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Real-Time Monitoring and Modelling of Ionospheric TEC Variations Using GNSS Data for Enhanced Space Weather Resilience

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The ionosphere introduces significant delays in satellite-based navigation and communication systems, particularly through variations in Total Electron Content (TEC). Accurate monitoring of these ionospheric TEC variations is essential for improving GNSS reliability, especially in equatorial and mid-latitude regions vulnerable to space weather events. This study explores a real-time framework for recovering ionospheric TEC using dual-frequency GNSS observations, where the geometry-free linear code combination is employed to isolate ionospheric delays along with Differential Code Biases (DCB) in both receivers and satellites [1].

Building on established techniques, a thin-shell ionospheric model is used alongside a mapping function to convert Slant TEC to Vertical TEC (VTEC), taking into account the effects of altitude selection on model accuracy [1]. High-resolution regional TEC maps are generated using data from Continuously Operating Reference Stations (CORS), which provide significant improvements over the coarser Global Ionosphere Maps (GIMs) offered by IGS, typically with 2-hour temporal and 2.5° × 5.0° spatial resolution [1].

The methodology follows a Precise Point Positioning (PPP) approach where ionospheric delays, DCBs, tropospheric residuals, and ambiguities are treated as unknowns and solved in a unified estimation filter [1]. With appropriate empirical constraints on temporal and spatial TEC variability, this framework aims to support real-time ionospheric modelling with applications in early warning systems and GNSS correction services, particularly in developing regions like Pakistan where atmospheric monitoring infrastructure is limited. This workshop will enhance my ability to contribute to regional GNSS resilience by applying these modern modelling techniques in national academic and operational contexts.

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A1-P-02

The state of the Ionosphere-Thermosphere during the May 2024 storm

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The behavior of the ionosphere-thermosphere system over Europe was examined during the intense geomagnetic storm of May 2024. From May 7 to 11, multiple X-class solar flares and at least five Earth-directed coronal mass ejections (CMEs) were recorded. The first CME strucks Earth at 12:30 PM UTC on May 10, causing a geomagnetic disturbance and triggering a negative ionospheric storm at mid-latitude European stations, which resulted in data gaps on May 11 due to the "G condition" (where the electron density at the F2 layer peak is equal to or less than that of the F1 layer peak). The forecasting EUROMAP [1] model is used to fill the gaps in the European region.
Using the THERION[2] method to analyze thermospheric parameters, a 60% rise in neutral oxygen [O] density at 300 km altitude was observed, along with approximately a 50% increase in thermospheric temperature. Meanwhile, columnar oxygen [O] concentrations decreased by about 30%. Enhanced equatorward winds reaching up to 79 m/s were detected between May 10 and 13. Comparison with other longitudinal sectors highlighted significant regional effects, underscoring the dynamic nature of the coupled ionosphere-thermosphere system during severe geomagnetic storms.[3]

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A1-P-03

Investigating Thermosphere-Ionosphere Response to Geomagnetic Storms by Multi-Instrumental and Modeling approach

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Understanding and modeling the thermosphere-ionosphere (T-I) response during geomagnetic disturbances remains a significant challenge due to the complex, multi-scale coupling processes involved. In this study, we investigate and compare the mid-latitude T-I response over Central Europe to two recent severe geomagnetic storms (October 2024 and January 2025), using data from ionosondes and GNSS receivers.

We apply the THERION (THERmospheric parameters from IONosonde observations) method [1, 2] to derive thermospheric parameters—neutral composition, temperature, and wind—from ionosonde measurements of f_oF2 and bottom-side $N_e(h)$ profiles under sunlit conditions. Observations from the Rome (41.8°N, 25.5°E) and Juliusruh (54.6°N, 13.4°E) ionosondes were manually validated to ensure data reliability. The derived parameters are compared with outputs from the empirical MSISE00 model to assess the model's capability to capture storm-time variability at mid-latitudes.

To further characterize ionospheric responses, co-located GNSS-based total electron content (TEC) data were analyzed, and ground-based geomagnetic field measurements from the INTERMAGNET network were used to examine associated current system variations. Each event is also contextualized using solar wind and magnetospheric conditions, emphasizing the unique nature of storm-time drivers.

This work highlights the utility of combining both ground- and satellite-based data with modeling approaches for characterization of T-I coupling during disturbed periods. The results support the integration of such methods into broader data assimilation frameworks for improved space weather modeling.

This study was carried out within the Space It Up project funded by the Italian Space Agency, ASI, and the Ministry of University and Research, MUR, under contract n. 2024-5-E.0 - CUP n. I53D24000060005.

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A1-P-04

Validation of the Ionospheric bubble probability (IBP) model in Fortran

Abstract

The Ionospheric Bubble Probability (IBP) model is used in this work to analyze the global and temporal distribution of ionospheric bubble occurrence probability. The findings are compared to observations from numerous satellite missions, including Swarm A, B, and C, and CHAMP. Ionospheric bubbles, which are places with low electron density, have a substantial influence on satellite communication and navigation systems. Understanding their distribution is critical to reducing these impacts.

The IBP model provides a probabilistic framework for forecasting the occurrence of ionospheric bubbles based on longitude, day of the year, local time, and solar activity for the altitude range of around 350-510 km at low geographical latitudes of +/- 45°. We confirm the model's predictions with in-situ measurements and ground-based GNSS receiver sites along the satellite's path using S4 indices and ROTI. This analysis includes various latitudes, longitudes, and local times, providing a complete picture of the geographical and temporal variability of ionospheric bubbles.

Preliminary results show a substantial connection between IBP model predictions in python and Fortran, with particularly good consistency in equatorial and low-latitude areas. The comparison demonstrates the model's ability to capture both seasonal and diurnal trends in bubble occurrence. Moreover, disparities in high-latitude regions indicate where the model should be improved. Furthermore, the Python version of the model is freely accessible. This comparative analysis emphasizes the need to combine many satellite data sets to better understand ionospheric processes. The findings help to construct more accurate prediction models, which are critical for increasing the dependability of space-based communication and navigation systems.

A1-P-05

Availability and Performance Evaluation of Multi-GNSS Radio Occultation Data

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The radio occultation (RO) technique can be applied to estimate atmospheric refraction using signals from Global Navigation Satellite Systems (GNSS) as they are intercepted by receiver embedded in Low Earth Orbit (LEO) satellites. Since its initial application in planetary exploration in the 1960s (JEREZ et al., 2022), RO has evolved into a key technique for investigating the Earth's atmosphere, with significant applications in Meteorology, Aeronomy, and Geodesy. RO is widely used in numerical weather prediction (NWP) models, climate change detection, disaster prevention, and the retrieval of Total Electron Content (TEC), among other areas (HAJJ et al., 2002). The advent of the new GNSS, composed by the American GPS (Global Positioning System), the Russian GLONASS (Global'naya Navigatsionnaya Sputnikovaya Sistema / Global Navigation Satellite Systems), the European Galileo and the Chinese BeiDou, and LEO constellations, such as the COSMIC-2 (Constellation Observing System for Meteorology, Ionosphere, and Climate-2) mission, has greatly expanded both the volume and research potential of RO data. In this context, the present study aims to investigate and validate multi-GNSS RO profiles, with a particular focus on the Brazilian region. Different RO atmospheric profiles provided by the COSMIC Data Analysis and Archive Center (CDAAC) are analyzed, assessing the global and regional (Brazilian) availability of data derived from different GNSS constellations. Subsequently, the performance of multi-GNSS RO profiles over Brazil is evaluated. An important result of this study involves the investigation and application of methodologies to validate atmospheric profiles from GNSS-RO data, using ionosonde in order to evaluate ionosphere products and radiosonde data as reference to troposphere variables, like pressure, temperature and humidity.

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A2-P-01 - AGYEI-YEBOAH Ebenezer

Occurrence of ionospheric irregularities during successive geomagnetic storms in November 2023

A2-P-02 - AIMOUCHE Nihad Kheira

the response to solar events of the ionospheric VTEC at high latitudes using GNSS data

A2-P-03 - AMARAL FERREIRA Arthur

Investigation on the seeding mechanisms of Equatorial Plasma Bubbles

A2-P-04 - DAS Tanmay

Characteristics of Plasma Structures observed by CU Radar during the Rising Phases of Solar Cycle 25

A2-P-05 - FERREIRA Lucas

Real-Time Ionospheric Scintillation Monitoring with Low-Cost GNSS Receivers

A2-P-06 - RODRIGUES DE PAULA Eurico

Spectral Characterization of Ionospheric Scintillation Effects on SBAS L1 Signals Using a Fading-Dependent Analysis

A2-P-07 - TABTI Lahouaria

Evaluation of Broadcast Ionospheric Models on Single-Frequency GPS Positioning Accuracy

A2-P-01

Occurrence of ionospheric irregularities during successive geomagnetic storms in November 2023

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In November 2023, the ionosphere experienced a sequence of geomagnetic storms of varying intensities, offering a unique opportunity to investigate storm-time dynamics and their influence on ionospheric irregularities. This study analyzes the temporal evolution of ionospheric total electron content (TEC) and irregularity patterns during the main, recovery, and post-storm phases of these events over the Brazilian low-latitude sector. A multi-instrument approach is employed, combining GNSS-derived vertical TEC (VTEC) measurements, ionosonde data (foF2 and h'F), and satellite observations from the Swarm and GOLD missions. A key advantage of this study lies in the temporal proximity of the storms, which allows for a unique experimental setup: all events share nearly identical quiet-day baselines. This common reference background condition ensures consistent comparison across events, allowing clearer identification of storm-induced anomalies and minimizes background variability and enhances the reliability of inter-storm comparisons. As a result, the analysis more accurately isolates storm-induced anomalies in plasma behavior and irregularity formation and provide insight into the suppression or enhancement of plasma instabilities under different geomagnetic forcing scenarios and contribute to ongoing efforts in understanding storm-time ionospheric variability. Preliminary findings indicate pronounced positive ionospheric storms during the main phases, with enhanced VTEC and elevated foF2 values across events, while h'F showed minimal variation - suggesting increased plasma production without significant F-layer uplift. Variations in the scale sizes and occurrence rates of ionospheric irregularities suggest differing electrodynamic drivers and background thermospheric conditions for each storm.

A2-P-02

THE RESPONSE TO SOLAR EVENTS OF THE IONOSPHERIC VTEC AT HIGH LATITUDES USING GNSS DATA

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Abstract:

This study investigates the variability of the Vertical Total Electron Content (VTEC) and ionospheric irregularities, indicated by the Rate Of TEC Index (ROTI), in response to solar events at high latitudes during the year 2022. Using GNSS data from IGS stations in both hemispheres, we analyze the ionospheric effects of high-speed solar wind (HSSW), coronal mass ejections (CMEs), and their combined influences. Results show a pronounced hemispheric asymmetry in VTEC amplitudes, strongly correlated with polar cap indices. VTEC decreases with increasing latitude, with rapid fluctuations and high ROTI values near auroral zones. In contrast, mid-latitude stations show smoother VTEC variations and weaker scintillation activity.Our methodology includes selecting high-latitude stations in both hemispheres and a reference mid-latitude station to compare ionospheric behavior during various levels of geomagnetic disturbance. We correlate VTEC and ROTI fluctuations with solar indices (e.g., F10.7), geomagnetic indices (Dst, Kp, ap), and polar cap indices (PCN/PCS).Our findings demonstrate that both HSSW and CMEs contribute to space weather effects, with Dst drops of -37 to -63 nT for HSSW, -76 nT for CMEs, and -81 nT for combined events. The VTEC exhibits a diurnal pattern tied to solar radiation incidence, with two peaks around 10:00 and 16:00 local time under calm conditions. These results underscore the critical impact of solar activity on GNSS signal integrity, especially at high latitudes, and provide insight for mitigating navigation errors caused by ionospheric disturbances.

Keywords: Ionosphere, solar activity, high latitudes, VTEC, ionospheric scintillations, ROTI index.

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A2-P-03

Investigation on the seeding mechanisms of Equatorial Plasma Bubbles

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Equatorial plasma bubbles (EPBs) correspond to sharp depletions in the ionospheric plasma observed during post-sunset hours in the equatorial and low-latitude regions. EPBs and their generation mechanisms have been investigated for decades, and although Rayleigh Taylor (RT) instability is widely accepted as the mechanism behind the development of EPBs, understanding the day-to-day variability of EPBs is still a challenge. Previous studies have associated such variability to the changes in the magnitude of the pre-reversal enhancement (PRE) of the zonal eastward electric field, suggesting that the PRE controls the day-to-day variability of EPB. Other studies have also suggested that thermospheric winds may also play a role in suppressing the RT instability and therefore, controlling the day-to-day variability of EPBs. In addition, atmospheric gravity waves acting as seeding mechanisms have also been hypothesised as a contributor to the EPB day-to-day variability [1, 2]. In this study, we conduct a multi-instrument investigation into the role of different mechanisms in the variability of EPB occurrence observed in a case study in August 2022. The analysis includes EPBs observations obtained from the Global-scale Observations of the Limb and Disk (GOLD) satellite, along with travelling ionospheric disturbances observations derived from GNSS data, and thermospheric wind data obtained from the Ionospheric Connection Explorer (ICON) satellite. The results of the investigation suggest that disturbed eastward zonal winds may have contributed to the observed day-to-day variability.

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Characteristics of Plasma Structures observed by CU Radar during the Rising Phases of Solar Cycle 25

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A fully active phased array radar which is operational at 53 MHz by University of Calcutta at Ionosphere Field Station (IFS) (22.93°N,88.50°E geographic; magnetic dip: 36.2°N), Haringhata located near the northern crest of Equatorial Ionozation Anomaly (EIA)[1,2]. This region around the northern crest of the EIA is also the seat of some of the most intense ionospheric irregularities which leads an important for studying ionospheric dynamics and coupling processes using CU-Radar. Ionospheric E region irregularities are normally observed from Kolkata during summer daytime and winter night-time.

A few notable cases of E and F region backscatter have been observed using the CU-Radar in the range of ~90– 140 km and ~210-450 km respectively during early evening hours to midnight of the summer/equinoctial months of 2019-2023. The observed Doppler velocities were in the range of - 80-130 m/sec with spectral width limited to 110 m/s. The observed E region backscatters are very much similar to signatures observed generally at off-equatorial low and mid-latitudes. Most of the observed signatures are descending and continuous in nature with patchiness. Similar studies have been made for F-regions FAI too. This paper presents results of occurrences of E and F regions backscatter and their characteristics during 2019-2023.

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A2-P-05

Real-Time Ionospheric Scintillation Monitoring with Low-Cost GNSS Receivers

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Nowadays, high-precision positioning is essential across a wide range of fields, including precision agriculture, infrastructure monitoring, autonomous navigation, and mining operations. To satisfy the strict requirements of these fields, systems must provide not only high-precision, but also continuous and reliable performance 24 hours a day.

However, between the antenna/receiver in the user's equipment and the GNSS satellites in orbit lies a huge layer of the ionosphere that the signals must traverse. During this journey, several factors can affect and degrade the signals directly. In equatorial and low-latitude regions such as Brazil, a common and significant problem is ionospheric scintillation. This phenomenon can degrade the performance of GNSS-based positioning services. In fact, Brazil is one of the most affected regions in the world when it comes to ionospheric scintillation [1].

To monitor and mitigate these effects, some initiatives and technologies have emerged, such as Trimble's IonoGuard™ [2] and Septentrio's IONO+ technology [3], which are integrated into their geodetic high-cost GNSS receivers.

In a previous project called Ionik, efforts were made to deploy a network of low-cost GNSS receivers (Arduino boards with GPS Adafruit Breakout modules) for continuous monitoring of ionospheric activity in Brazil through the calculation of the S4 index [4]. Inspired by this initiative, T2R Soluções Tecnológicas and INCT GNSS-NavAer partnered to develop an experimental software designed to calculate the S4 index using low-cost receivers. The software, named T2R-ScintillationMonitor, operates with u-blox receivers at 20 Hz, collecting raw GNSS data that is subsequently used to compute the S4 value.

This study focuses on evaluating the performance of the proposed low-cost monitoring solution. It presents a comparison between the S4 values calculated by the T2R-ScintillationMonitor and those obtained from a Septentrio PolaRx5S receiver, both sharing the same antenna through a signal splitter installed at UNESP in Presidente Prudente.

Overall, the S4 data generated by the experimental software showed results similar to those obtained with the Septentrio PolaRx5S receiver, sufficient to be considered a viable alternative to high-cost receivers and as a promising foundation for future developments in low-cost ionospheric monitoring systems.

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A2-P-06

Spectral Characterization of Ionospheric Scintillation Effects on SBAS L1 Signals Using a Fading-Dependent Analysis

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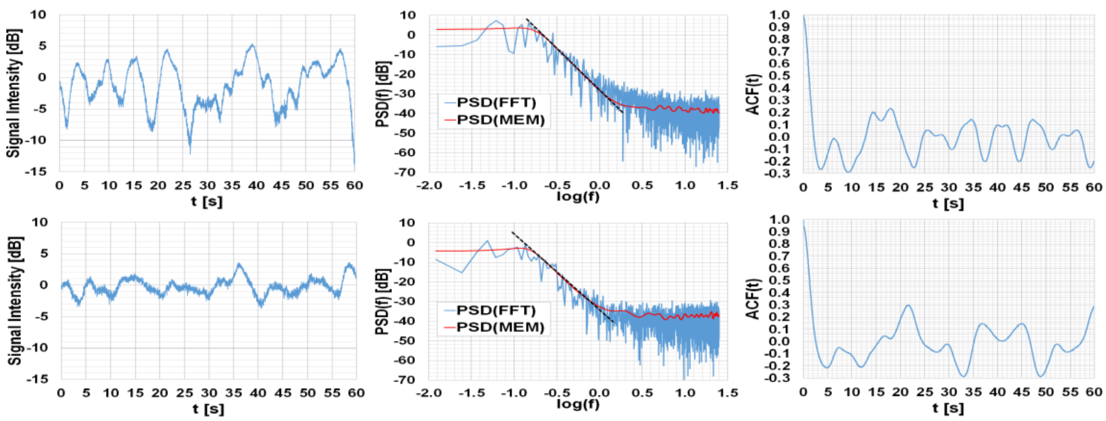
This work will investigate the spectral characteristics of ionospheric scintillation that affects GNSS signals at the L1 frequency (1575.42 MHz). It is based on the analysis of experimental data resulting from transmissions by the SBAS space vehicle with PRN 121, located at 5ºW, received at Cachoeira Paulista, Brazil (22.7°S, 45.0°W). Signal intensity recorded at 50 Hz is available to this study. For each minute (corresponding to 3000 samples spaced by 0.02 s), the signal is normalized to yield a signal with unit average intensity (E[I] = 1). Next, the amplitude scintillation index S_4 (standard deviation of the normalized intensity) is determined. Its power spectral density PSD(f) is then estimated by the Fast Fourier Transform (FFT) and Maximum Entropy Method (MEM). The inverse FFT of the former provides the corresponding autocorrelation function ACF(τ), normalized in such a way that ACF(0) = 1. From these results, a power spectral index m will be extracted from the section of the power spectral density which conforms to the model PSD(f) α f^{-m} and the signal decorrelation time τ_o will be estimated from ACF(τ_o) = e^{-1}. Each row of the Figure displays one data record and the associated PSDs and ACF. The corresponding (S_4, m, τ_o) values are (0.71, -4.30, 1.38 s) (upper row) and (0.33, -3.85, 1.54 s) (lower row). The analysis of (m, τ_o) will be categorized by the S_4 index. The above power-law model is particularly valid in the weak scintillation regime ($S_4 \leq 0.5$) Under this scenario, m represents a physically meaningful and interpretable indicator: a larger value of m (steeper spectrum) describes the domination of large scales with few fine-scale details, while a smaller m (flatter spectrum) describes intense small-scale irregularities, which more prominently contribute to L-band signals. For $S_4 > 0.5$, the signal-irregularity relation becomes more complex due to focusing/defocusing and multiple scattering effects. Under this regime, the power spectrum may no longer follow the single power-law model. However, a spectral slope m may still be obtainable from segments of the spectrum, yielding a conservative but still valuable insight into intrinsic irregularities. In this work the data processing involves separation of the data into weak and strong scintillation regimes. Time-series of night evolutions of (S_4, m, τ_o) values, their correlations and histograms will also be presented and discussed. Expected contributions are the identification of distinct spectral patterns corresponding to different scintillation regimes and the measurement of decorrelation time/ionospheric irregularity spectral content correlation. This fading-based approach provides accurate insight into the morphology of ionospheric irregularities in different propagation scenarios and is useful in model-building for signal integrity and performance in equatorial and low-latitude GNSS use. This work provides a firm basis for future endeavors toward incorporating spectral diagnostics into ionospheric threat models for GNSS application in equatorial regimes.



A2-P-07

Evaluation of Broadcast Ionospheric Models on Single-Frequency GPS Positioning Accuracy

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Abstract

The Global Navigation Satellite System (GNSS) is a satellite positioning system that enables users to determine their position at any time and from any location. The accuracy of GNSS positioning is influenced by several error sources, including satellite and receiver clocks, signal propagation delays caused by the ionosphere and troposphere, as well as measurement noise and multipath effects. One of the most significant factors affecting GNSS position accuracy is the ionosphere, which is a dispersive medium. Its influence can be corrected by using multiple frequencies. However, for low-cost single-frequency receivers, this error can significantly degrade positioning accuracy. To correct ionospheric errors, several models are proposed, including Klobuchar for GPS, KBDS for BeiDou, and NeQuick for Galileo. These models are based on parameters transmitted by GNSS satellites in their navigation messages. Additionally, the ionospheric correction transmitted by SBAS satellite augmentation systems (e.g., EGNOS) can be used to correct this error. The work aims to assess the positioning accuracy using these models, with a comparison to the ionospheric correction transmitted by EGNOS. The performance of these models is evaluated using real data collected at three sites in Algeria at different latitudes and longitudes, both within and outside the EGNOS service area. These sites include El Golea, Tindouf, and Djanet. The collected data were processed using gLAB software and Matlab programs. The results demonstrate a significant improvement in accuracy using the ionospheric correction transmitted by EGNOS for El Golea and Tindouf compared to the results obtained using the Klobuchar, BeiDou, or NeQuick models. The accuracy ranges between 1.98 m and 2.42 m for EGNOS, while it varies between 2.60 m and 3.56 m for the other three models. For the Djanet site, located outside the EGNOS service area, all three models provide better precision than EGNOS. Which has an accuracy of 28.62 m, attributed to the lack of RIMS stations in Algeria. As a future perspective, a comparison will be made using the Algerian Satellite-Based Augmentation System (AL-SBAS). This system uses the Alcomsat-1 telecommunications satellite to transmit corrections using a temporary code (PRN148).

Keywords: Ionospheric, delay, Single, frequency, Accuracy, GPS, Klobuchar, KBDS, EGNOS NeQuick.

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A3-P-01 - LOMOTEY Solomon Otoo

Variability of the equatorial ionization anomaly over the South American sector: Effects of electric field and effective meridional wind

A3-P-02 - MINI Rajput

Evaluating the Performance of the IRI-2020 and IRI-2016 model using GPS-TEC for Equatorial to high-latitude stations during a solar cycle period from 2004 to 2014

A3-P-03 - MUKA Peter Taiwo

NOCTURNAL OCCURRENCE OF SLANT SPORADIC E AT LOW LATITUDES REGION

A3-P-04 - TAHIR Afnan

Longitudinal Differences in Ionospheric Irregularities during the March 2023 Geomagnetic Storm: A Multi-Instrument Study of Driving Mechanisms

A3-P-01

Variability of the equatorial ionization anomaly over the South American sector: Effects of electric field and effective meridional wind

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Vertical Total Electron Content (VTEC) Maps over the South American Continent were utilized to investigate the temporal and longitudinal climatology of Equatorial Ionization Anomaly (EIA) using more than 350 Global Navigation Satellite Systems (GNSS) receivers. At a temporal resolution of 10 min, the EIA motions, morphologies, and evolutions were mapped using VTEC keogram along magnetic meridians lines. Between 2014 and 2019, characteristics of the EIA were studied at two different South American magnetic meridians (i.e., $3.36°$ E and $7.58°$ E) separated by ~ 555 km at an altitude of 300 km. The aim of this study is to examine the EIAs variability, monthly variations and occurrences at evenly spaced longitudinal sectors. The effects of effective meridional winds component and $\mathbf{E} \times \mathbf{B}$ drift velocity on the daytime asymmetry of EIA anomalies were studied using a physics-based numerical model, Sheffield University Plasmasphere-Ionosphere model at Instituto Nacional de Pesquisas Espaciais (SUPIM-INPE). We found that the EIA parameters such as strength, shape, intensity, and latitudinal positions are affected by the eastward electric field and effective meridional wind. The monthly variations in the EIA over two magnetic meridian sectors demonstrate a semiannual variation. The EIA crests were more symmetric in equinox than in solstice seasons. The asymmetries of the EIA observed during the December solstice are more intense than during the June solstice, whereas September equinox is less symmetric than March equinox seasons. Moreover, this study indicates that the vertical drift and the meridional neutral wind plays a very significant role in the development of the EIA asymmetry by transporting the plasma up the field lines. There was a notable contraction of the EIA southern hemispheric (SH) crests from the December solstice to the June solstice. Meanwhile, the EIA crest positions in the northern hemisphere (NH) expand from the December solstice to the June solstice. According to our observations, the March equinox season had the most EIA occurrences, which were then followed by the September equinox, the December and June solstices. The intensities of the EIA crests also considerably decreased with solar descending phases. Through modeling, this work provides the scientific community with new insights into the evolution/development of EIA and their latitudinal asymmetry, as well as the role of $\mathbf{E} \times \mathbf{B}$ drift and thermospheric neutral wind in assessing the statistical analysis of EIA variability using the largest VTEC database over the South American sector.

A3-P-02

Evaluating the Performance of the IRI-2020 and IRI-2016 model using GPS-TEC for Equatorial to high-latitude stations during a solar cycle period from 2004 to 2014

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The ionosphere affects satellite communication in addition to current space-based positioning, satellite tracking, and navigational control applications. Total electron content (TEC) is a crucial element to examine the variabilities of ionosphere. To improve the ionospheric delay error modeling practices it is significant to understand and predict the latitudinal behavior of the ionosphere [2]. The International Reference Ionosphere (IRI) model is the most widely used and periodically updated by scientific committees, necessitates performance evaluations across diverse regions to ensure its accuracy [1]. To achieve these objectives, we assessed the performance of the latest IRI-2020 model and its predecessor, IRI-2016 model, by comparing their TEC outputs with ground-based GPS-TEC measurements. Seasonal and annual variations of TEC have been analysed over the period of 11 years from 2004-2014, encompassing a complete solar cycle at 4 different stations spanning equatorial to near high-latitude stations nearly along same longitude: Bangalore, India (equatorial station, latitude: 12.97160, longitude: 77.59460) Varanasi, India (EIA station, latitude: 25.31760, longitude: 82.97390) Bishkek, Kyrgyzstan (mid-latitude station, latitude: 42.6800, longitude: 74.6940) Novosibirsk, Russia (near high-latitude station, latitude: 55.0310, longitude: 82.9090). The statistical analysis also have been carried out using Root Mean Square Error (RMSE) to assess the accuracy of IRI model. From this study, it is evident that there is a latitudinal gradient in ion production in the ionosphere. Results show that the seasonal variations of GPS-TEC is reproduced by both the versions of IRI model with slight discrepancies. The RMSE values reflect these over- and under-estimation of IRI-2016 and IRI-2020 model. The IRI-2020 demonstrates improved accuracy across the 75-82 degree longitude, in predicting seasonal trends and winter anomalies with lower RMSE values and better alignment with solar activity indices (F10.7 and SSN), particularly at mid- and near high-latitude station. The findings from this study contribute to efforts aimed at enhancing the ionospheric IRI model and improving the forecasting of ionospheric delay errors.

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A3-P-03

NOCTURNAL OCCURRENCE OF SLANT SPORADIC E AT LOW LATITUDES REGION

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ABSTRACT

Sporadic E (Es) layers are localized, transient enhancements in electron density that form between 90 km and 130 km altitude. Their formation is primarily driven by wind shear mechanisms, which play a crucial role in ionospheric structuring at these altitudes. In this study, we examine the occurrence frequency, characteristics, and possible driving mechanisms of slant-type Es layers. Ionosonde data from Jataí (JAT, 17.87° S; 51.83° W; dip lat. -12.6°) and São José dos Campos (SJC, 23.18° S; 45.89° W; dip lat. -19.35°) were analyzed. We investigate the possible effect of the zonal winds on the slant sporadic E (Es_s) using the E-region Ionospheric Model (MIRE). Finally we considered the possible roles of tides, gravity waves and electron density gradients in the formation of Es_s layers at low latitude.

A3-P-04

Longitudinal Differences in Ionospheric Irregularities during the March 2023 Geomagnetic Storm: A Multi-Instrument Study of Driving Mechanisms

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This work investigates the ionospheric irregularities that occurred during the March 2023 geomagnetic storm, analyzing data from the American and Asian sectors. The study synthesizes multi-instrument observations, including the rate of total electron content (TEC) index, ionospheric heights, Swarm plasma density, Formosat-7/Cosmic-2 (F7/C2) radio occultation profiles, Fabry-Perot interferometer driven neutral winds, and E region electric field. During the storm’s main phase, post-sunset equatorial plasma bubbles (EPBs) extend to higher latitudes in the western American longitudes, showing significant longitudinal differences in the American sector. Conversely, a suppression of post-sunset irregularities is observed over the Indian longitudes, which is attributed to the westward prompt penetration electric field (PPEF). At the early recovery phase, the presence of post-midnight/near-sunrise EPBs till post-sunrise hours in the American sector is associated with the disturbance dynamo-electric fields (DDEF). Additionally, a strong consistency between F7/C2-derived amplitude scintillation (S4) ≥ 0.5 and EPB occurrences is observed. Both the Asian and American sectors exhibit inhibition of ionospheric irregularities at the recovery phase, which is dominated by the disturbance dynamo effect. The findings suggest that storm-time ionospheric irregularities are controlled by the combined effects of PPEF and DDEF. This study contributes to a deeper understanding of ionospheric irregularities under the influence of storm-phase and local time-dependent electric fields.

A4-P-01 - HASSAN MOHAMED Hayam

A Study of Storm Sudden Commencements at Different Latitudes

A4-P-01

A Study of Storm Sudden Commencements at Different Latitudes

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Abstract

This study presents a comprehensive physical model of geomagnetic storm sudden commencements (SSCs), which are characterized by a rapid and global enhancement of the Earth's magnetic field. The model is developed through the integration of observational data from a wide range of geomagnetic observatories, spanning from polar to low latitudes. The analysis aims to investigate the latitudinal dependence and triggering mechanisms of SSC events. Our results emphasize the significant role of solar wind shocks and interactions with the interplanetary magnetic field (IMF) in initiating these events. This work contributes to a more detailed understanding of space weather dynamics and their implications for the Earth's magnetosphere.

A5-P-01 - MAHATO Somnath

Study of the First Intense Geomagnetic Storm of Solar Cycle 25 occurred on 10-12 May 2024 Over Low Latitudes

A5-P-02 - SHETTI Dadaso Jaypal

Studies of Ionospheric Response and TID Activity During the Intense May 2024 Geomagnetic Storm Using IRNSS/NavIC

A5-P-03 - SINKONDE Christopher Chikaonda

SPACE WEATHER EFFECTS ON GNSS: A CASE STUDY OF TRIMBLE CADASTRAL SURVEY EQUIPMENT IN MALAWI

A5-P-04 - SURCO ESPEJO Teddy Modesto

Assessment of GNSS Positioning during the May 2024 Geomagnetic Storm

A5-P-01

Study of the First Intense Geomagnetic Storm of Solar Cycle 25 occurred on 10-12 May 2024 Over Low Latitudes

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Keywords: Geomagnetic storm, Total Electron Contents, GPS, Low latitude.

Abstract:

During the maximum phase of Solar Cycle 25, the first intense geomagnetic storms of this solar cycle this year occurred on 10-12 May, 2024, and the shock related to it arrived at Earth's magnetosphere, which resulted in a very intense storm of the year 2024. This storm is significant not only because of the extremely high magnetic activity, but also due to its great impact on the geo-magnetosphere. The ionospheric response to this storm has been investigated using 03 GPS receivers at the low latitudes. Analysis of GPS-TEC data during the geomagnetic storm found a positive storm effect over low latitudes. The enhancement in VTEC data before the commencement of the geomagnetic storm is observed over all the locations in low low-latitude region, which is attributed to the pre-storm solar-induced events like CMEs, proton events. Disturbance in ionospheric TEC during the geomagnetic storm is a major issue in navigation/aviation/communication applications using GPS and other satellite communication systems at low latitudes, and advanced knowledge of such disturbances is useful to improve them.

A5-P-02

Studies of Ionospheric Response and TID Activity During the Intense May 2024 Geomagnetic Storm Using IRNSS/NavIC

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Abstract:
In May 2024, a severe geomagnetic storm with a Dst index reaching –412 nT was triggered by active sunspot region AR13664, which produced multiple X-class solar flares and coronal mass ejections (CMEs). This study investigates the ionospheric response over a low-latitude station in Sangli, India, using data from the Indian Regional Navigation Satellite System (IRNSS/NavIC) during the period of May 9–14, 2024. We analyzed Total Electron Content (TEC), the scintillation index (S4), and the Rate of TEC Index (ROTI), along with electric field estimations from the PPEFM model and neutral composition data (O/N_2) from GUVI/TIMED. A significant TEC depletion was observed during the main phase of the storm, attributed to westward electric fields suppressing the upward E×B drift. TEC enhancements during early May 11 were consistent with strong eastward prompt penetration electric fields. Although no S4 or ROTI activity was recorded during the main and recovery phases, clear irregularities emerged on May 12–13, likely related to residual storm effects and plasma bubble activity. Short-lived TEC enhancements were also observed following X-class flares, particularly the X5.8 flare on May 11, with stronger responses near local noon. In addition, analysis of NavIC data revealed the presence of Traveling Ionospheric Disturbances (TIDs) on May 11, and we further discussed their propagation characteristics using IRNSS observations. These results highlight the combined impact of solar flares, storm-driven electrodynamics, and TID activity on low-latitude ionospheric dynamics, and demonstrate the value of IRNSS/NavIC for space weather monitoring in the Indian region.

Key Words: Geomagnetic storm, Total Electron Content (TEC), Rate of TEC Index (ROTI), Solar flares, Traveling Ionospheric Disturbances (TIDs)

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A5-P-03

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TITLE: SPACE WEATHER EFFECTS ON GNSS: A CASE STUDY OF TRIMBLE CADASTRAL SURVEY EQUIPMENT IN MALAWI

Abstract:

Global Navigation Satellite Systems (GNSS) are increasingly vital for high-precision cadastral surveying. However, space weather phenomena, particularly ionospheric disturbances, can degrade GNSS signal quality, affecting positional accuracy. This study investigates the impact of space weather on the performance of Trimble GNSS survey equipment used in cadastral mapping across Malawi. Using geomagnetic indices, ionospheric data, and field measurements, we analyze correlations between space weather events and GNSS positional errors recorded during surveys. The findings reveal that increased ionospheric activity, particularly during geomagnetic storms, significantly affects GNSS accuracy and reliability. This research underscores the need for mitigation strategies and real-time monitoring tools to enhance the resilience of GNSS-based surveying in space weather-prone regions.

Keywords:

Space Weather, GNSS, Cadastral Surveying, Ionospheric Disturbance, Malawi

Assessment of GNSS Positioning during the May 2024 Geomagnetic Storm

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The Global Navigation Satellite System (GNSS) has an increasing role in air traffic control systems. However, the ionosphere may produce severe effects on the propagation of GNSS signals. Consequently, the ionospheric effects cause positioning error that degrades the accuracy, performance and availability to support GNSS positioning, particularly in the equatorial and low-latitude regions. Ionospheric scintillations are fluctuations in the phase and amplitude of the signals from GNSS satellites occurring when they cross regions of electron density irregularities in the ionosphere and hence can cause significant errors in positioning based on GNSS.

The importance of this study is due to the impact of geomagnetic storms on GNSS positioning. Geomagnetic storms influence the ionospheric TEC and the ionospheric scintillation that can degrade single and double-frequency navigation systems. Some effects could be due to overlapping with solar flares that occurred during the storm period.

This study investigates the impact of geomagnetic storms, specifically those occurring on May 2024, on the accuracy of positioning and total electron content (TEC) in different dip latitudes. The study focuses on GNSS stations analyzing data during significant geomagnetic storm events on May 2024. The GPS single frequency kinematic positioning present some abnormal errors, coinciding with these ionospheric disturbances. While the position should be stable at cm level, the positions estimated during the event showed strong variations of several decimeters up to one meter. This can be explained by the loss of the signal from several satellites at the same time implying an increase of the PDOP (position dilution of precision), i.e. a decrease in positioning accuracy.

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A6-P-01 - NUGRAHA Jimmi

Analysis of Total Electron Content (TEC) Anomalies Associated with Precursors of Strong Earthquakes in Indonesia in 2022

International Beacon Satellite Symposium 2025:

Analysis of Total Electron Content (TEC) Anomalies Associated with Precursors of Strong Earthquakes in Indonesia in 2022

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Abstract

Earthquake precursors remain an active area of research aimed at improving the ability to predict seismic events. One such potential precursor is Total Electron Content (TEC) anomalies, which are based on the assumption that seismic activity can influence the state of the ionosphere. This study analyzes TEC anomalies observed prior to strong earthquakes (Mw > 6) that occurred in Indonesia between January and May 2022.

TEC data were obtained from Global Ionosphere Maps (GIM), generated using observations from over 200 GPS stations worldwide, managed by the Center for Orbit Determination in Europe (CODE). Anomalies in TEC were identified using both autocorrelation and cross-correlation methods. A TEC anomaly was considered significant if the inconsistency value—represented as the ratio of the Deviation of the Correlation Coefficient (DCC) to the Standard Deviation of the Correlation Coefficient (SDCC)—was less than -1.

The autocorrelation method involved analyzing TEC data at coordinates closest to each earthquake epicenter, while the cross-correlation method compared TEC values at the epicenter with those from surrounding latitudes. Additionally, Disturbance Storm Time (DST) index data were utilized to distinguish ionospheric anomalies due to seismic activity from those caused by geomagnetic storms.

TEC anomalies were observed less than ten days prior to the Banda Sea earthquakes on January 4 and February 1, 2022. These anomalies may be linked to earthquake preparation processes and other contributing factors. The findings are consistent with previous research suggesting a relationship between TEC variations and seismic events.

Keywords: earthquake precursors, total electron content, cross-correlation, anomaly variations, geomagnetic storms.

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A7-P-01 - CASTRO CHAUPIS Armando

Deep Learning for Ionogram Parameter Extraction: A Time-Series Approach to Ionospheric Monitoring

A7-P-02 - HSIAO Tung Yuan

A Real-Time Plasma Bubble Detection Method Combining Neural Networks and All-Sky Imaging

A7-P-03 - MARTINON André

Proposal of a HPC-bound Machine Learning Framework for Short-Term Scintillation Prediction over Brazil

A7-P-04 - MOLINA Maria Graciela

Research to Operations: ML Techniques for Real-Time Space Weather and Ionospheric Modeling

A7-P-01

Deep Learning for Ionogram Parameter Extraction: A Time-Series Approach to Ionospheric Monitoring

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Ionograms provide a direct measurement of the ionosphere's electron density profile and its irregularities. By examining critical frequencies researchers can identify key parameters—such as the F region critical frequency (foF2), the height of maximum electron density (hmF2), and the presence of Spread F irregularities—that are vital for understanding signal propagation, space weather effects, and radio communication reliability. Over the past decades, tools have been developed for the extraction of ionospheric parameters of ionograms: ARTIST-5[1] and among others. There are approximations in previous works using deep learning for automatic scaling with parameters extraction of great importance as the identification of the E and F2 layer. These tools generally work for relatively quiet days (QD), but not for days with Spread-F, where a lot of variability is observed in the parameters obtained in those days and manual correction is necessary. In this work, we trained a model combining Convolutional Neuronal Network (CNN), Long Short-Term Memory (LSTM) and Dense layers that can capture the short-term variability of the ionosphere and our model returns the frequency profile. Ionograms were recollected from VIPIR ionosondes, part of the Low-Latitude Ionospheric Sensor Network (LISN)[2]. We tested and compared the frequency profiles from our model with manual correction and parameters obtained with ARTIST 5.0 showing significant differences.

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A7-P-02

A Real-Time Plasma Bubble Detection Method Combining Neural Networks and All-Sky Imaging

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Equatorial plasma bubbles (EPBs) are large-scale ionospheric irregularities that pose significant threats to satellite-based communication, navigation, and surveillance systems. These depletions in plasma density, triggered by post-sunset instabilities in the equatorial F-region, lead to trans-ionospheric signal scintillation and degradation. To address the need for real-time monitoring of such disturbances, this study proposes a deep learning–based method for the automatic and near-instantaneous detection of EPBs using all-sky airglow imagery.

We develop a convolutional neural network (CNN) trained on deviation images generated from 630.0 nm airglow data collected by a ground-based all-sky imager (ASI). The network is designed to distinguish plasma bubble structures from background emissions, enabling pixel-level identification without manual labeling or post-processing. A dataset of labeled EPB events was constructed for training and validation, incorporating various nighttime conditions and geophysical environments to ensure generalizability.

Unlike previous studies that relied on handcrafted features, thresholding, or offline pipelines, our method enables high-speed inference directly on processed ASI data streams. Evaluation at a low-latitude ASI observatory shows that the model achieves high precision and recall in detecting EPBs, with average inference time suitable for real-time applications. The system provides not only binary detection but also spatial localization of EPB regions, offering a valuable tool for integration into future space weather nowcasting and alert systems.

This work represents an important advancement toward operational, automated EPB monitoring using optical remote sensing and deep learning techniques. It also lays the foundation for expanding into multi-instrument integration for improved situational awareness of ionospheric conditions affecting GNSS and communication reliability.

Keywords: plasma bubble, equatorial ionosphere, all-sky imager, convolutional neural network, airglow, real-time detection, GNSS scintillation, space weather
.

A7-P-03

Proposal of a HPC-bound Machine Learning Framework for Short-Term Scintillation Prediction over Brazil

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A data-oriented approach using machine learning is proposed for the short-term, up to one hour, scintillation prediction over Brazil. It aims to support warnings for areas in Brazil affected by moderate/strong ionospheric scintillation, and also the corresponding probability of scintillation occurrence for those areas. Time series of bidimensional maps can be generated comprising amplitude and phase scintillation, and ROTI, using a recently proposed methodology [1]. The corresponding maps of probability of occurrence, a new concept [2], can also be generated. For instance, the period of study may cover months of September to April for the years 2022 to 2025, only for nighttime, in the growing phase of current solar cycle 25. Data for generating the maps can be acquired from the INCT and RBMC monitoring networks [3], which sum up almost 100 GNSS stations. The proposed prediction is a supervised learning problem that employs dimensionality reduction to make the processing time feasible. The chosen machine learning algorithms are XGBoost, Long Short-Term Memory (LSTM) and Recurrent Neural Networks (RNN). A machine learning framework is proposed providing an automatic process of data collection, and choice of the machine learning algorithm. This process will iteratively provide, in a closed cycle, the training that generates the predictive model, hyperparameter optimization, and its predictive performance evaluation. Even with the dimensionality reduction, this process will be computationally expensive, requiring the use of high-performance computing (HPC) hardware and techniques. A preliminary code for the framework was already developed using the Python language linked to Fortran libraries using the OpenMP parallel library. It was executed in a shared memory architecture with multicore processors. It is intended to develop an expanded version of the framework in order to execute in GPUs and/or in nodes of a supercomputer that is available for the study. Results of prediction and processing performance using this preliminary version of the framework will be presented.

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Research to Operations: ML Techniques for Real-Time Space Weather and Ionospheric Modeling

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As the machine learning based modelling, specially in ionospheric and space weather areas, is evolving many challenges arise regarding their implementation and deployment in real-time operational environments including: a) real-time data streaming, transformation and preprocessing, b) integration of AI-based models into existing software systems and workflows, c) data, model and performance metrics tracking and monitoring, d) continuous evaluation, update or even completely change models without affecting the operational pipeline, e) election and integration of appropriate technologies, among others.
Moreover, in real-time scenarios (e.g. in space weather prediction) the IA-based modeling is turned into a decision tool. As such, it is critical that these models are not only accurate and robust but also comply with being reliable, explainable and unbiased (if not completely, at least not harming the society).
In this work we discuss different techniques, strategies and technologies currently available to tackle the above mentioned challenges and present cases of study and future works.

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The development of the Italian National Space Weather Service

A8-P-01

The development of the Italian National Space Weather Service

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In order to develop and strengthen a National Space Weather Capability, it is essential to set up an operational Service that ensures real-time automatic processing of information gathered from different sources, allowing continuous monitoring of space conditions and producing reliable and accurate early-warning messages towards the users. Cooperation between the Italian Air Force and national scientific and research organisations as data provider, INGV and INAF, has been established and implemented in order to achieve a robust capability, ready for operations, as a standard mean for decisions making. By means of an user-friendly graphic user interface, the system is designed as an aggregator of different space weather related data, ingested from different data sources in various data format, enabling the consultation of both models as well as real-time observations, organized by product categories (e.g. solar radio data, ionospheric data, particle fluxes in geostationary orbit…). In particular, the service will provide real-time alerts when thresholds for specific parameters are exceeded and forecast impacts on several technological and industrial systems. In this work, it is presented the goal of the activities and the state-of-the-art of the prototype.