Analysis of the ionospheric scintillations during 20-21 January 2015 from SANAE by means of the DemoGRAPE scintillation receivers

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Abstract

This paper presents ionospheric scintillation data recorded at SANAE in Antarctica during a moderate geomagnetic storm on 20-21 January 2016 which gives evidence of the advantages of the new generation of instrumentation for monitoring ionospheric scintillation. The data was collected as part of the DemoGRAPE project aimed at the demonstration of cutting edge technology for the empirical assessment of the ionospheric delay and ionospheric scintillations in the polar regions which affect the accuracy of satellite navigation.

1. Introduction

The accuracy of satellite navigation in Antarctica is important due to the dependence on GNSS for travel for fieldwork & search & rescue operations. There is always the danger that people and vehicles can fall into a crevasse during a snowstorm. Satellite navigation systems are often used when visibility is limited and travel is restricted to following well-demarcated routes. SANSA (South Africa) and INPE (Brazil) are key collaborators with INGV, ISMB and Politecnico di Torino on an international project DemoGRAPE which is designed to improve satellite navigation in Antarctica.

This paper presents ionospheric scintillation data recorded at SANAE in Antarctica during a moderate geomagnetic storm on 20-21 January 2016 which gives evidence of the advantages of the new generation of instrumentation for monitoring ionospheric scintillation.

The storm was caused by a slow partial halo Coronal Mass Ejection (CME) observed by SOHO LASCO at 23:00 UT of 14 January 2016. On 20 and 21 January, the geomagnetic activity was unsettled to active due to waning effects of the 14 January CME/erupting filament transit around Earth. Higher latitudes such as Antarctica was under active to major storm levels (IPS Daily Report). The daily average solar wind speed recorded by ACE satellite reached 473 km/s on 22 January 2016 (Space Weather Prediction Center, Boulder USA).

The scintillation data was collected as part of the DemoGRAPE project (http://www.demogrape.net/), aimed at the demonstration of cutting edge technology for the empirical assessment of the ionospheric delay and ionospheric scintillations in the polar regions which affect the accuracy of satellite navigation [1]. The deployment of the new-concept of GNSS data acquisition system was implemented by Politecnico di Torino, SANSA and INGV with support from the Joint Research Centre of the European Commission (JRC).

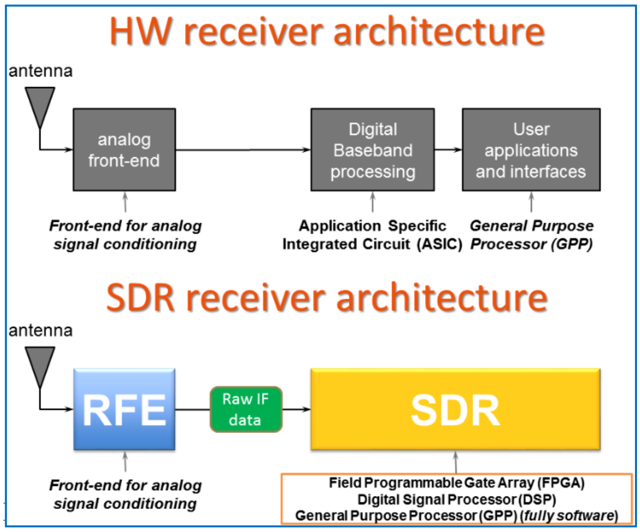
2. Data and Methods

DemoGRAPE equipment was been installed at the South African base (SANAE-IV) and Brazilian base (EACF) in Antarctica in October and December 2015 respectively. Installation includes a Septentrio PolaRxS Ionospheric Scintillation Monitoring Receiver (ISMR) and a new-concept of data acquisition system was installed at SANAE. The new system comprises a GNSS front-end and bit grabber and a GNSS software defined radio (SDR) receiver. It provides access to ionospheric delay and related measurements from not only the GPS (US) system of navigation satellites, but also to the Russian GLONASS and European Galileo satellites [3]. Software and data exchange is to take place via the Cloud computing infrastructure. The Septentrio and SDR share the same multiband choke-ring antenna mounted on top of the SANAE-IV building (Figure 1).

The ISMR sample GNSS signal amplitude and phase at 50 Hz and derive both RINEX data and 1 minute values of S4 and σ_φ. With SDR σ_φ indices can be derived up to 1 second intervals exploiting moving average filters. In the SDR approach, the GNSS analog signal is down-converted, digitized using an Analog to Digital Converter (ADC), and stored in memory as binary file (raw IF data) by the Radio Front-End (RFE). Raw IF data can then be post-processed by means of a fully software SDR-based GNSS receiver. In order to limit the volume of IF data generated by the RFE, the data collection is triggered by scintillation events exceeding predefined thresholds [2].

Figure 2 shows the concept and system architecture of a SDR-based receiver, compared to a traditional hardware GNSS receiver [3]. Quick look plots and compressed output files, generated by the software receiver, are sent to the data-node at SANSA every 24 hours. The scintillation measurements are compared to that of other space weather instruments co-located at SANAE, including magnetometers and radar data from the SuperDARN transceiver.

Figure 1. Antennas of the co-located GNSS receivers at SANAE, the South African Polar Research base in Antarctica. In the foreground is the antennas of the GPS and Novatel Scintillation receivers, and on the roof of the base (insert) is the antenna shared by the Septentrio PolaRxS PRO GNSS receiver and the software-based GNSS data acquisition system, comprising the 4tuNe front-end and a Software Defined Radio (SDR) GNSS receiver.



a SDR-based GNSS receiver as the one developed for the DemoGRAPE project.

3. Results

Figure 3 shows the variations in the components of the geomagnetic field at SANAE-IV for January 2016 showing the geomagnetic storm on 20-21 January which started by a 600 nT positive deviation on 20 January 2016 followed by a negative peak of 400 nT. The data in Figure 3 was recorded at 1 s intervals by means of a DTU 3-axis fluxgate magnetometer.

Figure 4 shows the monthly plot of the occurrence of 60 s phase scintillation parameters detected along ray paths from all three satellite configurations. Figure 5 presents the ionospheric scintillations detected during the period 18:00 to midnight on 20 January on the L1 frequency along ray paths from GPS and Galileo satellites. Figure 6 reports the phase scintillation index σ_ϕ during a strong scintillation event detected on January 20. In particular it refers to the GPS L1 C/A signal from PRN 7.

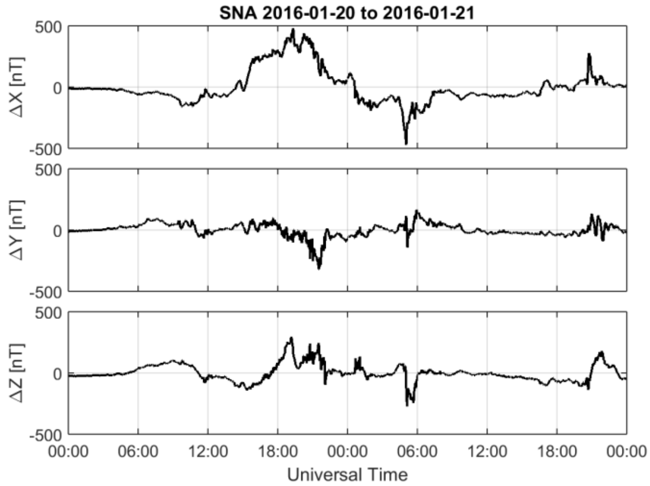


Figure 3. Recording of the variations of the components of the geomagnetic field at SANAE-IV for 20 January 2016.

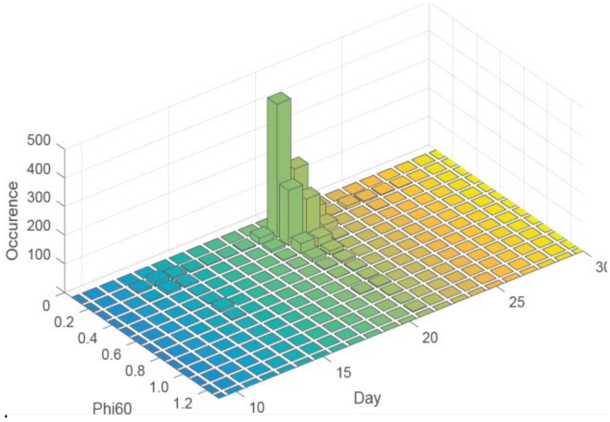


Figure 4. Monthly monitoring of the occurrence of 60 second phase scintillation parameters (Phi60) showing significant scintillation events detected at SANAE ((2.84^{0}W, 71.67^{0}S Mag 61.85^{0}S) on 20-21 January, 2016

The first consideration is on the good match between the estimates from the two instruments. This has already been proved in previous works on the topic [2, 3]. A second consideration is on the potentialities offered by the SDR-based post processing. The fully software GNSS receiver developed in the frame of the project and adopted in this configuration provides amplitude and phase scintillation indices at a higher rate with respect to the Septentrio receiver, exploiting moving average filters. This is possible thanks to the availability of raw IF data grabbed by the front-end during the event, and to the flexibility and possibility to reprocess data offered by the SDR approach.

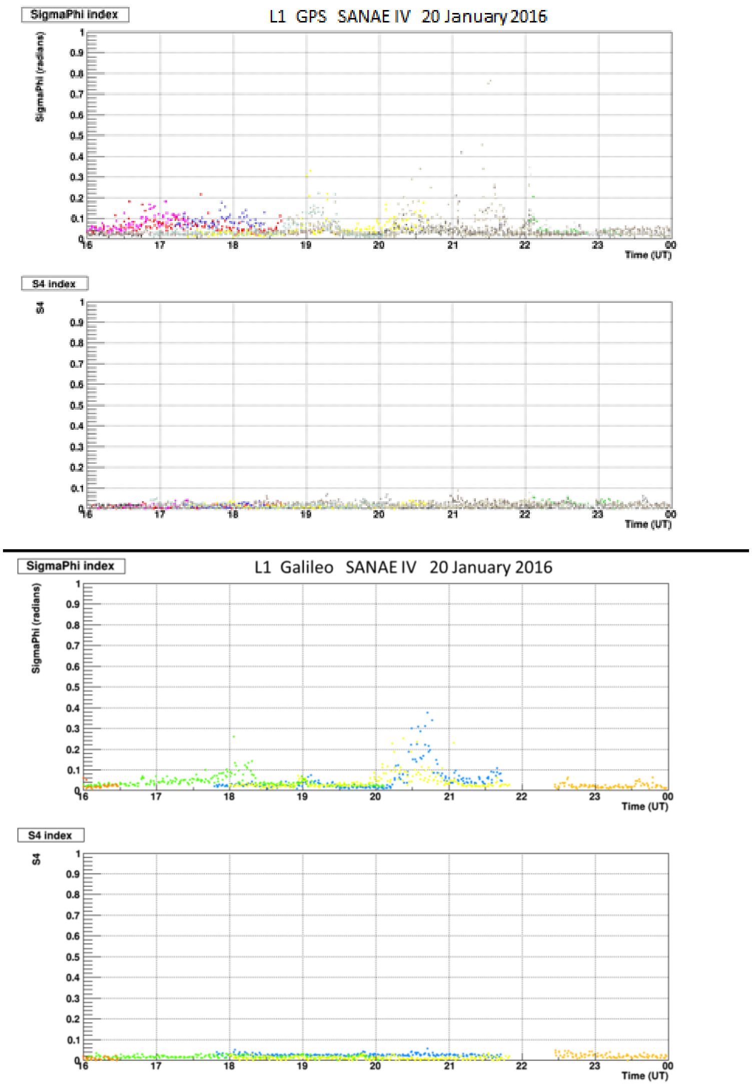


Figure 5. Recording of the ionospheric scintillations detected on 20 January on the L1 frequency along ray paths from GPS and Galileo satellites.

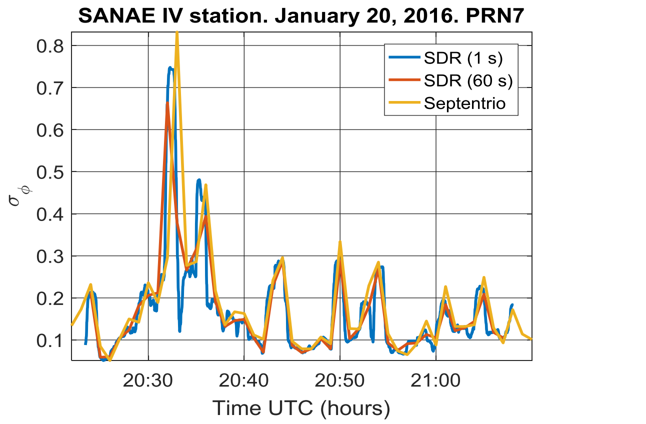


Figure 6. Comparison of the Phi60 index as computed by the Septentrio PolaRxS receiver and the SDR software receiver on GPS L1 C/A signals.

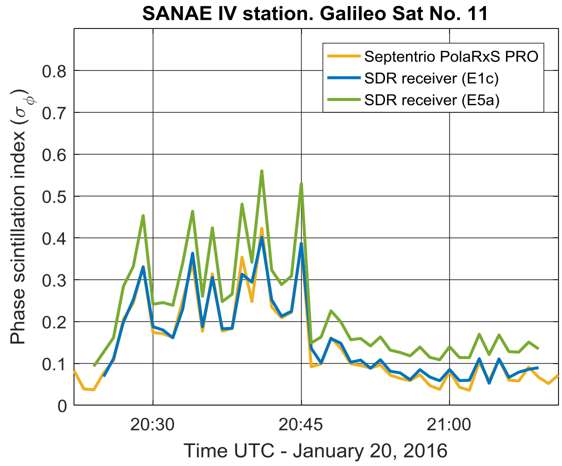


Figure 7. Phase scintillation index for Galileo satellites, in E1 and E5 bandwidth.

Despite the fact that each scintillation point is actually correlated with each other, the benefits of a higher resolution in the results are clear. The standard Phi60 index could actually mask some faster ionospheric behavior, as for example between 20:33 and 20:35 in Figure 6.

Figure 7 shows another advantage of the SDR approach for monitoring ionospheric scintillations. The GNSS front-end installed at SANAE station can grab GNSS signals in three different bandwidths (L1/E1, L2 and L5/E5a). The limited computational capabilities of the instruments used in the installation only allow to process in real time GPS L1 C/A signals. Nevertheless, the availability of the raw IF data captured by the front-end enables a post-process phase, exploiting most powerful machines and running updated software. In this case, raw data in the E1 and E5a bands were grabbed in January 20, and then post processed later on. The figure shows the phase scintillation index for Galileo PRN 11, both on E1c (pilot signal in the E1 bandwidth) and in E5a. The Septentrio E1 index is plotted as a reference. The reason of the small bias between the E1c and E5a plots is due to the well-known frequency dependence of scintillations. The influence of ionospheric perturbations is expected to be different for each frequency band, as ionosphere is a dispersive medium. In addition, the difference signal and code structures of each GNSS signals makes the algorithms for estimating the Phi60 slightly different, thus justifying some minor mismatch.

Similarly, Figure 8 reports the phase scintillation index, estimated by the SDR receiver, on GPS L1 and L5 signals, during the same event. A more detailed analysis of multi-constellation and multi-frequency observations is presented in [4].

Scintillation, as recorded here, is associated with the cusp and auroral oval. In Figure 9 (a) a SuperDARN convection map (see caption) is overlaid on a TEC grid and a map of the Antarctic on 20 January 2016 (17:35-17:40 UT). SANAE's location is marked at around -64^o magnetic latitude. The convection map, in combination with the TEC grid, allows us to identify the cusp region and broadly distinguish the auroral oval. The Heppner-Maynard Boundary (estimated in (a) as -54^o magnetic

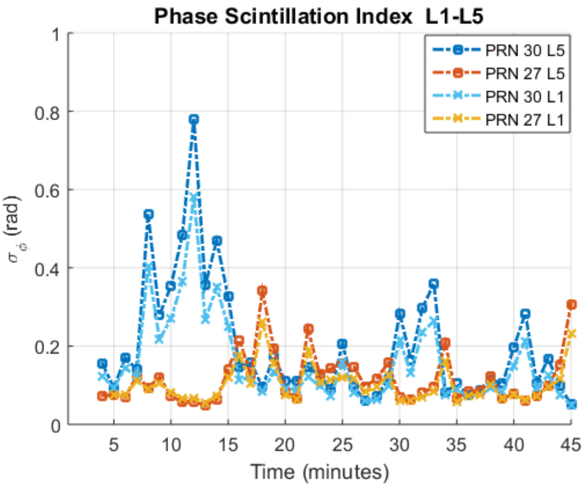


Figure 8. Phase scintillation index comparison between GPS L1 and L5 signals.

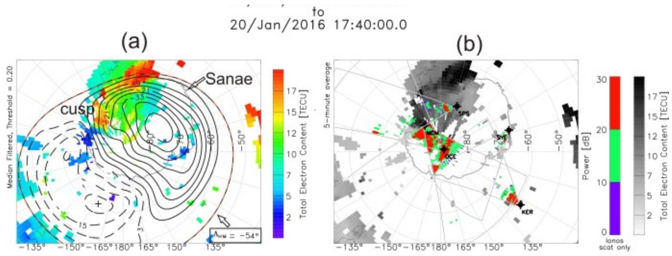


Figure 9. Combined TEC and SuperDARN plots for 20 January 2016 (17:35-17:40 UT). (a) TEC data is derived from the Worldwide GPS receiver network and has been median filtered (resolution 1° latitude by 2° longitude) and plotted on a geomagnetic grid. A SuperDARN convection map has been overlaid. This map is a unique representation of the ionospheric convection pattern obtained by combining all available SuperDARN Doppler velocity data with a spherical harmonic representation of the ionospheric electrostatic potential. (b) TEC is plotted (greyscale) together with backscattered power (5 minute averages) from some of the live radars. Strong returns are observed in the cusp, polar cap and auroral oval regions.

latitude) may be used as a rough proxy of the equatorward edge of the auroral oval. The poleward edge looks to be around -68° from TEC values. It may also be inferred that the regions of high TEC around 0-20° longitude connect to the high value TEC patch recorded at 70° longitude. These observations would lead us to conclude that SANAE is under the auroral oval at this time and scintillation would be expected. This is further corroborated by the plot (b). In this plot, TEC (in greyscale) is overlaid by active SuperDARN radars' backscattered power. Attention is drawn to the strong backscatter observed, in the latitude band in which SANAE lies, by the Kerguelen (KER) radar, indicating the presence of the auroral oval.

4. Discussion

The excellent correspondence between the data from the SDR-based receiver and Septentrio recorded on 20-21 January demonstrate the validity of the SDR approach to monitor the scintillations.

The enhanced ability of the SDR approach allows the detection of short-duration scintillations which are missed by conventional scintillation monitor 1-min indices. Furthermore, the flexibility and potentialities of such architecture allows for a reprocessing a replay of scintillation events and for a more detailed analysis of the same, opening up new possibilities for the scientific community.

These results also support the development of Ionosphere Prediction Services within Space Weather programs. Finally, a deeper knowledge of the scintillation environment at polar latitudes could support future EO missions for which the correction by ionospheric effects may be required.

5. Acknowledgements

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6. References

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