

Installation and configuration of an Ionospheric Scintillation Monitoring Station based on GNSS receivers in Antarctica

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Antarctica**

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Segreteria di Redazione

Francesca Di Stefano - Referente

Rossella Celi

Tel. +39 06 51860068

redazionecen@ingv.it

in collaborazione con:

Barbara Angioni (RM1)

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Rapporti tecnici INGV

INSTALLATION AND CONFIGURATION OF AN IONOSPHERIC SCINTILLATION MONITORING STATION BASED ON GNSS RECEIVERS IN ANTARCTICA

Nicola Linty¹, Ingrid Hunstad²

¹Politecnico di Torino (Dipartimento di Elettronica e Telecomunicazioni)

²INGV (Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti)

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Introduction

Global Navigation Satellite Systems (GNSSs), such as the US Global Positioning System (GPS), The Russian GLONASS or the European Galileo, are space-based navigation systems. GNSSs enable a generic user located anywhere on the Earth to determine in real time his Position, Velocity and Time (PVT), by means of a Radio Frequency (RF) electro-magnetic signal, the Signal-In-Space (SIS), transmitted by a constellation of satellites orbiting around Earth.

Uninterrupted Positioning, Navigation, and Timing (PNT) solution is determined by GNSS receivers, which continuously process the SIS from the satellites in view. GNSS receivers are part of the GNSSs ground segment. They are a suboptimal implementation of a maximum likelihood estimator of the SIS propagation time. The PNT solution is indeed based on the computation of the SIS Time Of Arrival (TOA), according to the satellite and receiver local clocks. This is achieved thanks to the presence of a different Pseudo Random Noise (PRN) spreading code in the modulated SIS broadcast by each satellite. In the GNSS receiver, the incoming signal is correlated with a local replica of signal code, obtaining the time difference information. The time difference is then transformed into a range information by multiplying it by the speed of light in the vacuum. However, since the receiver clock is not synchronized with the transmitters clock, this measure suffers of time bias, which is considered as an additional unknown in the navigation solution. Finally, the user position is determined on an Earth centred reference system with a process denoted trilateration, by exploiting the range information computed by the receiver and the information contained in the SIS navigation message, such as satellite ephemeris [Kaplan et al., 2005].

1.1 The impact of ionosphere in GNSS positioning

As GNSS signals propagate through the Earth's atmosphere, they undergo severe propagation nuisances, such as phase shifts, group delays and amplitude variations. Ionosphere is the largest and more variable cause of errors in single frequency GNSS receivers [Shanmugam et al., 2012].

GNSS signals are affected by the ionosphere both in terms of a temporal delay and of scintillations. The ionospheric delay is due to the refractive index of the plasma. When a GNSS signal crosses the ionosphere, a delay in the spreading code and an advance in the carrier phase are introduced. If these effects are not accounted for, the measurements result is corrupted by significant errors. There are several possibilities to compensate for the ionospheric delay: differential techniques; double frequency measurements; corrections broadcast by augmentation systems; or theoretical models of the ionosphere, like Klobuchar and NeQuick.

On the other hand, ionospheric scintillations are amplitude and phase fluctuations caused by non-regular distributions of electron concentration and rapid changes in the electron density. Ionospheric scintillations are frequent in Equatorial and Polar Regions; however, because of the different ionospheric morphology, they manifest with different characteristics. While amplitude fades are more intense at low latitudes, as a consequence of higher ionization levels, increased velocity disturbances lead to strong phase scintillations over the Poles. Unlike ionospheric delay, these phenomena cannot be empirically modelled. Both amplitude and phase scintillations can have a serious impact on the receiver performance: the measurements can be heavily corrupted, resulting in positioning errors of tens of meters or, in the most severe cases, in the complete receiver blackout. Scintillation effects on GNSS are particularly harmful for navigation and geodetic applications, because they are hard to predict and can challenge the receiver's ability to hold lock on a signal. For these reasons, ionospheric errors have to be identified and corrected.

1.2 GNSS-based ionospheric monitoring

If on one hand GNSS receivers performance is severely affected by scintillation, on the other hand GNSS receivers can be successfully used as alternative tools for upper atmosphere monitoring at low and high latitudes.

The amount of scintillation affecting a signal can be determined by exploiting the correlation outputs of a GNSS receiver tracking stage. Two indices are usually considered: S_4 and σ_ϕ . S_4 measures the amount of amplitude fluctuations due to scintillations in GNSS signals. It corresponds to the normalized standard deviation of the detrended Signal Intensity (SI) computed from the in-phase and quadrature-phase prompt correlation samples. σ_ϕ measures the phase scintillation and is calculated as the standard deviation of the detrended carrier phase measurements. Both indices are calculated over a varying observation interval; typically it is equal to 60 seconds (σ_ϕ is then known as Phi60) [Van Dierendonck et al., 2001]. Another

parameter commonly useful to characterize the ionosphere is the Total Electron Content (TEC). The presence of a big number of electrons in the ionosphere results in a higher delay, and thus in a more degraded performance. The slant TEC (sTEC) represents the number of free electrons in a cylinder of 1 m diameter along the SIS propagation path, while the vertical TEC (vTEC) represents the same quantity on a vertical cylinder. The rate of change of the TEC with respect to time is called ROT; ROT is then a measure of ionospheric irregularities with respect to time.

Commercial and professional dual frequency custom hardware GPS receivers, known as Ionosphere Scintillation Monitoring Receivers (ISMRs), have been successfully employed for a long time as measurement tools to provide post-correlation data used for modelling the atmospheric phenomena [Romano et al., 2013]. Nevertheless, recent trends in GNSS receivers implementation also consider Software Defined Radio (SDR) as a valuable technology, which enables access to intermediate and low level receiver processing stages. With respect to commercial hardware tools, they provide a larger subset of observables related to the signal processing stages, as well as a high grade of flexibility and re-configurability, depending on the user needs [Lo Presti et al., 2014].

GNSSs broadcast a variety of different signals, both civilian and military, and all of them are affected by ionospheric delay and scintillation. The most widely known and used is the GPS civilian L1 Coarse Acquisition (C/A) signal, in the L1 band (centred at 1575.42 MHz). Recently, a second and a third civilian signals have been added to the GPS constellation, namely the L2C signal and the L5 signal, respectively in the L2 band (centred at 1227.60 MHz) and in the L5 band (centred at 1176.45 MHz). So far only a subset of GPS satellites actually transmits these signals, but they are more and more used for position purposes and for scintillation monitoring. Galileo, Glonass and Beidou broadcast similar signals on the same frequency bands. In particular, the Galileo civilian signals are the E1B and E1C in the L1 band, and the E5a and E5b in the E5 band (centred at 1191.795 MHz). In order to process signals from different constellations and from different bands, proper antennas and receivers are required.

1.3 The DemoGRAPE project

This paper describes the installation and configuration of a SDR-based GNSS receiver and of a professional ISMR in Antarctica. The activity has been carried on in the frame of the project “DemoGRAPE – Dimostratore per GRAPE” (Demonstrator for GRAPE, <http://www.demogrape.net/>), coordinated by the National Institute of Geophysics and Volcanology (Istituto Nazionale di Geofisica e Vulcanologia, INGV). The Italian National Program for Research in Antarctica (Programma Nazionale di Ricerche in Antartide, PNRA) funded the project and the expedition in the framework of the XXXI Italian expedition in Antarctica.

The aim of DemoGRAPE is to improve the quality of the GNSS positioning in polar regions. The demonstrator, able to assess the corruption induced by ionospheric propagation on GNSS signals and to share data and results by means of a federated cloud infrastructure, will enable the development of new scientific and technological applications in Antarctica. Furthermore, a better knowledge of the ionospheric behavior in these singular regions could improve the reliability of global models, thus extending the advantages of this research to GNSS users worldwide.

In particular, for the first time, we have installed in Antarctica, parallel to a professional ISMR, an innovative GNSS data acquisition systems, based on radio frequency front-ends and on a SDR GNSS receiver [Peng and Morton, 2013; Curran et al., 2014; Linty et al., 2015]. These systems are based on a two-step signal analysis:

- acquisition from the antenna of the raw GNSS signal: a stream of digital samples sampled at high frequency (up to 30 MHz) and quantized at high resolution (up to 16 bits);
- post-processing of the raw data through a receiver entirely developed in software.

This approach presents several advantages, in terms of flexibility, configurability of the receiver, possibility to replay the events, installation cost and access to intermediate measurements, usually not available in a commercial receiver.

2. Installation overview

This paper refers specifically to the installation, configuration and maintenance of a GNSS-based ionosphere monitoring station in the Antarctica research station *Estação Antártica Comandante Ferraz* (EACF), which took place from November 8 to 16, 2015. However, the procedures described can be easily generalized for future installations in similar environments.

EACF is a permanent Antarctic research station, managed by the Brazilian Antarctic Program (*Programa Antártico Brasileiro*, PROANTAR). The station is located in the Admiralty Bay (*Baía do Almirantado*), in King George Island, near the tip of the Antarctic Peninsula, 130 km from South America. The coordinates of the station are reported in Table 1.

Latitude	Longitude	Altitude
62° 5'7.86"S	58°23'29.32"O	8 m AMSL

Table 1. Location of EACF station.

A GNSS multi-frequency and multi-constellation antenna has been installed on the main station module (*Modulo Antártico de Emergencia*, MAE), on a mast about 4 meters high. A 30 meters cable connects the antenna to the receivers, located in the lab inside the MAE. Pictures of the antenna installation and of the antenna location in the MAE are reported in Figure 1. The station is oriented in the direction North-South, the antenna is located in the South-East corner of the station.

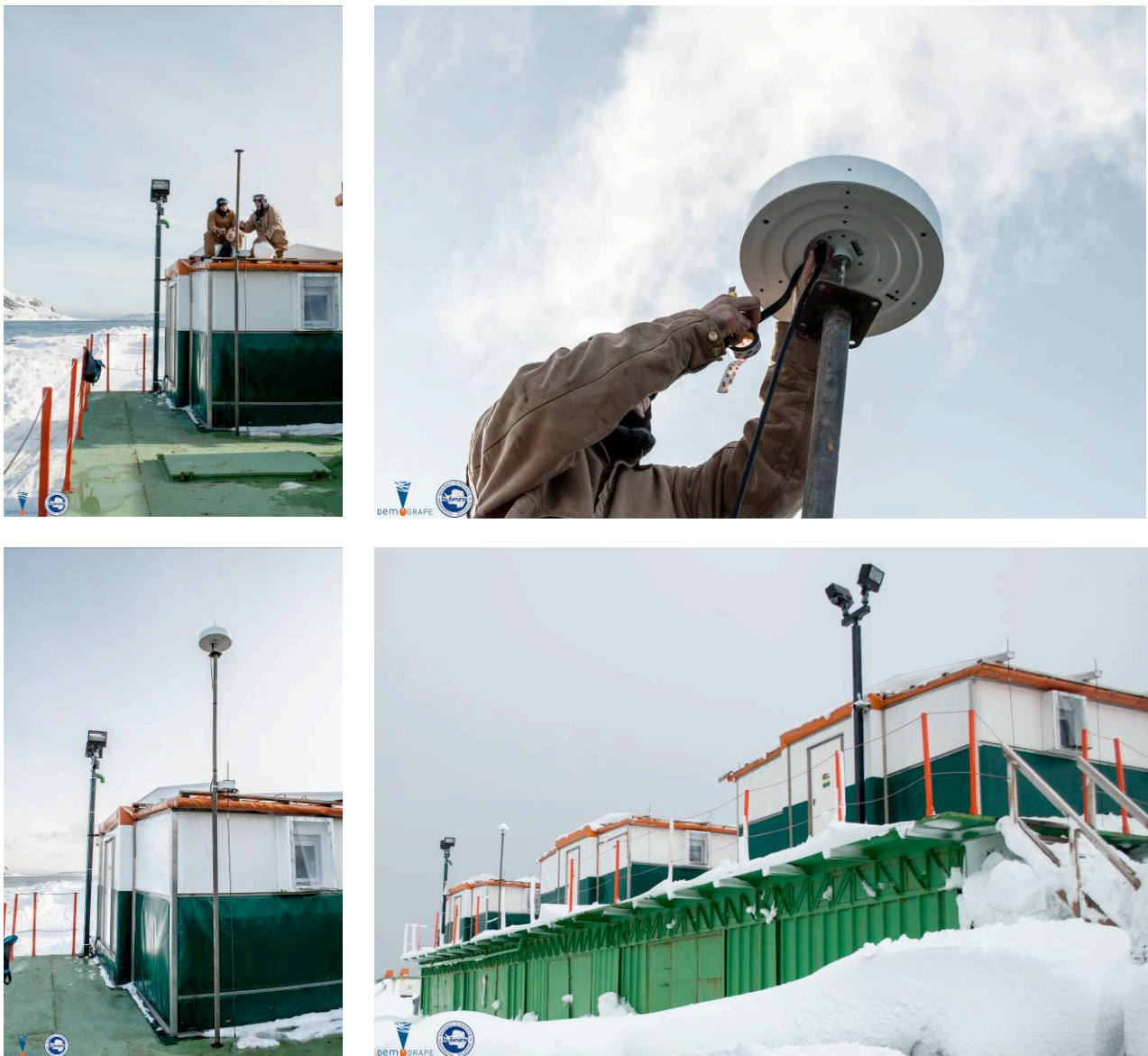


Figure 1. Installation of the GNSS antenna on the MAE in EACF.

The monitoring station has been installed in the principal lab of the station EACF. Pictures of the lab installation are reported in Figure 2.

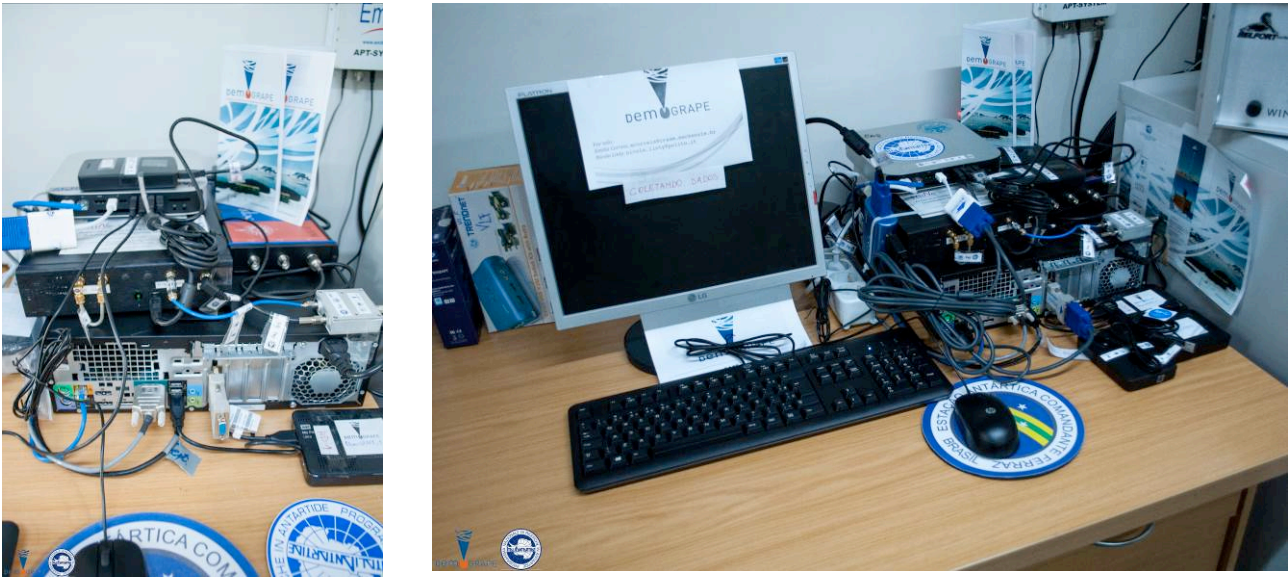


Figure 2. Installation of the receivers in the EACF lab.

3. Description and block diagram of the installation

The DemoGRAPE ionosphere monitoring station installed in EACF includes three GNSS receivers:

- a Septentrio PolaRxS PRO professional ISMR, particularly suited for ionospheric monitoring in the L1, L2 and L5 bandwidths and able to process GPS, Galileo and Glonass signals (in the upper-left frame of Figure 3);
- an experimental GNSS raw data acquisition system based on a four-band RF front-end, called *4tuNe*, developed by the Joint Research Centre (JRC) of the European Commission (<https://ec.europa.eu/jrc/en/about/jrc-site/ispra>), and on a SDR-based receiver (upper-right frame of Figure 3);
- a second experimental raw data acquisition system, based on the use of Universal Software Radio Peripherals (USRPs), a Rubidium atomic clock and a SDR receiver, sketched in the lower frame of Figure 3.

While the first two systems are permanent, the third was installed and used only during the stay in the research station.

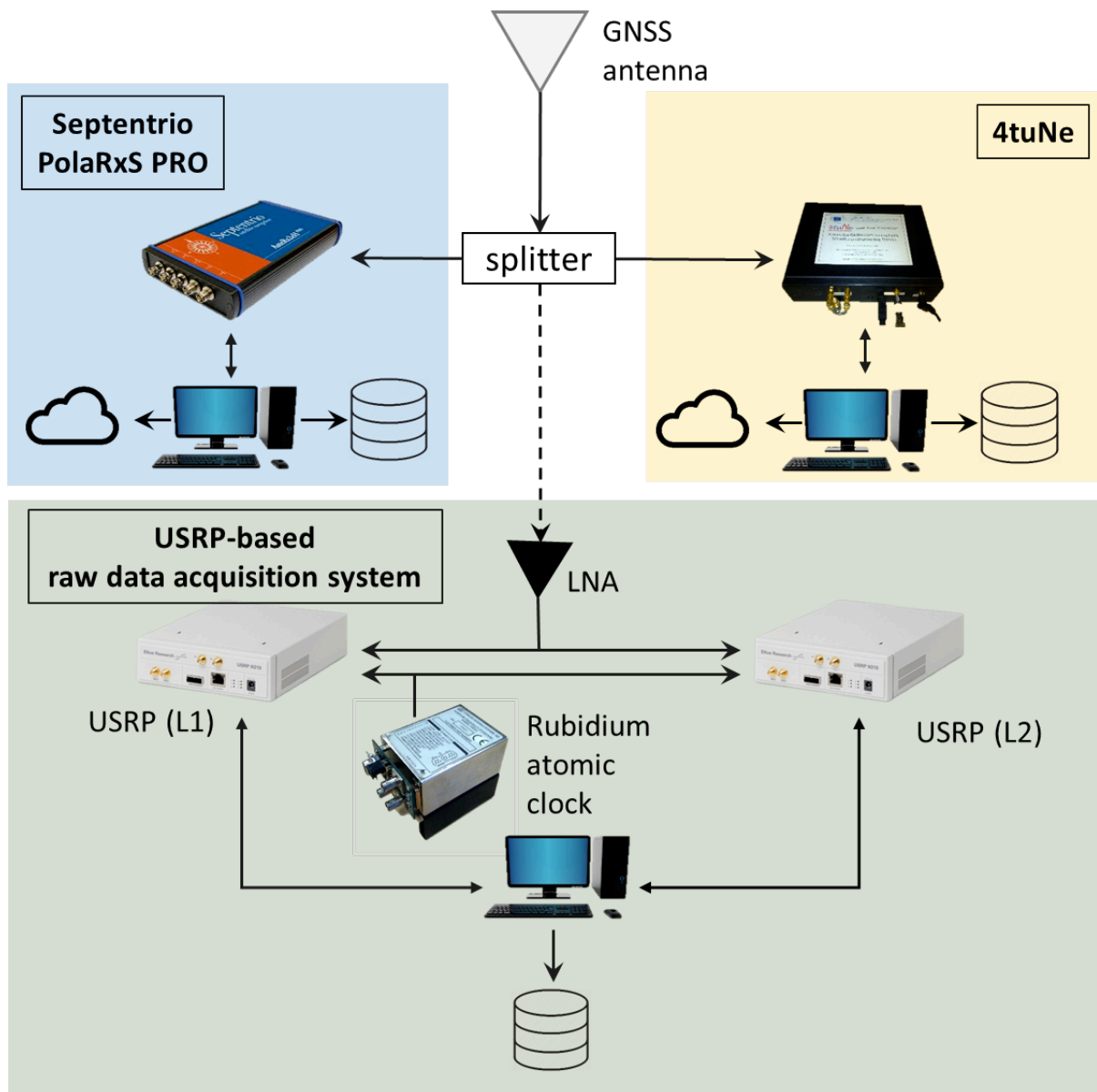


Figure 3. Block diagram of the DemoGRAPE ionosphere monitoring station in EACF.

More in details, the permanent installation of the DemoGRAPE ionosphere monitoring station (upper part of Figure 3) includes:

- a Septentrio 700031 GNSS choke ring antenna, installed outside the station (Figure 1);
- a 30-meters antenna cable, connected to a 2 ways splitter:
 - 1st way to the Septentrio receiver. The receiver powers the antenna. The receiver is then connected to a Linux workstation (running Ubuntu 15.4, 32 bits, operating system), for receiver configuration (with Septentrio *RxTools* software) and data storing to:
 - external hard drives;
 - a network shared folder.
 - 2nd way, equipped with a DC block to prevent the flow of direct current frequencies, connected to the SDR-based data acquisition system *4tuNe*. The box is then connected to a computer (Apple MacMini running Microsoft Windows 7 operating system), for grabbing raw GNSS data and post-processing them with the SDR receiver. Raw data and results of the post-processing are then stored to:
 - external hard drives;
 - a network shared folder.

The following devices require power supply and have been connected to an Uninterruptible Power Supply (UPS), to guarantee complete functionalities in case of a power outage.

- Linux workstation
- MacMini computer
- Monitor (optional during maintenance)
- *4tuNe* front-end
- Septentrio receiver

4. Data acquisition set-up

This section describes the GNSS data acquisition strategy adopted for both the ISMR and the SDR-based receiver.

4.1 Septentrio receiver

The Septentrio PolaRxS PRO and the Linux Workstation have been configured according to the steps reported below. For further information, refer to the Septentrio *RxTools* manual [Septentrio, 2015]. The username of the Linux machine considered in this example is *demogrape*.

- a) Check the Linux Ubuntu installation; note that some problems were experienced with Ubuntu 64 bits distributions when using the software provided by Septentrio.
- b) Check the power management in the workstation BIOS, to enable the power-on option and the automatic daily wake up, in case of power outage or electrical problems.
- c) Check that the serial ports of the PC are owned by root, by typing on the terminal:

```
ls -la /dev/tty*
```

if not, type:

```
su -u root chmod 660 /dev/ttyS0
```

- d) In order to access the serial ports, used by the Septentrio receiver, the user must be part of the *uucp* group. To modify, edit the file */etc/group*, by changing three lines as follows:

```
uucp:x:10:uucp,demogrape
dialout:x:20:demogrape
tty:x:5:demogrape
```

- e) Reboot the workstation to update the settings.
- f) Check all the available serial ports to connect the receiver to the PC, typing the command:

```
dmesg | grep tty
```
- g) Connect the antenna cable to the receiver.
- h) Connect the USB cable on the receiver's COM3-4/USB port and on the workstation USB 3.0 port.
- i) Connect the serial cable on the receiver's COM2 port and on the workstation serial port.
- j) Connect the power cable of the receiver.
- k) Install the Septentrio *RxTools*; the *RxTools* uses two different programs to connect the PC to the receiver: *RxControl* and *RxLogger*.
- l) Open the *RxControl* and create a serial connection using the correct port.
- m) Check the version of the firmware of the Septentrio receiver by creating a *Diagnostic file* (File, Display Diagnostic Report); the version is reported in the section *Connected Receiver Information* and should be at least 2.9.0 for ionosphere monitoring.
- n) Open the *RxLogger* and create a USB connection using the correct port. The *RxLogger* must be configured for scintillation and TEC monitoring, as follows:

- a. Create a new file (*startup-script.sh*), containing the 3 following lines:

```
setAGCMode, all, frozen
setTrackingLoopParameters, all,,,,,off
setCN0Mask, all, 15
```

- b. In the main window of *RxLogger*, select the *Global* tab: set the *Log Directory* (e.g. *home/demogrape/DATA/*); check the box *SBF Messages*; enter the location of the startup script created at point a.; check the box *Always resend the script if the connection is lost*.
- c. Select the *File Naming* tab and set the field *File Naming Convention* to IGS 15 minutes. Then click on the *Set Station Settings* button, select the tab *Station Settings* and set the

following parameters related to the SBF file name:

<i>Marker name</i>	Septentrio
<i>Marker number</i>	<serial number of the receiver>
<i>Marker type</i>	PolaRxS Pro
<i>Observer Agency</i>	INGV

d. Select the *SBF* tab and create the 5 streams clicking on the button *Add Stream* as follows:

<i>Stream</i>	<i>Interval</i>	<i>Parameters</i>
Stream A	20 ms (50 Hz)	IQCorr
Stream B	1 s (1 Hz)	MeasEpoch MeasExtra
Stream C	10 s	ReceiverStatus ChannelStatus ReceiverSetup
Stream D	“on change”	GPSNav GLONav GALNav CMPNav QZSNav
Stream E	15 s	Rinex

e. Select the *Post Processing* tab and add two conversions:

- ISMR conversion: SBF ISMR conversion, with standard values and no compression;
- Rinex conversion: SBF Rinex conversion, with standard values, no GPS Navigation and no compression.

o) Start logging by pressing the *Start Logging* button.

It is important to periodically check the status of the receivers and of the logger; this can be done by checking the *Status* tab, by creating a *Diagnostic Report*, or by opening the expert console (*RxControl*, then *Tools*, *Expert Console*). For further information, refer to the *RxTools* Manual [Septentrio, 2015].

With these settings, *RxLogger* creates an SBF (Septentrio Binary Format) file and it calls the two converters every 15 minutes. Hence, three types of files are saved:

- Septentrio proprietary SBF files, with extension `.15_` (where 15 is the year, 2015);
- Septentrio proprietary ISMR files, with extension `.ismr`;
- Rinex files, with extension `.15N` (where 15 is the year, 2015).

In addition to the configuration of the Septentrio *RxLogger* software, the computer has been specifically configured and tuned to account for the needs of the remote installation.

- The Linux workstation BIOS has been configured to automatically restart in case of power outage.
- The Linux workstation has been configured to automatically launch the *RxTools RxLogger* after a reboot, exploiting the tool *Startup Applications*. More in details, a script called `Unlock-Start-RxLogger.sh` (reported in Appendix 8.4) is launched at power-on, and performs the following operations:
 - o renames the serial lock files (present in the case in which the *RxLogger* is not properly switched off), to allow the serial communication link to be established);
 - o launches the *RxLogger* with the `-A` option (start previous configuration and start logging immediately).
- All the files are saved in the local folder `/home/demogrape/DATA`.

With the present receiver configuration, one full day of files corresponds to about 1.5 GB. Therefore it is expected that the full capacity of the disk (1.9 TB) will be reached after about 1250 days. Since the installation is expected to end after one year, the files are kept in the local drive without any compression.

- Every day at 05:00 local time, all the files collected the previous days are zipped and copied to an external hard drive, as a backup. At the same time the same folder, but without the raw files, is

copied to a shared folder (`/mnt/data-demogrape/`) for cloud synchronization (See Section 5.4). Both operations are performed by the script `ExternalDriveBackup.sh`, reported in Appendix 8.2.

- Every five minutes a script called `checkSSH.sh` checks if the SSH tunnel is on, if not, it opens the SSH tunnel again. More details about the SSH tunnel are reported in Section 5.4.
- The file `/etc/apt/apt.conf` has been properly modified to enable certain commands using the proxy server. The file is reported in Appendix 8.3.
- The file `~/.bashrc` has been modified to enable certain programs using the proxy server. The modified lines of the file `~/.bashrc`, are reported in Appendix 8.5.
- The file `~/.profile` has been modified to add the proxy password, by adding the lines reported in Appendix 8.6, to avoid password prompt when using the SSH tunnel.

4.2 SDR-based receiver

Both SDR receivers have not a strict configuration scheme. This is due to the fact that they represent a research tool rather than a final product. In addition, the philosophy behind the SDR approach makes it very flexible regarding configuration. Having access to the raw data represents indeed the possibility to post-process them with any possible configuration.

For this reasons the parameters of the software receiver are free and not included in this paper. Suggested parameters for the data acquisition related to the front-end are reported in Table 2; however, all of them can be modified according to the needs and purposes of the users.

Sampling frequency (L1)	5 MHz
Sampling frequency (L2)	5 MHz
Sampling frequency (L5)	30 MHz
Quantization (L1)	1 bit or 2 bytes, depending on the front-end chosen
Quantization (L2)	1 bit or 2 bytes, depending on the front-end chosen
Quantization (L5)	6 bit or 2 bytes, depending on the front-end chosen
Sampling format	IQ
Intermediate frequency	0 Hz or about 4 kHz, depending on the front-end chosen
Data chunk duration	50 minutes
Elevation mask	20 degrees

Table 2. Suggested configuration for the SDR-based GNSS data acquisition.

The price payed for the high configurability and flexibility of the SDR approach is the huge dimensions of the raw data files. With any of the configuration reported in Table 2 it is common to reach the throughput of 1 GB of data per minute. For this reason, it is not possible to store all the data acquired in a campaign. In the frame of the activity of the DemoGRAPE project, a rule has been established to automatically determine whether to keep the raw data or not, depending on the presence of interesting ionospheric events during the time interval. The software routine controlling the front-end has then be configured to perform the following cyclic operations:

1. grab a chunk of raw GNSS data;
2. quick post-processes the data in L1, saving the values of the Carrier-to-Noise power density ratio (C/N_0) and of the scintillation indices (S4 and Phi60) in a log file;
3. depending on the value of the C/N_0 , the S4, the Phi60 and of the satellites elevation, decide whether scintillation has occurred, and thus whether to keep or not the raw data;
4. keep in any case the log files.

This algorithm allows to keep under control the acquisition system and to save interesting raw data for further post-processing in the lab. Clearly, any parameter can be configured and properly tuned according to the needs and the constraints, in order to improve missed detection and false alarm rates.

5. Data management and transfer

This section describes the strategy adopted for data files management, naming and transfer.

5.1 Septentrio output files

Septentrio files are saved:

- in a local folder of the Linux workstation;
- in an external hard drive, for backup in case of failure of the workstation;
- in a local folder mapped on the network and shared with a server located in Italy (see Section 5.4).

The name of the output files follows the following format:

- 3 characters identifying the site (e.g. EAF for *Estação Antártica Comandante Ferraz*);
- 1 progressive number, starting from 0, for each receiver installed;
- 1 letter identifying the receiver type (e.g. P for PolaRxS);
- one underscore;
- 3 characters, indicating the date mark in Julian day;
- 1 letter, indicating the hour of the day (from a to x); small case indicates a periodicity of 15 minutes;
- 2 numbers indicating the minutes incrementing by 15 (00, 15, 30, and 45);
- a dot;
- 2 numbers, indicating the year (e.g. 15 for 2015);
- some characters indicating the file type
 - o an underscore for the SBF files;
 - o N for Navigation RINEX files;
 - o O for Observation RINES files;
 - o .ismr for the ISMR files.

Example: EAF0P_297a00.15_

5.2 SDR-based data acquisition system output files

SDR receiver log files are saved:

- in an external hard drive, along with raw files;
- in a local folder mapped on the network and shared with a server located in Politecnico di Torino, Italy.

The name of the output files follows the following format:

- 3 characters identifying the site (e.g. EAF for *Estação Antártica Comandante Ferraz*)
- 1 progressive number, starting from 0, for each receiver installed;
- 1 letter identifying the receiver type (e.g. N for NavSAS software receiver);
- an underscore;
- 6 characters identifying the date in the format YYMMDD;
- an underscore;
- 6 characters identifying the time of the day in the format HHMMSS;
- an underscore;
- 3 characters, indication of the time coordinate (e.g. UTC);
- an underscore;
- 4 characters, identifying the front-end (e.g. USRP, or 4tuNe);
- an underscore;
- 2 characters, identifying the bandwidth (L1 or L2);
- a dot;
- the extension (binary files .bin, .dat, .grab, or log files .zip, .png);

Example: EAF0N_151030_235400.UTC_USRP_L1.bin

5.3 Data transfer and network limitations

As described above, all data from both receivers are saved locally and in an external hard drive. In addition, a selection of data is transferred to a server in Italy. Despite the fact that network resources in the Antarctica station are limited, expensive and not reliable, it is important to constantly keep a communication link between EACF and Italy in order to:

- monitor the status of the receivers and eventually tune their configuration;
- receive the output data of the receiver and share them through a federated cloud infrastructure.

All the computers are connected to the network through an Ethernet interface with a fixed IP address. In order to access the internet, a proxy server with authentication has to be configured. In addition, most of the ports of the proxy servers are closed, and it is not possible to change the proxy configuration. Therefore, tricky solutions have been adopted for transferring the data. In the following section the procedure followed to transfer files in the case of the Linux computer and Septentrio receiver is reported. A similar procedure has been followed for the SDR-based acquisition system.

5.4 Septentrio Linux workstation data transfer

In order to overcome the limitations of the network interface, an HTTP-SSH tunnel has been created, exploiting the `connect-proxy` program. The `~/.ssh/config` file has been modified, enabling the use of SSH with the proxy. The content of the file is reported in Appendix 8.4. A line containing the proxy password has been added in the `~/.profile` file to avoid the password prompt, especially in the case of automatic procedures, as reported in Appendix 8.6. A local folder, which is used as a Network File System (NFS) network folder, named in this case `data-demogrape`, has been created in the `/mnt` folder with the command:

```
sudo mkdir /mnt/data-demogrape
```

An SSH tunnel towards the server in Italy is created with the command:

```
ssh -fN -L 1234:123.000.0.0:1234 demogrape@123.000.0.0
```

where `123.000.0.0` is the IP of the server in Italy, `1234` is the port used and `demogrape` is the name of the user of that server (the true IP address and port number are substituted with false ones, for safety's sake). In order to ensure that the SSH tunnel is always on, a script called `checkSSH.sh` and reported in Appendix 8.7 is used and managed by the Linux crontab, as described in Section 5.5. Then the NFS folder is mounted; this can be done temporary, with the command:

```
sudo mount -o port=1234 -t nfs4 localhost:/exports /mnt/data-demogrape
```

or permanently, by adding in the file `/etc/fstab` the following line:

```
localhost:/exports /mnt/data-demogrape nfs auto,port=1234 0 0
```

In this way, any file saved in the `/mnt/data-demogrape/` folder is automatically backed-up the server in Italy.

5.4.1 Monitoring from Italy

In order to check and get the content of the NFS folder from Italy, it is possible to launch the following command on a linux machine:

```
sudo mount -t nfs -o port=1234 123.000.0.0:/exports <path-to-your-folder>
```

where `<path-to-your-folder>`, for example `/home/user/demogrape-data-folder`, is a folder in the Linux computer that will contain the files transferred from EACF station. The access to the server requires authentication.

Alternatively, an FTP interface allows an easier access to the data. It is an Apache installation that provides access to the shared folder via a web browser (i.e., it allows to visualize and navigate the content of the shared folders). It is possible to access it pointing the web browser to the proper IP address, with the proper port, and by typing the credentials when authentication is required.

5.5 Scheduled tasks and maintenance procedures

In the Linux workstation, the Linux cron controls some operations. The following lines were added to the crontab:

```
0 5 * * * /home/demogrape/ExternalDriveBackup.sh
5 * * * * /home/demogrape/checkSSH.sh
```

As described in Section 4.1, the script `ExternalDriveBackup.sh` creates a copy of some files in an external hard drive and on a shared NFS network folder, while the script `checkSSH.sh` constantly checks that the SSH tunnel is on.

The actions reported in Table 3 have to be performed periodically by personal involved in the maintenance.

Action	Who	When
Check the presence and the consistency of the data in the network folders	Team in Italy	Daily (suggestion)
Manage the NFS folder	Team in Italy	When required
Delete the files in the local /mnt/data-demogrape folder after successful transfer, to avoid full disk state	Team in Italy	When required
Backup of all the data in an external hard drive and shipping to Italy	Person in EACF	At the end of his stay in EACF

Table 3. Periodical actions for installation maintenance.

6. Preliminary results

This section reports a few early results, with the main purpose to show and prove that the set-up is properly working. First, Figure 4 shows the signal quality report, generated by the Septentrio PolaRxS PRO receiver at the end of the receiver configuration; this confirms the excellent quality of the installation.

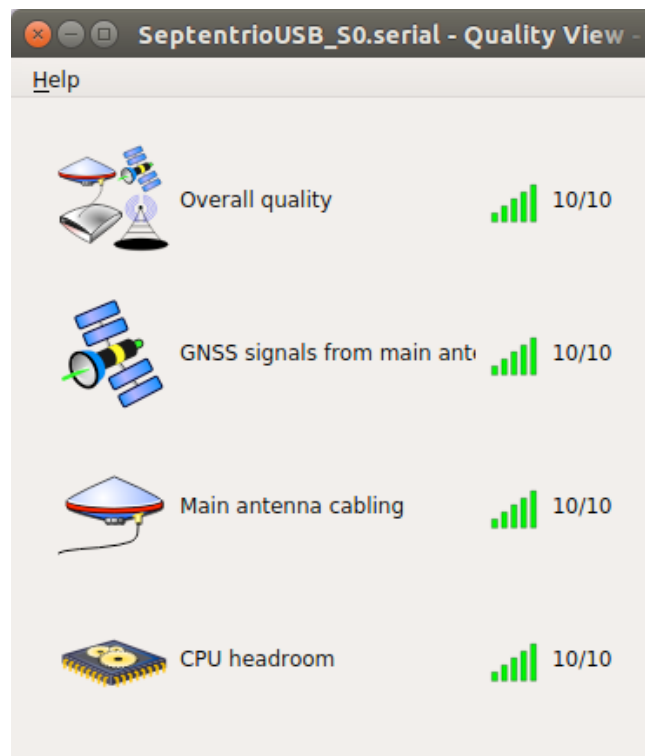
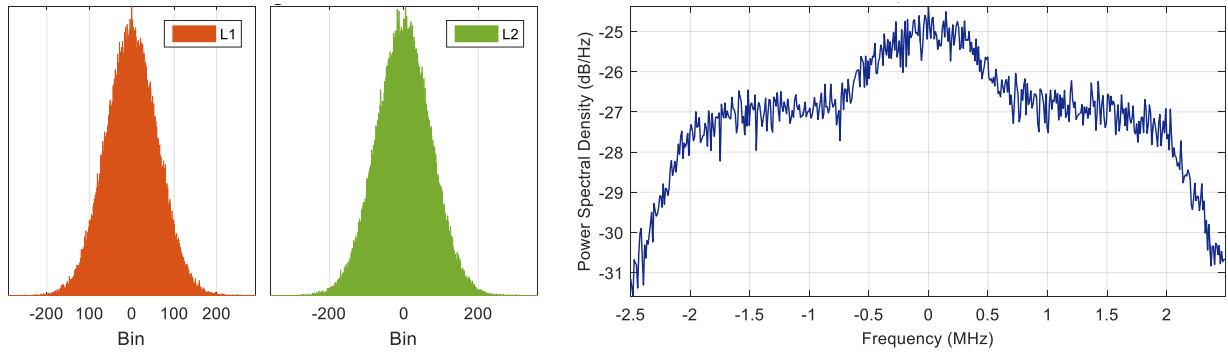


Figure 4. Quality report generated by the Septentrio *RxTools* software.

The following results are relative to a block of raw GNSS data collected with Septentrio and USRP-based receivers during the expedition in Antarctica, on November 13, 2015 (Julian day 319), from 09:30 to 10:05 UTC.

A first tool to validate the quality of the raw GNSS signals grabbed with the SDR-based data acquisition system is the time and frequency pre-correlation analysis. Figure 5a shows the histogram of a portion of the samples in the L1 and in the L2 frequency bands, grabbed with the front-end based on the USRP. In both cases, as expected, the shape follows a Gaussian distribution, meaning that the front-end is correctly grabbing raw GNSS data. The dynamic of the signal after the analog to digital conversion is in the

range $[-300; +300]$. This means that about 10 bits of quantization, out of the 14 bits offered by the USRP, are actually used. Figure 5b reports the frequency spectrum of the signal in L1. The typical shape of the main lobe of the GPS L1 C/A signal can be recognized in the portion around $[-0.5 \text{ MHz}; +0.5 \text{ MHz}]$. Most of the power of the signal is contained in the portion around $[-2 \text{ MHz}; +2 \text{ MHz}]$, because of the filtering process within the front-end. The spectrum is very clean, smooth and no harmful peaks, due to interference from other electromagnetic emissions, are present.

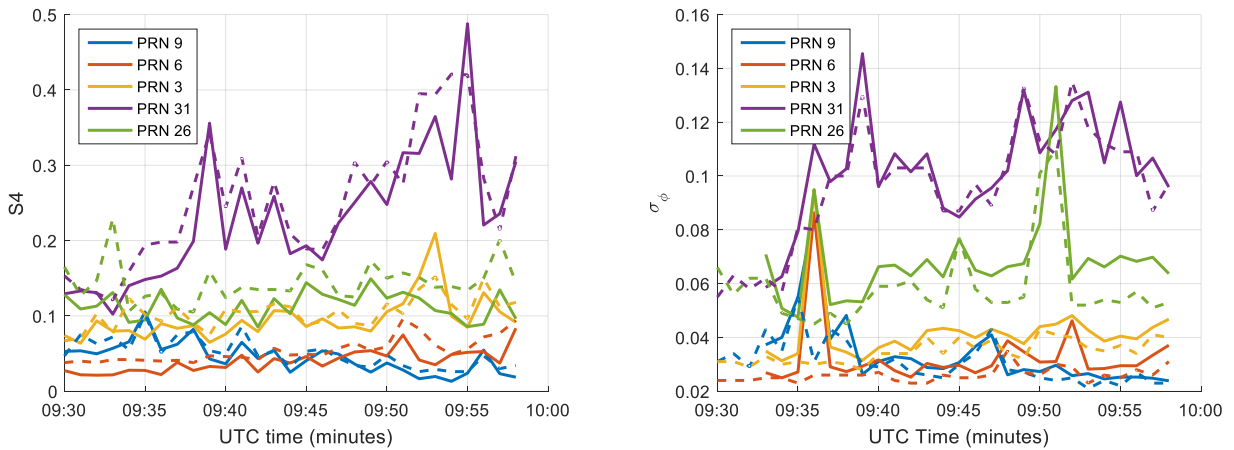


a) Histogram of the samples

b) Frequency spectrum

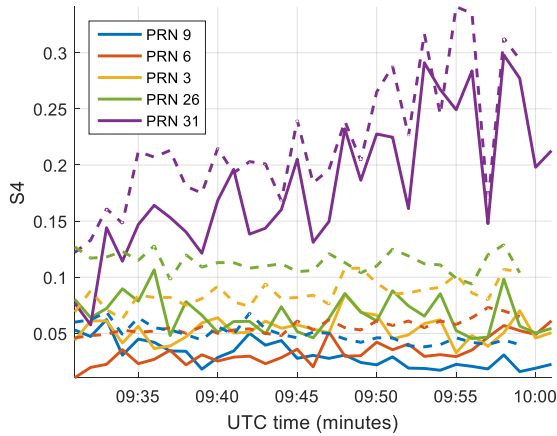
Figure 5. Raw samples analysis in L1 and L2 bandwidths.

Figure 6 shows the scintillation indices as computed by the two receivers installed at EACF station. Upper plots are referred to GPS L1 C/A signals, lower plots to GPS L2C signals. Left plots report the amplitude scintillation index S_4 , while right plots report the phase scintillation index σ_ϕ . The dashed line is related to the results of the Septentrio PolarXs PRO professional receiver, while the continuous line shows the indices as computed by the software receiver post-processing raw GNSS data grabbed with the URSP-based configuration.

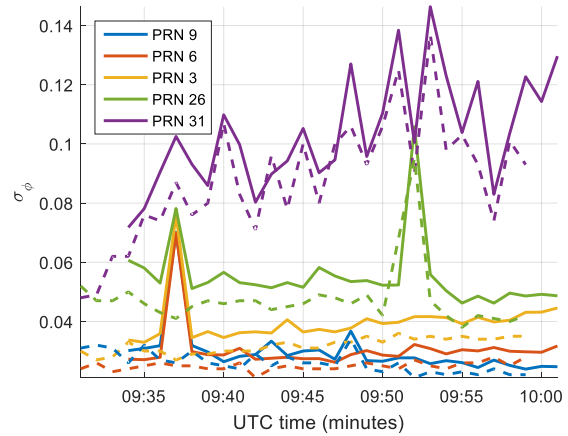


a) Amplitude scintillation, GPS L1 C/A signals

b) Phase scintillation, GPS L1 C/A signals



c) Amplitude scintillation, GPS L2C signals



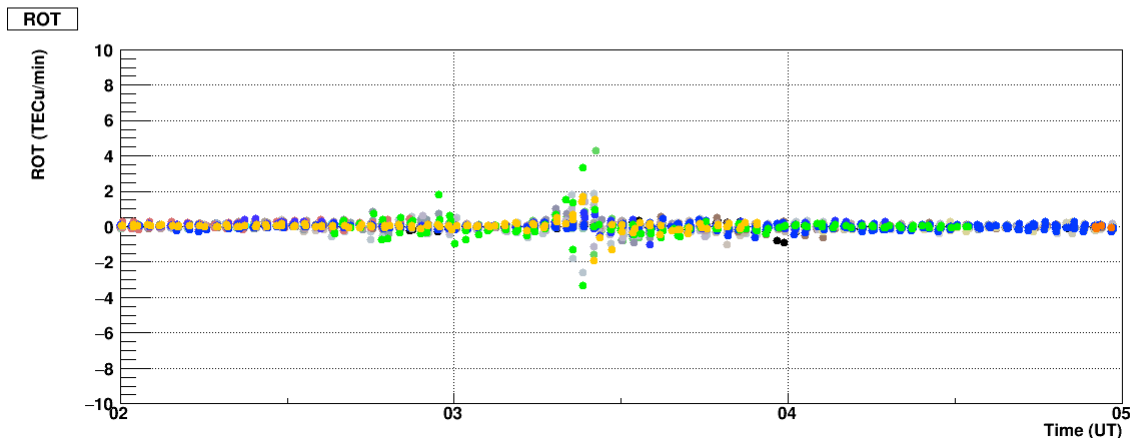
d) Phase scintillation, GPS L2C signals

Figure 6. Amplitude and phase scintillation index on GPS L1 C/A and L2C signals – SDR-based receiver (continuous line) vs. Septentrio (dashed line) – EACF, November 13, 2015.

Unfortunately, no strong scintillation events have been detected during the first days of the campaign; therefore both the S_4 and the σ_ϕ are below the scintillation threshold, usually set to 0.4. Only the signal identified by PRN 31 exhibits slightly higher S_4 value; this is due to its low elevation and multipath effect. However, the results are representative of the potentialities of the ionosphere monitoring station. What is more, the good match between the results of the two receivers is a confirmation of the validity of the software approach in monitoring ionosphere, as an alternative to ISMRs.

Similar plots are automatically generated daily for monitoring purposes, using the data received through the cloud infrastructure. In the case in which a scintillation event is detected it is possible to raise an alert and to deeply investigate it. Further and updated results can be found in [Linty et al., 2016].

Figure 7 reports the plots of ROT and σ_ϕ during a moderated geomagnetic storm, on May 16, 2016. Both plots have been generated by processing the ISMR and RINEX files shared with the cloud infrastructure. Each colour is related to the signal from a different satellite, including GPS L1 C/A, Glonass L1 and Galileo E1 signals. The ROT, reported in the upper part of the figure, is a measure of ionospheric irregularities. While most of the time ROT values are bounded in the interval $[-1 \text{ TECu/min}; +1 \text{ TECu/min}]$, around 03:30 UTC two satellites exhibits higher values, symptoms of moderate geomagnetic activity. This is confirmed by the Phi60 phase scintillation index, reported in the bottom plot. Phi60 values pass the scintillation threshold, equal to 0.4 rad, on the same time instants.



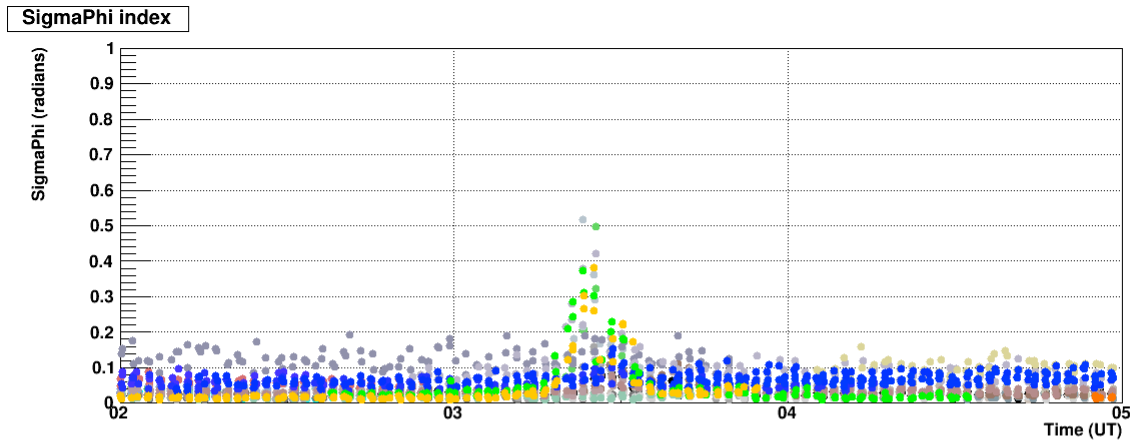


Figure 7. ROT and Phi60 values estimated by the Septentrio PolaRxS receiver on GPS L1 C/A, Galileo E1 and Glonass L1 signals - May 16, 2016.

7. Conclusions

This paper reports the procedure followed to install, configure and maintain a scintillation monitoring station based on commercial and experimental software-based GNSS receivers, in a remote and challenging environment such as an Antarctica research lab. A solution to several issues is proposed and some suggestions for the receivers configuration are given. A quick overview on the first preliminary results is also provided.

8. Attachments

This section reports useful scripts and files configurations.

8.1 Script `UnlockStartRxLogger.sh`

The content of the script `UnlockStartRxLogger.sh`, used to automatically launch the Septentrio *RxLogger* at the startup, is reported hereafter. It first renames the `USB.serial.lock` and the `SERIAL.serial.lock` files, which keep the ports locked in case of power fails, to `USB.serial` and `SERIAL.serial`; then it starts *RxLogger* with `-A` option.

```
#!/bin/bash

# This is a script to automatically rename the USB.serial.lock and the
# SERIAL.serial.lock that keep the ports locked in case of power fails,
# to USB.serial and SERIAL.serial, then starts RxLogger - A

# User settings
LOCKED_RxLogging_FILE='DemoGRAPE_USB.serial.lock'
LOCKED_RxControl_FILE='DemoGRAPE_serial.serial.lock'

UNLOCKED_RxLogging_FILE='DemoGRAPE_USB.serial'
UNLOCKED_RxControl_FILE='DemoGRAPE_serial.serial'

cd /home/demogrape/.septentrio

if [ -e "$LOCKED_RxLogging_FILE" ]; then
  mv $LOCKED_RxLogging_FILE $UNLOCKED_RxLogging_FILE
fi

if [ -e "$LOCKED_RxControl_FILE" ]; then
  mv $LOCKED_RxControl_FILE $UNLOCKED_RxControl_FILE
fi

cd ../RxTools
./runRxlogger -A
```

Note that:

- DemoGRAPE_USB.serial.lock and DemoGRAPE_serial.serial.lock are the name of the USB and serial connections created during the receiver configuration;
- demogrape is the username of the Linux machine.

8.2 Script ExternalDriveBackup.sh

The content of the script `ExternalDriveBackup.sh`, used to launch the backup the Septentrio results, is reported hereafter. It saves the data of the day before on an external hard drive and on a network shared folder using *rsync* protocol.

```
#!/bin/bash

# This is a script to automatically save backup files of the Septentrio RxLogger
on the external hard drive

#####
# Backup on the external hard drive the outputs of the day before
#####

# Name the input file, according to Septentrio convention:
# y is the year, j is the Julian day. We need yesterday's Julian date.
# This works also on January 1st
IF=`date +%y%j -d "yesterday"`

# The output file is the same with .tar.gz extension
OF="$IF.tar.gz"

# Move to the output data folder
cd /home/demogrape/DATA

# Compress the content of the folder in a .tar.gz file to save space
tar czf $OF ./${IF}/*

# And move it to the external hard drive; then delete the local archive
rsync --remove-source-files -vh $OF /media/demogrape/DemoGRAPE_1/data # >
/home/demogrape/DATA/CopyLog.txt

# Compress the content of the folder, without raw files, in a .tar.gz file
tar czf $OF ./${IF}/*.ismr ./${IF}/*.o

# And move it to the NFS folder; then delete the local archive
rsync --remove-source-files -vh $OF /mnt/data-demogrape/ # >
/home/demogrape/DATA/CopyLogNfs.txt
```

Note that:

- demogrape is the username of the linux machine;
- /home/demogrape/DATA is the location of the Septentrio output data;
- media/demogrape/DemoGRAPE_1/data is the location of the data folder in the external hard drive;
- /mnt/data-demogrape is the location of the network shared folder.

8.3 File /etc/apt/apt.conf

The content of the file /etc/apt/apt.conf, modified to configure proxy authentication, is reported hereafter.

```
Acquire::http::proxy
"http://<proxy_user>:<proxy_password>@<proxy_address>:<proxy_port>/" ;
Acquire::https::proxy
"https://<proxy_user>:<proxy_password>@<proxy_address>:<proxy_port>/" ;
```

Note that:

- <proxy_address> is the address of the proxy server;
- <proxy_password> is the password for the proxy authentication;
- <proxy_user> is the username for the proxy authentication;
- <proxy_port> is the port of the proxy server.

8.4 File ~/.ssh/config

The content of the file ~/.ssh/config, modified to configure proxy authentication for the proxy-command program, is reported hereafter.

```
# Outside of the firewall, with HTTPS proxy
Host 123.000.0.0
  ProxyCommand connect -H <proxy_user>@<prozy_address>:<proxy_port> %h 22
# inside the firewall (do not use proxy)
Host *
  ProxyCommand connect %h %p
```

Note that:

- <proxy_user> is the username for the proxy authentication;
- <proxy_address> is the address of the proxy server;
- <proxy_port> is the port of the proxy server.

The program does not allow to include the authentication password; to overcome the problem the password is saved in the `~/.bashrc` and `~/.profile` file, reported respectively in Appendix 8.5 and 8.6.

8.5 File `~/.bashrc`

The last lines of the file `~/.bashrc`, modified to configure proxy authentication, are reported hereafter.

```
http_proxy=http://<proxy_address>:<proxy_password>@<proxy_user>:<proxy_port>
export http_proxy
https_proxy=https://<proxy_address>:<proxy_password>@<proxy_user>:<proxy_port>
export https_proxy
```

Note that:

- <proxy_address> is the address of the proxy server;
- <proxy_password> is the password for the proxy authentication;
- <proxy_user> is the username for the proxy authentication;
- <proxy_port> is the port of the proxy server.

8.6 File `~/.profile`

The last lines of the file `~/.profile`, modified to configure proxy authentication, are reported hereafter.

```
export HTTP_PROXY_PASSWORD=<proxy_password>
```

Note that:

- <proxy_password> is the password for the proxy authentication;

8.7 Script `CheckSSH.sh`

The content of the script `CheckSSH.sh`, used to keep the SSH tunnel up, is reported hereafter.

```
#!/bin/bash

res=`ps aux | grep "ssh -fN -L 1234:123.000.0.0:4001 demogrape@123.000.0.0" |
wc -l`
# echo $res
tstamp=`date`
if [ $res -ge 2 ]
then
echo " SSH available"
echo -e "\n $tstamp - SSH tunnel available " >> /mnt/data-
demogrape/demogrape.log
else
export HTTP_PROXY_PASSWORD=<proxy_password>
ssh -fN -L 1234:123.000.0.0:1234 demogrape@123.000.0.0
echo " ERROR: ssh not found -> relaunch"
echo "\n $tstamp - SSH tunnel not found " >>
/home/demogrape/demogrape.error
fi
```

Note that:

- 123.000.0.0 is the IP address of the server in Italy
- 1234 is the port used by the SSH tunnel
- demogrape is the username on the server
- /mnt/data-demogrape is the local network shared folder
- <proxy_password> is the password for the proxy authentication
- demogrape.log and demogrape.error are log files

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Via di Vigna Murata, 605

00143 Roma

Tel. +39 06518601 Fax +39 065041181

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