the PolaRxS is able to calculate every minute the slant values of the phase (σ_Φ) and amplitude (S4) scintillation indices on all available frequencies from all satellites in view [4, 5]. PolaRxS is able also to provide 1-minute measurements of the uncalibrated Total Electron Content (TEC) and of the rate of TEC change (ROT).

Figure 2. GreenLab installed in Mario Zucchelli Station

After the acquisition of GNSS signals, data are stored on a local hard drive and organized in two main sets: (*i)* raw data and (*ii)* pre-processed data.

Raw data, being of a significant size (up to 1.5GB/day), are only stored locally into the GreenLab. Pre-processed data, whose size is almost 30 MB/day, are forwarded to the wireless transmitter and sent directly to the receiver module, that is always active, waiting for incoming data. These data, being of smaller size and thus easier to be transferred with the limited resources available in the base, are shared almost in real time with the scientific community.

The building blocks of the low power communications system are the same for transmission and reception: a classical phased-array (formed by 4 patch antennas) coupled with a Beam-Forming Network based on phase-shifter, able to steer the antenna beam of about ±50° in the horizontal plane.

The signal acquired by the antenna is down-converted to baseband and digitized by exploiting a Universal Software Radio Peripheral (USRP) B200mini-i. It is a transceiver with the dimensions of a business card and can be employed in a frequency range from 70 MHz to 6 GHz. At the end of this processing chain, the signal is digitized, through an Analog to Digital Converter (ADC), and it can be elaborated by the communication board.

The digital stream is elaborated with a fully software implementation of a standard WiFi 802.11 receiver, which exploits the signal information to control the antenna and to optimize the direction and the power of the signal to be transmitted/received. The automatic pointing has been performed by a control board developed by ISMB through an interface that converts the digital signal coming from the SW to a voltage that it is able to steer the main beam.

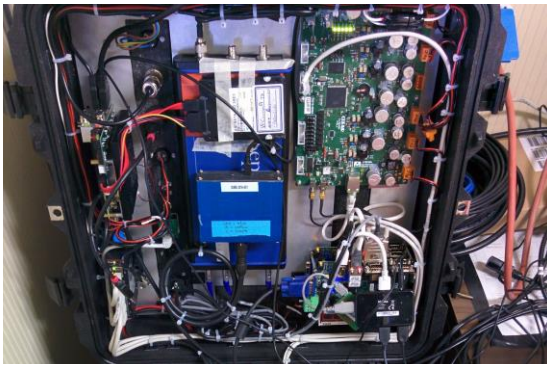

Figure 3. Core components of the GreenLab

For the specific test case, a point-to-point communication has been implemented and, to perform the link in a low-power perspective, the data collected and processed by the computing board are sent to the main station once an hour. In this way the power consumption is optimized since the board and all peripheral devices (e.g. antenna controller, USRP, etc.) are switched-on every hour only for the time to perform the transmission, allowing to further reduce the power consumption of the entire system.

4. Validation results

Data acquired from the PolaRxS receiver have been analyzed and tested against the acquisition of GSV4004 receiver [4]. A GSV4004 is present in Mario Zucchelli Station since 2006 and, similarly to PolaRxS, it is able to provide 1-minute values of σ_Φ, S_4, TEC and ROT starting from GPS L1 and L2 signals data. To perform such comparison, we focused on the data acquired during 24 December 2016, which was characterized by the presence of phase scintillation events in the second half of the day, as shown in **Figure 4**. To minimize the impact of the multipath, an elevation angle mask of 30° is applied to the data of both receivers. Moreover, to minimize the impact of the geometry of the satellite-receiver configuration, the slant values of both indices are projected to the vertical, as described in [6, 7], assuming the ionosphere as a single thin irregular layer located at 350 km. The criticalities of the index verticalization are critically reviewed in [8].
Hereafter we refer to the vertical values of the phase and amplitude scintillation indices as σ_Φ and S_4, respectively. **Figure 4** reports Time profiles of ROT (top), σ_Φ (middle) and S4 (bottom) as recorded by the GSV4004 (panels a) and the PolaRxS (panels b) receivers on 24 December 2016. Colors represents different satellites in view. Both receivers are able to catch the phase scintillation events, highlighted with blue shaded rectangles. No meaningful enhancement of S_4 is found, confirming again that the phase scintillation is most probable to occur at high latitude with respect to amplitude one [6]. In correspondence with the bulk of the scintillation events, the ROT values enhance, confirming the presence of the meaningful electron density gradients, leading to scintillation [7].

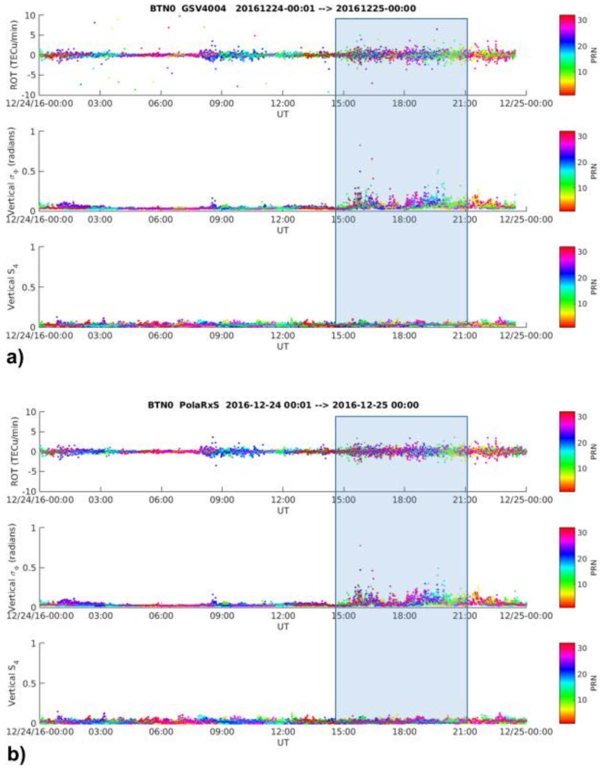

Figure 4. Time profiles of ROT (top), vertical σ_Φ (middle) and vertical S_4 (bottom) as recorded by the GSV4004 (panels a) and the PolaRxS (panels b) receivers.

To better highlight the capability of the GreenLab in catching the scintillation events, a scatter plot reporting the values of σ_Φ by both receivers on 24 December 2016 is reported in **Figure 5**.

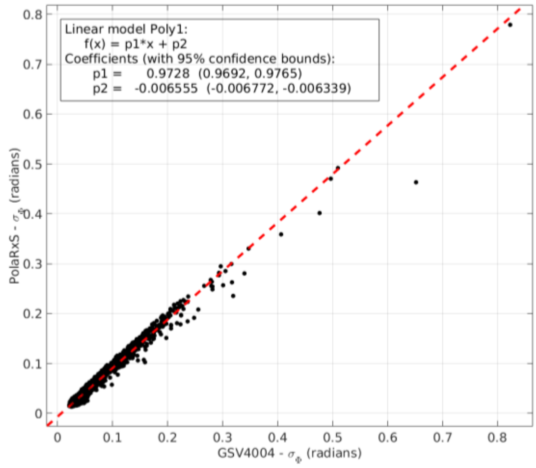

Figure 5. Scatter plot of vertical σ_Φ from GSV4004 (x axis) and PolaRxS (y axis). Red dashed lines indicates the linear fit, whose results are reported in the box.

The agreement between the two independent measurements is demonstrated by the linear fit (red dashed line in the figure), whose angular coefficient and intercept are 0.97 and -0.01 radians, respectively.

5. Final remarks

The provision of real time data acquired in very hard conditions, like the Antarctica ones, is very challenging for many reasons, both environmental and logistic. In fact, outdoor installations are exposed to extreme climate, while fixed observatories are tightly bound to the base where they are deployed.
The GreenLab is an all-in-one, self-powered solution integrating a GNSS receiver, a data-logger with a pre-processing cluster and a wireless communication system with an automatic pointing system. It allows to extend the measurements campaigns to remote sites and to make data available to the base station in real time. The technological innovations implemented in this prototype allow to move it in different locations while it automatically reconfigures the wireless antenna in order to point exactly towards the base station optimizing the transmitted power.
This solution has been realized and tested on field in Antarctica, during the XXXII summer campaign at the Italian base "Mario Zucchelli", and the recorded data are being saved continuously.
The goodness of data recorded from the GreenLab has been validated, compared to an existing fixed receiver.

6. Acknowledgements

The authors are grateful to the PRNA-Programma Nazionale di Ricerche in Antartide for supporting the project "Upper atmosphere observations and Space Weather" within PNRA D.C.D. 393 del 17/02/2015 PNRA14_00110 - Linea A1 and to all contributors: CLEAR elettronica Srl, SOLBIAN energie alternative Srl and ENEA.

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