



# A Brief Review on Global Navigation Satellite System (GNSS) and Software- Defined Radio as tools for Space Weather

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**Abstract.** *This document aims to present the state of the art of Software Defined Radio use as a tool for improving the public outreach of the space weather. the state of the art is carried out, describing the evolution of the application of SDR tools in the development of space weather and space missions. The Software Defined Radio concept is defined as a platform that uses radio techniques developed and applied in the software domain. This feature adds greater flexibility in handling and applications since issues routinely associated with “hardware” are transferred to a predominantly “software” approach. In general, the system is configured to contain antennas operating across the entire radio frequency range, depending on the desired application, an analog to the digital signal converter, and commercial hardware and software subsystems. The conclusions in the monograph report the trajectory and feasibility of this theme for doctoral research.*

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**Key Words:** Global Navigation Satellite System; Software defined Radio; Space Weather; Public Outreach.

## 1. Introduction

The ionosphere is a highly dynamic medium through which radio waves propagate, but also the medium that interferes with this propagation. It is a weakly ionized plasma located between around 60 km and 1000 km in altitude (The Observatori de l'Ebre, 2021), formed by solar radiation mainly in the UV and X rays' range, and which has high daily variability, as well as dependence on solar activity, the season of the year, and the geomagnetic activity, and others. Complexes electrodynamic processes are responsible by the occurrence a fountain effect and subsequent appearance of crests of ionization at both sides of magnetic equator, named Equatorial Ionization Anomaly, EIA (Balan et al., 2018). Worth noting is the development of plasma instabilities and irregularities around post-sunset in the equatorial and a low latitude regions, which consist of fluctuations in the plasma density from centimeters to thousands of kilometers. The large-scale plasma depletions which develop



from the geomagnetic equator are generally referred as equatorial spread F or Equatorial Plasma Bubbles, EPBs.

The radio waves propagation in the ionosphere can, therefore, be degraded in situations where the ionosphere is disturbed, reducing the quality of the signal sent by the satellites that make up the navigation and positioning systems, such as the constellation of GNSS satellites (Global Navigation Satellite Systems). The process that degrades radio signals is known as ionospheric scintillation, which in turn consists of observed fluctuations in the amplitude and phase of radio signals associated with EPBs. EPBs develop around post-sunset at the geomagnetic equator, move vertically and propagate simultaneously eastward and toward higher latitudes, by diffusion, pressure gradient, and gravity. An Ionospheric flicker can cause phase errors, ambiguity due to the number of cycles, increased carrier wave Doppler instability, or signal losses, which can induce errors of tens of meters or complete signal interruption.

The objective of using SDR tools in ionospheric sounding geomagnetically quiet periods and during space weather events is the advantage of having higher coverage in terms of applications in the space area, using the constellation of GNSS (Global Navigation Satellite Systems) satellites. Such applications include probes with ground receivers as well as miniaturization processes for application as payload to CubeSats satellites. In addition to developing these capabilities for space research, it is intended to study the feasibility of their applications in the area of accident and disaster prevention, as well as in the area of air defense and telecommunications, all of the technological, strategic, and social interest.

## **2. Methodology**

According to Vargas et al. (2015) the state of the art is a qualitative-documentary research methodology of a critical-interpretive nature that reviews the states produced by people in their bibliographic representation, made up of three phases: 1) planning and design, 2) management and analysis, 3) formalization and elaboration. The research was carried out initially from 4 main keywords: Global Navigation Satellite System; Software-defined Radio; Space Weather; Scintillation. The results were organized in a bibliographic matrix in order to create an analytical instrument very useful to define the new research's opportunities.

## **3. Results and Discussion**

The interest in designing low-cost systems is the goal of a growing number of organizations and companies in 2021 to reach the public outreaches of the space weather. Figures 1 and 2 show the characteristics of the collected information or state-of-the-art of Software Defined Radio in space missions or directly in space weather.

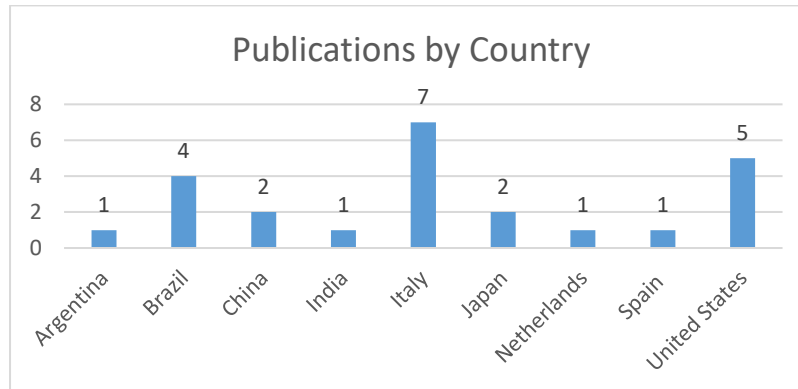


Figure 1. Country vs number of publications

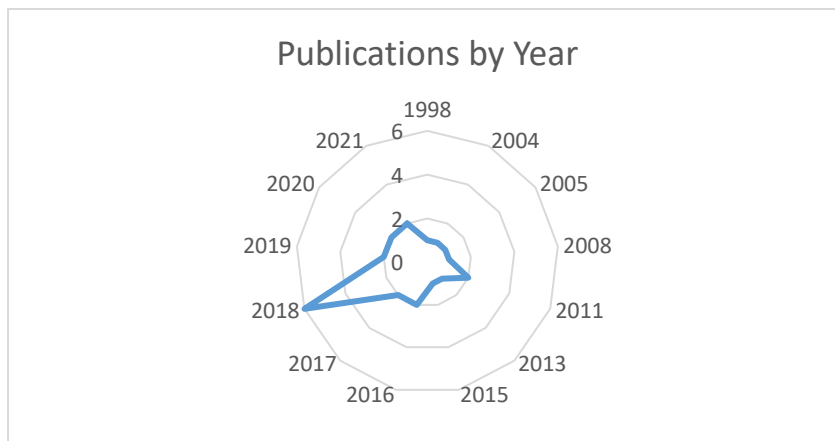


Figure 2. Year vs number of publications

Figure 3 details the document type in the collected information. A previous classification was carried out that found that the largest number of documents including the keywords: SDR, Scintillation, and GNSS. Some of the documents weren't a defined type, in order to include in this state of the art it was classified as undefined.

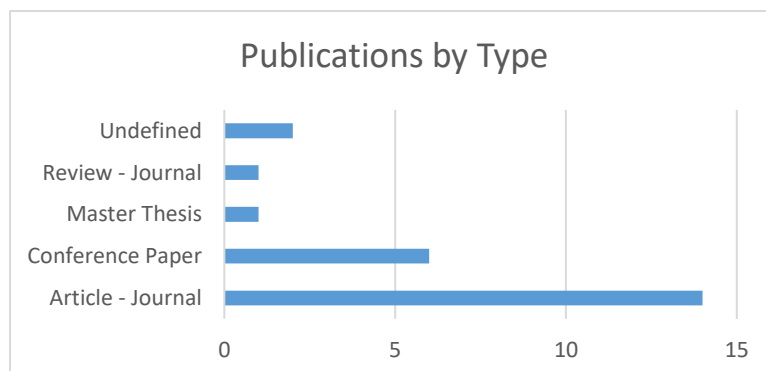


Figure 3. Document type vs number of publications

The information in Table 1. was organized by year, place, document type, authors and their affiliation, and the main concepts found in each result.



**Table 1 - Works collected in the literature study.**

Year	Place	Document type	Author and institution	Title	Concept
1998	United States	Conference Paper	A. J Van Dierendonck, Quyen D. Hua GPS Silicon Valley, Los Altos, CA	Crystal Oscillator Noise Effects On The Measurement Of Ionospheric Phase Scintillation Using GPS	The authors start considering the "new" term: Software-modified to measure the effects of ionospheric scintillation on signals passing through the ionosphere. During the development of the Ionospheric Scintillation Monitor (ISM) they had oscillator frequency jumps. Early testing eliminated the use of low-cost (low-noise oven-controlled crystal oscillator) and replaced them with low-noise oscillator because the (low-noise oven-controlled crystal oscillator) errors Masked the effects of ionospheric phase scintillation on the signal
2004	United States	Conference Paper	Dr. A. J. Van Dierendonck, B. Arbesser-Rastburg - European Space Agency/European Space Research and Technology Centre (ESA-ESTEC) Noordwijk, The Netherlands, Bertram.	Measuring ionospheric scintillation in the equatorial region over Africa, including measurements from SBAS geostationary satellite Signal	The authors discuss the results of a GPS Ionospheric Scintillation and TEC Monitor (GISTM) deployed in a near-equatorial location in Africa (Douala, Cameroon -- 4°01'N, 9°43'E). This receiver could measure the amplitude and phase scintillation indices on the SBAS signal received from a geostationary satellite.
2005	United States	Undefined	Glenn MacGougan, Per Ludvig Normark and Christian Stahlberg	Satellite navigation evolution: the software GNSS receiver	This work states the application of software-defined radio (SDR) techniques represents an evolutionary step in the development of modern global navigation satellite system (GNSS) receivers. The undefined text indicates the grow up of the techniques used in the global navigation satellite system development.
2008	Japan	Article - Journal	Mamoru Yamamoto Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan	Digital beacon receiver for ionospheric TEC measurement developed with GNU Radio	In this work, a reflection on an experiment based on the frequency dependence of the refractive index of radio waves in the ionospheric plasma is carried out. In this experiment, A simple digital receiver named "GNU Radio Beacon Receiver (GRBR)" was developed for the satellite ground beacon experiment to measure the ionospheric total electron content (TEC)..
2011	Italy	Review - Journal	Bacci G.b, Principe F.a, Giannetti F.b, Luise M.b - a EM Framework Design Laboratory, Ingegneria Dei Sistemi (IDS) S.p.A., 56121 Pisa, Italy, Dipartimento di Ingegneria dell'Informazione, Universit di Pisa, 56122 Pisa, Italy	Software-defined radio technologies for GNSS receivers: A tutorial approach to a simple design and implementation	The authors describe Flexibility as both easily upgradeable for future needs and/or on-the-fly reprogrammable to adapt to different signal formats, and it is easily found in the approach of the software-defined radio (SDR) paradigm. Based on Mitola (1995), the authors defined the advantage use of SDR instead of hardware-based systems: (i) Configurability, (ii) Updatability/Upgradability, and (iii) Flexibility.



2011	Spain	Conference Paper	Fernandez-Prades C, Arribas J, Closas P, Aviles C, Esteve L - Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Carlos Avilés Software (CAS), Germany, Universitat Politècnica de Catalunya (UPC), Spain	GNSS-SDR: An open source tool for researchers and developers	This paper introduces other Word that increases the importance of the SDR in the GNSS development, the open-source Global Navigation Satellite System software-defined receiver based on GNU General Public License (GPL). The document describes the software architecture design and provides details about its implementation, targeting a multiband, multisystem GNSS receiver.
2013	Argentina	Article - Journal	G. R. L. La Valle, J. G. García, P. A. Roncagliolo, Member, H. Muravchik. - Universidad Nacional de La Plata (UNLP), Comisión de Investigaciones Científicas de la Provincia de Buenos Aires (CICPBA) y	An Experimental L1/L2 GNSS Receiver for High Precision Applications	The authors worked to develop and implement a GNSS receiver that could work with the civil signals of the L1 and L2 bands of GPS and GLONASS, and the E1 Open Service signal of Galileo. It is observed in this article, a conclusion about conventional technology used in GNSS, the authors state that commercial receivers do not have the capability to be reprogrammable, because their digital processing stages cannot be modified by the user.
2015	Italy	Conference Paper	Nicola Linty, Rodrigo Romero, Fabio Dovis and Lucilla Alfonsi - Department of Electronics and Telecommunications, Politecnico di Torino, Italy, Istituto Nazionale di Geofísica e Vulcanologia (INGV)	Benefits of GNSS software receivers for ionospheric monitoring at high latitudes	This work includes detailed information about the relationship between ionosphere phenomena and GNSS systems. Ionospheric propagation is harmful for the electromagnetic signals broadcast by Global Navigation Satellite System (GNSS) satellites, mainly because of the presence of electron density anomalies. The paper as the other work mentioned before in this survey, there are some Advantages of SDR for GNSS, summarized in four main concepts: 1) Accessibility, 2) Configurability, 3) Modularity and 4) Flexibility.
2016	Italy	Article - Journal	Ilaria Lucreti, Alessandro Di Carlofelice, Piero Tognolatti, University of L'Aquila, L'Aquila, Italy	SDR-based System for Satellite Ranging Measurements	This document does not talk about Scintillation, however, establishes the utility of the GNURadio. The authors discuss the generation of source codes for programmable hardware, that will provide a signal-processing toolkit that permits to implementation of radio systems using low-cost external RF hardware.
2016	China	Article - Journal	Hailong Xu, Xiaowei Cui and Mingquan Lu - Department of Electronic Engineering, Tsinghua University, Weiqing Building, Tsinghua, Beijing 1	An SDR-Based Real-Time Testbed for GNSS Adaptive Array Anti-Jamming Algorithms Accelerated by GPU	Due to the vulnerability of Global Navigation Satellite System (GNSS) signals to radiofrequency (RF) interferences, anti-jamming design has always been an important issue in both military and civilian applications.
2017	United States	Conference Paper	Moses B. Mwakanyjala, M. Reza Emami, Jaap van de Beek - Luleå University of Technology, Kiruna, 98128, Sweden	Software-defined radio baseband system for satellite management services	This paper presents functional analysis and system specifications of a baseband system based on software-defined radio (SDR) technology. The analysis was carried out primarily based on the CCSDS standards. It covers telemetry, telecommand, ranging,



					and Doppler measurements, as well as some specifications of the associated physical layers..
2017	United States	Article Journal	- Erick Schmidt, David Akopian, Daniel J. Pack	Development of a Real-Time SoftwareDefined Radio GPS Receiver Exploiting a LabVIEW-based Instrumentation Environment	This paper presents a LabVIEW (LV) and C/C++-based GPS L1 receiver platform with real-time capabilities. The system relies on LV acceleration factors as well as other C/C++ techniques such as dynamic link library (DLL) integration into LV and parallelizable loop structures, and single input multiple data (SIMD) methods that leverage host PC, multi-purpose processors. A hardware testbed is presented for compactness and mobility, as well as software functionality and data flow handling inherent in the LV environment. Benchmarks and other real-time results are presented as well as compared against other state-of-the-art open-source GPS receivers.
2018	Italy	Article Journal	- Nicola Linty , Alex Minetto, Fabio Dovis , and Luca Spogli - Department of Electronics and Telecommunications,	Effects of Phase Scintillation on the GNSS Positioning Error During the September 2017 Storm at Svalbard	The authors show that scintillations induce a considerable clustering effect on the smoothed positioning solutions; therefore, a methodology to detect the boundaries of the scintillation event automatically and autonomously is suggested according to such a high-level effect.
2018	Italy	Article Journal	- Nicola Linty, Fabio Dovis, Lucilla Alfonsi a Politecnico di Torino, Corso Duca degli Abruzzi 24, Turin, 10129, Italy b Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata, 605, Rome, 00143, Italy	Software-defined radio technology for GNSS scintillation analysis: bring Antarctica to the lab	A argue of the Professional commercial GNSS receivers, widely used for scintillation monitoring entails the race to find the contrary, custom-designed solutions based on data grabbers and software receivers constitute novelty, enabling a higher level of flexibility and configurability, which is important when working in remote and severe environments.
2018	Brazil	Article Journal	- David julian m. Peralta, douglas s. Dos santos, auro tikami, walter a. Dos santos and edson w.r. pereira- instituto nacional de pesquisas espaciais, instituto tecnológico de aeronáutica, liga de amadores brasileiros de radio emissão/labre - amsat-br.	Satellite Telemetry and Image Reception with Software Defined Radio Applied to Space Outreach Projects in Brazil	This work presents Two case studies, the first one, for supporting affordable ground segment and promoting satellites projects in Brazil called: Reception from the 1st Brazilian picosatellite, Tancredo-1, with specific software developed, UbaTM. A second one, called: NOAA satellites imagery over VHF band and decoded by specific software freely available. The authors Use the proposed SDR approach, it can adapt to projects mainly those with a limited budget and outreach for major inclusion on space topics in Brazil.
2018	Brazil	Master Thesis	David Julian Moreno Peralta - Instituto Nacional de Pesquisas Espaciais	Uma abordagem em rádio definido por software para operações em terra de pequenos satélites	This master thesis does not deal with scintillation but is a reference in terms of the use of SDR in projects in Brazil.



2018	Brazil	Article Journal	- Nicola Linty, Emilia Correia, Ingrid Hunstad, Amauri S. Kudaka - Politécnico de Torino (POLITO-Itália), Instituto Nacional de Pesquisas Espaciais (INPE-Brazil), Instituto Nacional de Geofísica e Vulcanologia (INGV-Itália), Universidade Presbiteriana Mackenzie (UPM-Brazil)	Installation and configuration of an ionospheric scintillation monitoring station based on GNSS SDR receivers in Brazil	This work shows the installation and configuration of an ionospheric scintillation monitoring station based on GNSS SDR receivers in Brazil, the paper discusses the impact of the ionosphere in GNSS positioning, the ionosphere affects the GNSS signals both regarding a temporary delay and of scintillations.  Ionospheric scintillations are amplitude and phase fluctuations caused by non-regular distributions of electron concentration and rapid changes in the electron density.
2018	Netherlands	Undefined	James T. Curran, Carles Fernandez-Prades, Aiden Morrison and Michele Bavaro	GETTING BETTER ALL THE TIME: The Continued Evolution of the GNSS Software-Defined Radio	This undefined paper presents Software Defined Radio (SDR) evolution, and its behavior in GNSS. The author sets the proliferation of collaboration and code-sharing sites such as GitHub has enabled communities so share and co-develop receiver technology; the rise in the maker-culture and crowdsourcing has led to the availability high-performance radio-frequency front ends; and the adoption of SDR by some major telecommunications industry has led to the availability suitable integrated circuits
2019	Italy	Conference Paper	Matteo Cutugno, Umberto Robustelli, Giovanni Pugliano - Department of Engineering, Parthenope University of Naples.	Testing a GNSS software receiver for end-user utilization	This work established, that still in 2019, the current systems in GNSS are a black box preventing users to access algorithms involved in the positioning process and, often, limiting the possibilities of upgrading, allowing to SDR be able to reach extreme customization to the user access, besides of visualize and modify signal processing blocks.
2019	Brazil	Article Journal	- Eurico R. de Paula, Cesar B. A. de Oliveira, Ronald G. Caton, Patricia M. Negreti, Inez S. Batista, André R. F. Martinon, Acácio C. Neto, Mangalathayil A. Abdu, João F. G. Monico, Jonas Sousasantos and Alison O. Moraes	Ionospheric irregularity behavior during the September 6–10, 2017 magnetic storm over Brazilian equatorial–low latitudes	Due to magnetic storm in 07/08/2017, this work carried out a study of the ionospheric irregularity over São Luís (02.5°S, 44.3°W, dip lat – 04.67°) using data from the VHF, Digisonde, and GPS receivers. Electron density data from the satellite SWARM-A were also analyzed for those orbits close to São Luís, and they presented large fluctuations during the storm night.
2020	India	Article Journal	- B. P. Kumara, and C. S. Paidimarrya - Department of Electronics and Communication Engineering, University College of Engineering, Osmania University, Hyderabad-500007, Telangana, India	Improved Real Time GPS RF Data Capturing for GNSS SDR Applications	This paper proposes an efficient approach to capture the real-time GPS data by using the USRP N210 kit. If the receiver is not tuned with the exact parameters, the problems of data overflow and underflow occur. A novel data controlling queue thread method is introduced to overcome this problem. It is evident that the results obtained from our method are very close to those of Ublox GPS.



2020	Italy	Conference Paper	Hossein Ghobadi, Caner Savas, Luca Spogli, Fabio Dovis, Antonio Cicone, and Massimo Cafaro - Istituto Nazionale di Geofisica e Vulcanologia, Rome,	A Comparative Study of Different Phase Detrending Algorithms for Scintillation Monitoring	This work analyzes the implementation and compares the performance of different phase detrending algorithms to improve scintillation monitoring, using three different phase detrending methods, namely, three cascaded second-order high pass filters, six order Butterworth filter conducted by cascading six first-order high pass Butterworth filters, and Fast Iterative Filter (FIF) are considered in this paper.
2021	China	Article - Journal	Qiang LI a,b, Yanbo ZHUa,b, Zhipeng WANGa, Kun FANGa - University, Beijing 100191, China Aviation Data Communication Corporation, Beijing, 100191, China	A method for automatic detection and characterization of plasma bubbles using GPS and BDS data	This paper develops a robust method to automatically identify TEC depletion and derive its parameters. The most interesting thing here is that this is a conventional technology, and there is a possibility of using this method applying SDR concepts
2021	Japan	Article - Journal	Kanya Kusano, Kiyoshi Ichimoto, Mamoru Ishii, Yoshizumi Miyoshi, Shigeo Yoden, Hideharu Akiyoshi, Ayumi Asai, Yusuke Ebihara, Hitoshi	PSTEP: project for solar-terrestrial environment prediction	The authors sought to answer the fundamental questions concerning the solar-terrestrial environment and aimed to build a next-generation space weather forecast system to prepare for severe space weather disasters.

#### 4. Conclusions

24 documents were presented reporting projects with related concepts, where the authors demonstrate that the main characteristic of the paradigm shift has to do with: Accessibility, Configurability, Modularity, Flexibility, which provides the SDR in space systems use.

Designing a successful dependable system is a matter challenging that is a matter of ongoing investigation in the literature. Different approaches will have to be adopted to analyze and check the dependability of an SDR-GNNS system design. It is intended with the future doctoral thesis to contribute by developing prototypes that help in the development of low-cost instrumentation in space weather.

This document highlights the importance and relevance to the thematic change of paradigm to achieve more accessible commercial technology in the use and development of research in space weather. The study shows that many works have been studied, but there is still much to be done.

As a doctoral research, it is expected to obtain an SDR monitoring system with high flexibility, configurability, accessibility, and applicability in the space area. In addition to ionospheric scintillation in the L1 frequency range = 1,757 MHz, it is possible to monitor signals in the VHF bands (240-260 MHz), the ionospheric density, and the Total Electronic Content of the ionosphere, TEC, parameters of interest in ionospheric monitoring.

As mentioned in Linty et al. (2017) in Effects of Phase Scintillation on the GNSS Positioning Error During the September 2017 Storm at Svalbard, it is necessary to carry out the inspection of data sets with stronger scintillations in different geographical areas is expected





to better assess the results of the current study. In this case, a case study could be carried out in two different areas Brasil and Colombia as further research.

In Cutugno, Robustelli and Pugliano (2019) there is a need in terms of future work consist in taking advantage of SDR represent an innovative low-cost and flexible platforms for multipath error studies, ionospheric scintillation analysis and, above all, GNSS Reflectometry test and development.

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