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Algeria

Contribution of GNSS to stability monitoring of engineering structures: the case study of Beni Haroun Dam in Algeria

Hicham DEKKICHE, Sofiane Khelifa, Walid Bouaoula, Younes Ahmed Betchim
Space Techniques Centre - Algerian Space Agency
hdekkiche@cts.asal.dz

Nowadays, the Global Navigation Satellite Systems (GNSS) makes an accurate tool contributing to the studies related to the deformation of the earth's crust and engineering structures like dams, bridges, viaducts, etc. Further than the usual studies of monitoring dam deformation by classical geotechnical and topographical (triangulation/trilateration) methods, in this study the methodology aims to evaluate the deformations of the Beni-Haroun Dam (located in the North-East of Algeria) by processing the continuous GPS data and the analysis of the generated coordinate times series.

This study is part of the scientific convention between the Space Techniques Centre (CTS) / Algerian Space Agency (ASAL) and the National Agency for Dams and Transfers (ANBT), relating to the contribution of space positioning techniques to the geodetic monitoring of dams.

Since February 2014, ANBT has set up a permanent GPS network to monitor the behavior of the Beni-Haroun dam (the largest dam in Algeria). This monitoring network consists of six permanent single-frequency GPS stations: four on the dam and two on the shores, on geologically stable rock. This allows to continuously measuring the movements of the dam with millimeter precision, which will improve the degree of control of the dam safety, in view of its large volume of water (up to 960 million cubic meters) that can abruptly flow downstream in the case of a rupture. However, the measurement results must also be analysed in order to assess the movement of the dam relatively to its environment.

In this study, GPS data covering more than 7.5 years (from February 2019 to September 2021) were post-processed in relative mode to generate the coordinate time series expressed in the Earth-Centred, Earth-Fixed (ECEF) frame. These time series are then transformed in a local coordinate system linked to the Beni-Haroun dike for a more intuitive and precise interpretation.

The resulting daily coordinate time series of the permanent GPS stations of Beni-Haroun dam were analysed in order to investigate the dam deformation (displacement of stations). The analysis consists in evaluating their trend (long-term evolution of the dam displacement), their seasonal components (periodic displacements) and their noise (residual displacement).

The proposed analysis methodology is based on three different approaches: (1) the Singular Spectrum Analysis (SSA) method to estimate the trend, seasonal components and noise in the phase space, (2) the spectral analysis to characterize the noise spectrum and (3) the wavelet thresholding method to assess the noise in the frequency space.

The analysis results reveal that the residual movement of the studied stations can be assimilated largely to annual errors. Due to the low values of linear displacement (less than 1 mm/year) and noise level (less than 1 mm), the Beni-Haroun Dam can be qualified as stable.

KEYWORDS: Beni Haroun dam, GPS time series, Deformation.

China

Ionospheric space weather monitoring and its applications on GNSS

Qi LIU[1,2]
[1] *Henan Industrial Technology Academy of Spatio-Temporal Big Data, Henan University, China*
[2] *The College of Geography and Environmental science, Henan University, China*
qi.liu@henu.edu.cn

The ionosphere contains numerous free electrons with uneven distribution and intricate variations at different regions, which is one of the main focuses for both GNSS and space weather communities. The irregular variations significantly affect GNSS signals that pass through the ionosphere. Severe ionospheric space weather events, such as ionospheric storms and disturbances, can have a profound impact on both GNSS positioning services and shortwave communication. Ensuring precise correction of ionospheric errors at different scales from regional to global, as well as refining the handling of space weather events, has become a critical bottleneck in achieving robust GNSS high-precision navigation. Recently, novel ionospheric monitoring methods including real-time global Total Electron Content (TEC) inversion, ionospheric storm, ionospheric perturbation, and characterization of ionospheric TEC spatial structure, has been proposed. In addition, the applications of proposed methods to GNSS positioning demonstrates a noticeable improvement.

KEYWORDS: GNSS, ionospheric space weather, positioning

China

BDS High Accuracy Service of BDS Public Service Platform

LIU Shuo
China Academy of Information and Communication Technology
liushuo3@caict.ac.cn

With the gradual advancement of 5G network and the continuous improvement of terminals, the huge scale of smartphone users have an increasingly urgent demand for high-precision positioning. The Smartphone has gradually become an important terminal for the public to obtain high-precision location services, and also the most important carrier for the realization of BDS high-precision location services. Smartphones using A-GNSS data to enhance positioning capabilities has become a mainstream trend. This year, Galileo Satellite Navigation System released the official version of HAS (High Accuracy Service), is providing related services. This report will focus on researching and proposing a low-cost, standardized, and scalable PPP enhancement service based on BDS.

KEYWORDS: BDS, PPP, Smartphone

China

Precise Point Positioning test results with two CENTISPACE™ experimental satellites

Qiangwen Yang; Xiaodong Du; Long Yang; Mingliang XU
Beijing Future Navigation Technology Co., Ltd
yangqw@centispace.com; duxd@centispace.com; yangl@centispace.com; xuml@centispace.com

Beijing Future Navigation Technology Co., Ltd. is developing the CENTISPACETM low earth orbit satellite navigation augmentation system. Several experimental satellites have been launched. Based on real observations from a regional monitor station network, the results of real LEO augmentation data quality and LEO-enhanced precise point positioning (PPP) performance is presented. A framework for LEO augmentation data processing is established, and a three-step approach for LEO clock synchronization and antenna calibration is proposed. PPP convergence performance is significantly enhanced. The average convergence times of static solutions with one, two, and three GNSS systems are 32.7, 17.9, 14.2 min, respectively, which are reduced to 16.7, 8.9, and 5.7 min after adding two experimental satellites data. Averagely, the convergence time of augmented PPP is 2.1 times shorter than GNSS-only solution.

KEYWORDS: LEO augmentation; GNSS; Precise point positioning (PPP)

Croatia

Airplane trajectory reconstruction and analysis using GNSS-based ADS-B data: what to do with the open access data using the open source software

Renato FILJAR[1,2], Robert Spudić[2]
[1]Faculty of Engineering, University of Rijeka, Rijeka, Croatia
[2]Laboratory for Spatial Intelligence, University of Applied Sciences Hrvatsko Zagorje Krapina, Krapina, Croatia
renato.filjar@gmail.com

The Automatic Dependent Surveillance–Broadcast (ADS-B) is an ICT technology and services aimed at improving the situation awareness for aviation. The global mandatory ADS-B deployment benefits various aspects of aviation, from air navigation to Air Traffic Control (ATC). ADS-B utilises GNSS position estimation, as well as an open communication interface, with broadcasts in the VHF portion of radio spectrum. Systematical collection of the ADS-B messages worldwide has led to formation of massive data sets, with several being available in the open access manner. The massive ADS-B data offers a foundation for a vast new discipline of airplane trajectory data collection, aggregation, collation, reconstruction, and analysis.

Here we present and demonstrate an organised approach to the access of the ADS-B data provided by OpenSky Network, an EU project establishing and maintaining the world-wide ADS-B structured data collection, and airplane trajectory reconstruction and analysis using tailored machine learning methods. ADS-B trajectory reconstruction and analysis presented is conducted in the open-source R environment for statistical computing, using general and bespoke R packages, and the R-based software developed by our team.

The systematical discussion of the GNSS-based trajectory reconstruction and analysis results is proposed and demonstrated, as a case of machine learning-based inference of the relevance and contribution to and empowerment of processes in air navigation, convergence of trajectories into corridors, ATM, surface navigation, logistics, and strategic developments. The airplane trajectory reconstruction and analysis using GNSS-based ADS-B data is discussed in the reverse engineering sense, as a novel and invaluable tool for estimation of the world-wide spatial real-time GNSS positioning performance indication.

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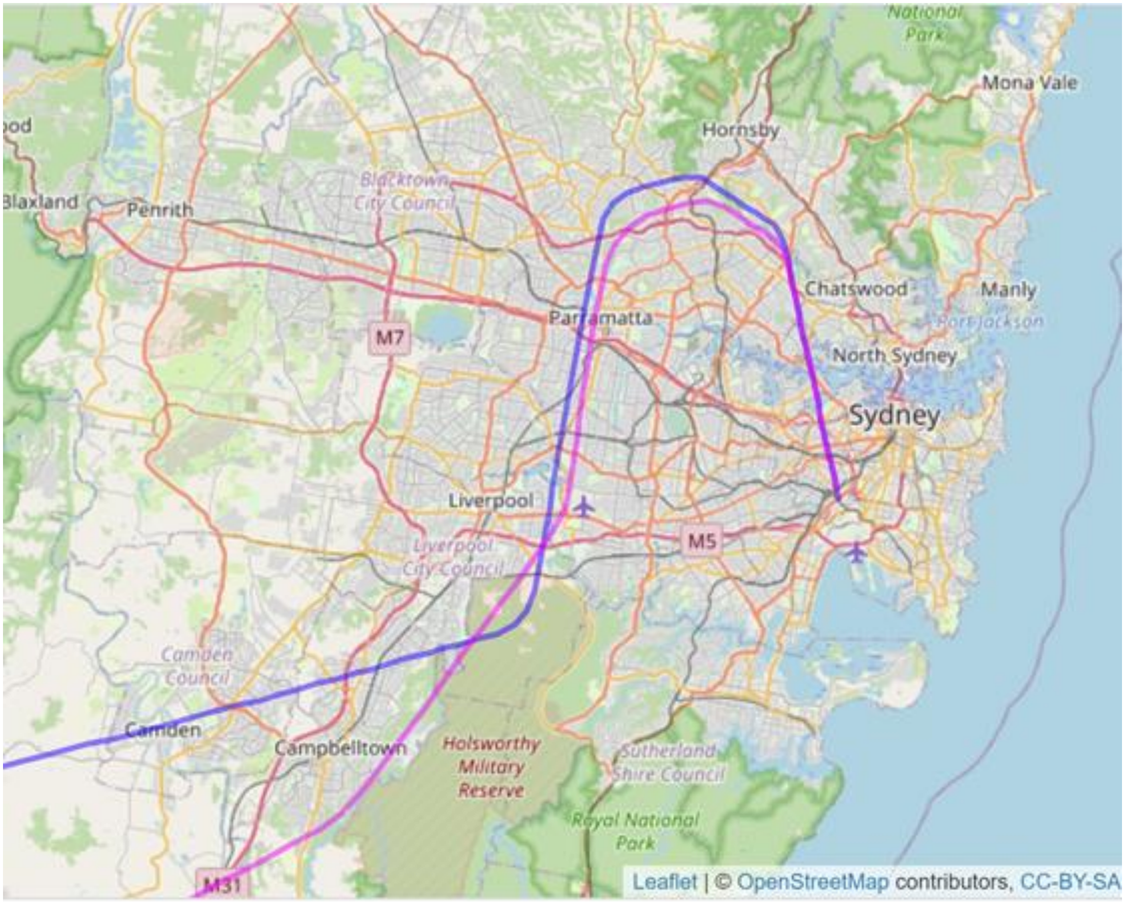


Figure 1: An example of the airplane trajectory reconstruction using OpenSky Network GNSS ADS-B data in the R environment

KEYWORDS: GNSS, ADS-B, trajectory reconstruction

Cyprus

GNSS related activities to ionospheric and tropospheric studies in Cyprus

Haris HARALAMBOUS
Frederick University, Cyprus
eng.hh@frederick.ac.cy

GNSS remote sensing of the lower and upper atmosphere is an established technique that provides 24/7 monitoring capability of an array of meteorological and space weather driven phenomena that can impact various economy sectors of our modern society. The scope of this presentation relates to activities at Frederick University in Cyprus towards the development of a GNSS satellite service over the eastern Mediterranean region to provide near-real time information on the variability of ionospheric and tropospheric characteristics that define the state of these two crucial atmospheric regions. From the tropospheric perspective these activities include a pilot transnational severe weather service based on tropospheric products (BeRTISS) and also collaboration with a company (CLOUWATER LTD) that develops low-cost GNSS receivers to augment the spatial resolution of monitoring Precipitable Water Vapor (PWV), which is a direct indicator of extreme precipitation events and a valuable data source for high resolution limited area Numerical Weather Prediction (NWP) models. The ionospheric perspective will highlight the complementary benefit that GNSS remote sensing provides for Travelling Ionospheric Disturbance (TID) monitoring in order to provide a more complete characterization of ionospheric irregularities that pose a serious threat to a range of positioning and navigation application.

KEYWORDS: Ionosphere, Troposphere, low-cost GNSS

Egypt

Bridging the Gap: Advancing Space Weather Services for Aviation in Egypt

A. SHAKER[1], Hassan Nooreldeen[1], Amira H. Hussein[1]
[1]Egyptian Space Agency (EgSA), Egypt
abdulla.shaker@egsa.gov.eg

The recent establishment of the Space Weather Center within the Egyptian Space Agency signifies a significant milestone in the realm of space weather monitoring and analysis in Egypt. This state-of-the-art center encompasses an extensive network of 46 GNSS stations strategically positioned across the Egyptian region. Its primary objective is to provide local services, particularly catering to the air navigation sector, which stands as a critical stakeholder in the country's aviation landscape. These GNSS stations serve as vital sources of real-time information, offering comprehensive insights into the dynamic ionospheric conditions prevalent over Egypt and the broader northeastern African continent. The center's immediate data analysis capabilities enable the timely provision of critical resources to air navigation services. Specifically, it furnishes these services with up-to-date ionospheric maps, depicting the temporal evolution of total electron content and S4 – scintillation data. Moreover, the center supplements air navigation services with crucial meteorological data encompassing variables such as wind speed, wind direction, atmospheric pressure, humidity, and temperatures. These comprehensive offerings empower aviation stakeholders with enhanced situational awareness, facilitating informed decision-making and promoting operational efficiency. This presentation aims to showcase the remarkable capabilities of the Egyptian Space Weather Center and its vital role in supporting air navigation services within Egypt. Furthermore, it will delve into insightful analyses of notable solar events occurring during the solar cycle 25, shedding light on their implications for aviation operations. In this presentation, we will show bridging the gap between cutting-edge space weather science and the precise requirements of the aviation industry in Egypt. The ultimate goal is to ensure the safety and reliability of aviation operations in Egypt while paving the way for continued growth and prosperity in the sector.

KEYWORDS: GNSS, TEC, S4

Ethiopia

Comparison of low-latitude coronal holes area between solar cycles 23 and 24

Alene SEYOUM (Ethiopian Space Science and Geospatial Institute (SSGI))
aleneseyoum4@gmail.com
Prof Nat Gopalswamy (NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA)
Dr Melessew Nigussie (Washera Geospace and Radar Science Laboratory, College of Science, Physics Department, Bahir Dar University, Bahirdar, Ethiopia.

Based on the area of coronal holes CHs on Extreme Ultraviolet EUV synoptic maps derived from the Heliophysics Event Knowledge Base HEK system, as well as solar wind parameters from the OMNI database and geomagnetic storm disturbances from the World Data Center for Geomagnetism Kyoto during the maximum and early declining med phases of solar cycles 23 and 24, these are examined. Geomagnetic activity is primarily driven by solar wind highspeed streams HSSs from coronal holes CHs in the equatorial region, as well as by SIRCIR SWs emitted from CHs.

The area of CHs recorded between central meridian distances of 30 o, the so-lar wind' s characteristics flow velocity V, proton density n, temperature T, and the interplanetary magnetic field B, and the geomagnetic indices Dst are all subjected to crosscorrelation analysis. A crosscorrelation study shows that there is a significant association between all of the studied parameters. We explicitly show that the Dstindex is much more sensitive to SIRCIR and the region of CHs during 23 SC as compared to 24 SC. Since the equatorial CHs area has a higher SW speed than SC 24, more SIRCIR are generated in SC 23. We have more geomagnetic storms during the March and September equinox periods than we do in 24 at the maximum phase of 23 SC.

The most significant outcome from the perspective of space weather is that the established empirical connections enable onehour resolution forecasting of the SIRCIR resulting in HSS features and the associated geomagnetic activity a few hours in advance.

KEYWORDS: Storm, Equatorial, Coronal holes

Ethiopia

Overview of GNSS Applications in Ethiopian Context

WELDU Eden Tadese
Ethiopian Space Science and Geospatial Institute
hamerawi2022@gmail.com

The Global Navigation Satellite System (GNSS) has become an integral part of various applications worldwide, including navigation, positioning, and timing. In the Ethiopian context, GNSS technology has gained significant importance due to its potential to enhance various sectors such as transportation, agriculture, disaster management, and surveying. Despite the potential benefits of GNSS applications in Ethiopia, there are challenges that need to be addressed. Limited infrastructure, including insufficient ground-based reference stations and data processing facilities, hampers the full utilization of GNSS technology. Additionally, capacity building efforts are required to enhance the local expertise in GNSS data analysis and interpretation. By leveraging GNSS technology, Ethiopia can achieve improved efficiency, productivity, and resilience in these domains. However, addressing infrastructure limitations and investing in capacity building are crucial for the successful implementation of GNSS applications in the country. This paper, overview of GNSS application in the Ethiopian context, showcases its potential to revolutionize various sectors such as transportation, agriculture, disaster management, and surveying.

KEYWORDS: GNSS, Navigation, Positioning

Finland

Observation and real-time analysis of space weather effects on GNSS through GNSS measurements

Jens BERDERMANN
German Aerospace Center
jens.berdermann@dlr.de

Space weather can significantly affect satellite-based navigation services, leading to increased risks to safety and economic losses.

Radio signals used by global navigation satellite services (GNSS) are, for example, influenced during propagation through the ionosphere. Therefore, GNSS-based navigation services used in aviation can be affected by ionospheric disturbances, limiting safety and efficiency. Operators of such critical infrastructure are increasingly aware that extreme space weather events can have severe impacts on their systems. Therefore, since 2019, the International Civil Aviation Organization (ICAO) has been operating global space weather centers with the goal of providing real-time information and forecasts to aviation users. In the presentation we will provide past and current examples of space weather impact on navigation services used in aviation. We will also show how ground- and space-based GNSS data, combined with appropriate models, can provide unique information about the ionosphere and its impact on navigation services. In addition, we will discuss existing real-time products and new developments in terms of their potential to mitigate the effects of space weather on aviation. Finally, we will use the available information to assess the current space weather situation as we approach the 25th cycle solar maximum.

KEYWORDS: Space Weather, Ionosphere, GNSS

Finland

GNSS: a useful tool to study the impact of solar activity at Earth

BERGEOT Nicolas, Chevalier Jean-Marie, Marqué Christophe, de Patoul Judith, Maneva Yana, Vanlommel Petra, Janssens Jan
Royal Observatory of Belgium
Solar-Terrestrial Centre of Excellence
nicolas.bergeot@oma.be

An increasing demand for better modelling and understanding of the behavior of the Geospace environment is required by the scientific community and users of advanced technologies. Especially those using electromagnetic wave signals reflecting on or passing through this system.

In that frame, the Global Navigation Satellite Systems (GNSS, i.e. GPS, GLONASS, Galileo) is an useful tool to monitor and better characterize the ionosphere and plasmasphere layers and their response due to solar activity variations.

In this paper, we will first introduce the different products available allowing the monitoring of the solar activity impact at Earth Geospace level. These products consist of Total Electron Content (TEC) Maps, at global or regional scales. We will present the monitoring done in near-real time of the ionosphere/plasmasphere over Europe done since 2010 in the frame of the Solar-Terrestrial center of excellence (STCE) which are made available to the public (visualization tools and data).

Then we will show their role for fundamental research on the physics of the ionosphere and the plasmasphere during quiet and disturbed geomagnetic conditions.

Another impact of extreme Solar event is the degradation of the Signal-to-Noise ratio of the electromagnetic wave at ground antenna level. The so called solar radio bursts (SRBs) impact the GNSS signal reception causing errors in several applications such as kinematic positioning.

In this paper, we will introduce a daily global index based on the International GNSS Service (IGS) network. Finally, we will explain why the GPS-only monitoring was sometimes interfered since 2018 due to flex power changes on the signals of the GPS block IIR-M and IIF satellites, and how it is mitigated.

Finally, we will present the different applications of these products for the scientific and civilian communities:

- The Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities (PITHIA-NRF); a H2020 project aiming at building a European distributed network that integrates observing facilities, data processing tools and prediction models dedicated to ionosphere, thermosphere and plasmasphere research (https://pithia-nrf.eu/)
- The PECASUS global center consortium of the International Civil Aviation Organization (ICAO), providing real-time space weather advisories to the international aviation (https://pecasus.eu/).

- The AGATA Scientific Research Programme (SRP) aiming at significantly advance the current knowledge of the Antarctic atmosphere and geospace, in the bipolar, interhemispheric context (https://www.scar.org/).
- The NASA InSight's Rotation and Interior Structure Experiment (RISE) aiming at study the rotation of Mars to better understand its internal structure (https://mars.nasa.gov/)

KEYWORDS: GNSS, Solar activity, applications

Finland

National Time and Time Services

Thomas FORDELL, Kalle Hanhijärvi, Anders E. Wallin, Thomas Lindvall
VTT Technical Research Centre of Finland Ltd, National Metrology Institute VTT MIKES, Espoo, Finland
thomas.fordell@vtt.fi

One of the tasks of National Metrology Institutes is to maintain physical realizations of Coordinated Universal Time (UTC) and to disseminate it to the society. The International Bureau of Weights and Measures (BIPM, Paris) determines UTC in three steps. First, the free atomic time scale (EAL) is calculated as a weighted average of about 420 free-running atomic clocks (cesium beam clocks, hydrogen masers) in 80 laboratories distributed world-wide. Next, the frequency of EAL is steered to maintain agreement with the SI second by frequency comparisons to primary frequency standards, most notably cesium fountain clocks, but today also optical clocks. Finally, leap seconds are added to keep UTC within 0.9 s of UT1, which is a time scale derived from the non-uniform rotation of the Earth. Currently, most time links between laboratories are based on GPS satellite observations using multi-channel, dual-frequency receivers. Precise point positioning analysis is then carried out by the BIPM to yield the time difference between the participating laboratories. A small number of institutes also operate Two-Way Satellite Time and Frequency Transfer (TWSTFT) links.

Since the invention of the frequency comb, which enables easy measurement of optical frequencies, the development of optical frequency standards has blossomed, and today the best optical clocks have frequency uncertainties two orders of magnitude below cesium fountain clocks. The Finnish National Metrology Institute VTT MIKES is developing its own optical clock based on a trapped and cooled 88Sr+ ion. On one hand, the clock can contribute to the steering of UTC; on the other hand, it can reduce our reliance on GPS for national timekeeping.

Frequency is the physical quantity that can be realized the most accurately, and as such, the development of better performing clocks and their remote comparisons via fiber-optic networks is important for fundamental science. Concurrently, our society is getting increasingly connected and ever more reliant on accurate synchronization of different parts and on time stamping of events, which also increases the need to develop time dissemination methods. Global Navigation Satellite Systems (GNSS) can provide accurate, widely available time information at low cost; however, recent world events have shown the need for alternative, GNSS-independent timing sources for critical systems. Fiber-optic time services can provide the highest accuracy but suffer from poor availability and/or high cost. On the other hand, low-frequency radio broadcasts are widely available but suffer from low-accuracy without augmentation. The presentation will discuss approaches for making accurate fiber-optic time signals available to a larger number of distant users as well as how to improve the accuracy of distant, low-frequency radio time broadcasts.

KEYWORDS: UTC, atomic clocks, time transfer

Finland

Use case demonstration on the SWIGPAD API service for creating GNSS Performance indicator maps

Elias HIRVONEN, Kirsti Kauristie
Finnish Meteorological Institute (FMI), Finland
elias.hirvonen@fmi.fi
Jens Berdermann, Paul David, Martin Kriegel
German Aerospace Centre (DLR), Germany
Vincent Fabbro
ONERA / DEMR Université de Toulouse F-31055 Toulouse– France
Knut Stanley Jacobsen
Norwegian Mapping Authority, Norway

Understanding space weather conditions is essential for a variety of end users that rely in the Global Navigation Satellite System (GNSS) services. The European Space Agency's Space Weather Service Network (ESA-SWE) provides observations and data products that describe the conditions affecting GNSS signal quality. However, the effect of space weather is complicated and monitoring each relevant data product and understanding their effects to specific systems can be demanding for more inexperienced users. A solution for simplifying the GNSS monitoring experience was created as the Space Weather Impact on GNSS Performance Application Development (SWIGPAD) project. The objective of SWIGPAD is to provide a single indicator that describes the GNSS performance with simple traffic-light colored threshold levels. Thus, the user can quickly interpret the GNSS signal reliability for the specified use, location and time excluding the need for detailed understanding of the individual observations.

The SWIGPAD project concluded to six GNSS Performance Indicators (GPI) that are optimized for different user cases. The indices combine a variety of space weather related products such as ionospheric scintillation indices (S4, ROTI, σϕ), electron content of the ionosphere (TEC), geomagnetic activity (Kp) and positioning errors (RTK).

The GPI is available through the ESA-SWE Portal and provided by the German Aerospace Center (DLR). The tool can be used manually through a graphical user interface (GUI) for quick requests for a single location and up to six timestamps. However, many users might be interested of visualizing the GPI on a map instead of a single location. Fortunately, SWIGPAD offers an application programming interface (API) allowing the possibility to receive the GPI from a script that can be used for more detailed requests.

In this presentation, we demonstrate the possibilities of SWIGPAD including an usage example creating a map of the GPI values. This provides an overlook to the GNSS performance in multiple locations and could then be used to monitor a larger scale territory, as in our case Finland. In addition, we discuss the API limitations and provide suggestions for optimizing the data retrieval.

KEYWORDS: GNSS, Performance indicator, SWIGPAD

Finland

Positioning technologies and Location Innovation HUB

Antti JAKOBSSON
National Land Survey of Finland
antti.jakobsson@nls.fi

The Location Innovation Hub (LIH) is a centre of excellence in location information coor-dinated by the Finnish Geospatial Research Institute. LIH services are produced in con-junction with a partner network. Our customers are particularly companies that want to solve the challenges of digitalisation and strengthen their competitiveness. We also serve the public sector.

Our customers can make their operations more efficient by developing data interopera-bility, using precise positioning and new generation positioning technologies. We pro-duce tools and test environments and provide consultation, and training, as well as pro-vide support through networking for companies to obtain funding.

Our development work focuses on four different themes: the built environment, bioe-conomy, health and wellbeing, transport, logistics and traffic. In these sectors, our cus-tomers can develop businesses related to artificial intelligence, high performance com-puting and cybersecurity.

In accordance with the European Data Strategy, interoperable information combined with location information is an indispensable resource for developing competitiveness and innovation capacity. Our activities are aimed at making efficient use of data spaces, for example on developing digital twins. Our goal is to create a functional, permanent location innovation ecosystem for seeking funding, testing services and developing new innovations in Europe.

The Location Innovation Hub, supported by the European Commission, is one of the four digital innovation hubs in Finland (EDIH) and is part of the European network of innova-tion hubs.

KEYWORDS: location intelligence cybersecurity, innovation

Finland

ESA Space Weather System for GNSS applications

JUHA-PEKKA Luntama, Alexi Glover
European Space Agency
juha-pekka.luntama@esa.int, alexi.glover@esa.int

Space Weather, the solar activity driven dynamic variation of the environment in space, is a potential threat to many elements of the human made infrastructure in space and on the ground. The risks of space weather impacts are not limited to the infrastructure, but also on any services and applications that need this infrastructure to function as intended. Global Navigation Satellite System (GNSS) is one of the elements of the infrastructure potentially at-risk during space weather events. GNSS satellites operate in a very demanding environment within Earths radiation belts and they are designed to be robust against radiation. Space weather events, however, can add extra energy into the radiation environment around the GNSS satellites and increase risk of anomalies in the onboard electronics. Even if the GNSS satellites themselves survive a space weather event, additional ionization of the upper atmosphere caused by the event may distort the GNSS signal propagation and reduce the accuracy of GNSS based applications or make them completely unavailable.

Today's society is utilizing GNSS in many application areas and a major space weather event could cause socio economic damage worth of billions of Euros. In the future the sensitivity of the society on space weather impacts is foreseen to increase as our infrastructure becomes more efficient and sophisticated. Utilization of GNSS in new application areas can be seen as part of this evolution. We do not have means to prevent solar events from happening, so alerting GNSS operators and the operators and users of GNSS based services about forecasted and detected space weather events is the best available measure to minimize adverse impacts.

This presentation will outline the ESA Space Weather System, its objectives, current development status, and how the system is designed to support mitigation of space weather impacts on the infrastructure and services critically depending on space-based assets. GNSS applications and the systems supporting GNSS including EGNOS are specific topics in this presentation.

KEYWORDS: ESA, Space Weather, GNSS

Finland

The Artic Space Weather demonstrator in the European Accelerators Programme

Kirsti KAURISTIE
Finnish Meteorological Institute
kirsti.kauristie@fmi.fi
Knut Stanley Jacobsen and Kristin Skjerven
Norwegian Mapping Authority
Yngvild Andalsvik
Norwegian Space Agency

ESA's Member States have decided to work together to strengthen Europe's space sector and to ensure its continued service to European citizens. Efforts towards those goals are coordinated under the Accelerators umbrella programme. Protection of Space Assets is one of the three main themes under Accelerators. It addresses the hazards that space-based constructions may experience by continuously increasing amounts of space debris and by solar activity driven space weather storms. The Protector also recognizes the increasing needs for efficient space traffic management at the most crowded satellite orbits.

Our presentation reviews the plans and findings of a space weather related pilot project which Finland and Norway have decided to conduct as a contribution to Accelerators. The Arctic Space Weather Demonstrator will present concrete and fresh examples on space weather impacts in operations of critical infrastructures facilitating our everyday life. In this context Global Navigation Satellite Services (GNSS) have a specific dual role. GNSS observations are widely used in space weather services to monitor spatio-temporal evolution of ionospheric disturbances although the system by itself can occasionally suffer from space weather storming. With the approach of the next of solar activity maximum – according to current estimates it will take place in early 2024 – it is not just the increased storm activity that will challenge GNSS performance. The gradual longer-term changes in the ionospheric background conditions may also challenge some solutions developed and tested during years of lower solar activity. Besides the challenges and risks, our presentation will also discuss the means to mitigate them with the focus on the portfolio of space weather monitoring and forecast services that are maintained under the ESA Space Safety programme.

KEYWORDS: ESA, space-based positioning, ionosphere

Design of Payload and Satellite for Low Earth Orbit Mega-Constellations

MAYANK[1], Z Saleem[1], S Sharma[1], J Praks[1], E. S. Lohan[2], S. Kaasalainen[3], H. Kuusniemi[4]
[1] Aalto University, Finland;
[2] Tampere University, Finland
[3] Finnish Geospatial Research Institute (FGI), Finland;
[4] University of Vaasa, Finland
mayank@aalto.fi, zainab.saleem@aalto.fi, shikha.sharma@aalto.fi, jaan.praks@aalto.fi, elena-simona.lohan@tuni.fi, sanna.kaasalainen@nls.fi, heidi.kuusniemi@uwasa.fi

Positioning, navigation, and timing (PNT) services may see changes influenced by the evolving Low Earth Orbit (LEO) constellations, owing to the continuous progress in satellite technology. This transformation is driven by the compelling requirement for resilient and robust PNT services across multiple sectors.

Small satellites offer advantages such as low cost, simple design, and fast manufacturing, allowing for rapid developments. However, there are still challenges and technological gaps that prevent such satellites from offering PNT services at their full potential. Integrating multiple antennas for multi-frequency navigation, as well as addressing the unique challenges associated with compact iso-flux antennas and power requirements, are notable issues in the small satellite domain.

This presentation proposes a LEO PNT system architecture addressing the challenges surrounding PNT payload and satellite design.

This study investigates a conceptual payload design for a Low Earth Orbit (LEO) satellite, focusing on its low power consumption and multi-frequency capabilities. The payload concept provides the foundation for small satellite design, enabling estimations for mass and power budgets for foreseen satellites.

The proposed constellation concept seamlessly integrates with existing GNSS infrastructure, pushing further the range of navigation services available to the world. Moreover, numerous optimization factors are examined in the payload design to ensure that the PNT constellation can sustain independently and maintain short-term accuracy without external assistance.

Using estimated power and mass budgets, commercial-off-the-shelf (COTS) components and systems were selected in order to validate the proposed satellite design viability. The study converges on a baseline design of a 12U CubeSat, able to handle the complexities of multiple antennas for transmitting and receiving the navigation and telemetry signals. The proposed satellite design can adapt up to three navigation frequencies, which offers improvements in PNT services by mitigating errors related to doppler shift and ionospheric interference.

With these considerations, our study plots a road for the development of an efficient and fully functional LEO PNT satellite system.

KEYWORDS: LEO PNT constellations, small satellites, PNT payload

Finland

Ionospheric 3D imaging with TomoScand

Johannes NORBERG
Finnish Meteorological Institute
johannes.norberg@fmi.fi

The ionosphere is a region of partially ionised gas surrounding the Earth between 50 and 1000 km altitude. It is controlled by several physical processes, including solar radiation and particle precipitation. One of the key ionospheric parameters is the electron density, which can be measured by instruments such as incoherent scatter radars (ISR), ionosondes and in-situ satellite measurements. These instruments give very accurate measurements of the ionospheric electron density structure, but only in the vicinity of the instrument. Due to the cost of these instruments, their number and geographical coverage is limited and not sufficient for regional or global ionospheric monitoring.

The geometry-free combination of dual-frequency GNSS measurements provides a measurement of the ionospheric total electron content (TEC) along the signal between the transmitter and receiver. Today's extensive networks of fixed GNSS dual-frequency receivers provide the most comprehensive measurements of the Earth's ionosphere. Perhaps the most commonly used application of GNSS measurements for ionospheric monitoring is the TEC map. In the TEC maps, the electron density contribution to the measurement is assumed to come from a thin layer at an altitude of 350 km. This is a widely used and useful method, but it does not provide any information about the height structure of the electron density, and the coarse height assumption introduces errors in the resulting distribution of TEC.

To reconstruct the three-dimensional structure of the ionosphere from GNSS measurements, tomographic imaging techniques are needed. Typically these methods suffer from two major bottlenecks. First, the problem is mathematically an ill-posed inverse problem that requires regularising information for a unique solution. In ionospheric imaging this additional information is usually provided by using ionospheric models as the background. However, in regional scale, models contain systematic biases that cannot be corrected by GNSS measurements. The second bottleneck is that in a three-dimensional situation, the number of unknown variables can easily become so large that solving them computationally becomes a challenge.

The TomoScand programme avoids the use of ionospheric models by using the few but accurate local measurements from ionosondes and ISRs to provide the required additional information. The numerical representation is aided by Gaussian Markov random fields, which considerably reduces the computational burden. Together, they enable near real-time, three-dimensional monitoring of the ionosphere on a regional scale. In addition to presenting the method, we look at the results over Northern Europe and the USA.

KEYWORDS: Ionospheric imaging , electron density, TEC

Finland

HydroGNSS – Spaceborne Use of GNSS for Climate Variable Sensing

Martin Unwin, Surrey Satellite Technology Ltd (SSTL), UK
Nazzareno Pierdicca, Sapienza University of Rome, IT
Estel Cardellach, Institut d'Estudis Espacials de Catalunya (IEEC), ES
Kimmo RAUTIAINEN, Finnish Meteorological Institute (FMI), FI
Leila Guerriero, Università di Roma Tor Vergata, IT
Giuseppe Foti, National Oceanography Centre (NOC), UK
Emanuele Santi, Institute of Applied Physics, IT
Paul Blunt, University of Nottingham, UK
Jean-Pascal Lejault, European Space Agency (ESA), NL
kimmo.rautiainen@fmi.fi

HydroGNSS is a small satellite mission under the ESA Scout Programme tapping into NewSpace, as part of ESA's FutureEO Programme, within a budget of €30m and a schedule of three years from mission kick-off to launch. The HydroGNSS satellite development is led by Surrey Satellite Technology Ltd (SSTL), and the science consortium consists of seven universities and institutes from Italy, UK, Spain and Finland. The HydroGNSS mission consists of two satellites using an innovative GNSS-Reflectometry instrument to collect parameters related to the Essential Climate Variables (ECVs): soil moisture, inundation, freeze/thaw, biomass, ocean wind speed and sea ice extent. GNSS-Reflectometry is a type of bistatic radar utilizing abundant GNSS signals as signals of opportunity, empowering small satellites to provide measurement quality associated with larger satellites.

The HydroGNSS instrument collects reflected GPS measurements processed on-board into Delay Doppler Maps (DDM) as on its predecessors on UKSA TechDemoSat-1 and NASA CYGNSS missions. Beyond this, HydroGNSS introduces new measurements, exploiting Galileo signals (E1b+c), dual-polarization, complex 'coherent channel' (amplitude/phase) and second frequency (L5/E5a) acquisitions. These measurements enable HydroGNSS to innovate the Level 2 products to access improved resolution on the ground, sensing of inundated locations and separation of roughness and vegetation effects from soil moisture. HydroGNSS uses the SSTL-21 platform and at approximately 65 kg, is practical for a low-cost future constellation. Although primarily targeting land, the payload will operate at near-100% duty cycle over the globe, including over oceans and the cryosphere.

Water is a natural resource vital to climate, weather, and life on Earth, and unforeseen global variability in hydrology poses one of the greatest threats to the world's population. The primary objectives of the HydroGNSS mission are to measure hydrological variables, closely related to GCOS ECVs

- **Soil Moisture** – knowledge is needed for weather forecasting, hydrology, agricultural analysis, and wide scale flood prediction.
- **Inundation / Wetlands** – this knowledge is important as the fragile water-dependent ecosystems in wetlands, often hidden under forest canopies, can also turn into sources of methane, whilst elsewhere an over-supply of water can lead to inundation and destructive flooding.

- **Soil Freeze/Thaw state** affects the surface radiation balance and the exchange rates of latent heat and carbon with the atmospheric boundary layer, and acts as a tracer for sub-surface permafrost behaviour in high latitudes.
- Forest Above Ground **Biomass** – using attenuation of signals in combination with knowledge of underlying surface and soil moisture characteristics, feeding into the understanding of carbon stock in forests and a sink in the carbon dioxide cycle, with a coupling to biodiversity.
- As a secondary objective, to measure **ocean wind speed** and **ice extent**, which address GCOS ECVs Ocean Surface Stress and Sea Ice Extent.

Level 1 products will comprise of GNSS DDMs and coherent channel measurements with sufficient metadata for calibration and recovery of surface reflection coefficients at the specular reflection points. The products will be shared publicly with registered users over the web. The planned delivery of reflectometry EO products to the scientific community will be based upon ESA's 'free and open' policy.

Following Kick Off in October 2021, the HydroGNSS mission preparation is well underway. The ride-share launch has been agreed and is provisionally allocated to a launch slot in late 2024. After launch, a short campaign will be undertaken to calibrate and validate products before they are released as data-delivery service. Subsequently HydroGNSS will generate products that will contribute towards hydrological ECVs feeding into better knowledge of the Earth's climate.

KEYWORDS: GNSS-R, ESA Scout mission, Hydrological ECVs

Finland

Advanced machine learning for anomaly detection and jammer localization

Laura RUOTSALAINEN
University of Helsinki
laura.ruotsalainen@helsinki.fi

To protect the critical infrastructure dependent on GNSS, the quality of navigation signals should be continuously monitored. Any anomalies should be immediately detected, isolated, and back-up solutions brought into use when required. At present, GNSS anomaly detection methods are mainly concentrating on one interference type only. Deep learning models are powerful in recognizing complex patterns in the data and thereby attractive framework for a pervasive anomaly detector.

We will present a Long Short-Term Memory (LSTM) network based autoencoder, which will which take advantage of the fact that GNSS data has temporal correlation. Our model learns via unsupervised training which frees us from laborious labelling work usually slowing down the modelling of complicated real-world phenomena. We will also process the anomaly detection in the complex domain respecting the fact that the received GNSS signals are complex valued by nature and thereby receiving a more accurate detection response. We will present the experimental results of our architecture using simulated and real-world data.

In addition to discussing the anomaly detection method, we will present our research on localizing jammers in a city environment. Our method uses another machine learning architecture, a Support Vector Machine, to first localize jammers in a coarse accuracy with C/N0 and AGC measurements. Then, we utilize a Gravitational Search Algorithm (GSA) with raytracing for finer searching of the location.

While simulation of the GNSS signal propagation is possible using a Orolia-8 simulator, it does not support the propagation of the jamming signal in a city environment. Therefore, we have developed a ray-tracing technique based on real-life city model to guarantee the high fidelity of signal propagation in urban environments. Raytracing is a general propagation modeling tool that provides estimates of path loss, angle of arrival/departure, and time delays by numerically solving Maxwell’s equations. Using our tool, we have created a jamming scenario at a shopping mall area in Finland and experiment our SVM+GSA method on localizing the jammers there. We will present the localization results and discuss the restrictions set by the method.

KEYWORDS: jammer localization, anomaly detection, machine learning

Finland

GNSS System's Services for Supply Chain and Logistics Tracking and Tracing: A Literature Review

Ahm SHAMSUZZOHA
University of Vaasa
ahsh@uwasa.fi

An efficient supply and logistics chain helps to support the global economy. The movement of goods from one place to another with reduced costs and minimum environmental impact is an important need for companies. In addition, it is critical to ensure the safety of the transported goods. To ensure safety, it is paramount important to enhance the supervision and monitoring of the transported goods movement with advanced tools and technologies. The objectives of supervision and monitoring are on the one hand to avoid serious risks and on the other hand to minimize possible damages. To comply with requirements of robust asset management in e.g., the manufacturing or food industry, supply chain management systems need to be operated in such a way that they can trace a product's origin and its transformation process. One of the most important factors in supply chain management is to ensure order visibility. This visibility ascertains the ability to access or share information across the supply chain. In supply chain management, it is often very difficult to support identification, traceability and real-time tracking of goods, due to the heterogeneity of platforms and technologies used by various actors of the chain. Transparency in the supply chain can be ensured when its visibility is high. In general, transparency in the supply chain can be referred to through its ability to track and trace each piece of information within its network. It can also be noted that this tracking and tracing system should be decentralized to improve traceability solutions in supply chain management. However, usually, traditional supply chain systems are operated individually which restricts their capabilities to provide comprehensible provenance information. This outcome restricts various inefficiencies among the supply chain stakeholders that include a lack of trust between stakeholders, isolated data storage, and improper standardization in data communication and formats. Traceability in the supply chain unveiled major shortcomings for many complex use cases. To ensure the traceability of goods, it is essential to convert the physical goods into a digital representation. The benefit of such a transition is allowing goods to be tracked from creation to retail and enabling it to anti counterfeits. This anti-counterfeit supports consumers to comply with certain ecological and ethical standards of their ordered goods. Over the past decade, it is getting increasing attention to providing traceability of consumers' goods from resource to retailer. Due to the growing complexity in today's global business environment, it is critical to maintain quality management, regulations, and international standardizations towards supply chain management. To provide traceability in the supply chain, various technologies are available such as blockchain, IoT, GNSS, etc. Recent developments in GNSS technology are gaining popularity with its tremendous applications in various fields, particularly in supply chain management. This technology can provide a decentralized and distributed database system that supports stored information securely. Many firms globally have already started deploying GNSS-enabled transparency into their supply chain activities. The advancement of GNSS technology provides a new approach to collecting, transferring, storing and sharing information throughout the supply chain actors and facilitates efficient cooperation and interoperability between the actors. Based on the above prospects of GNSS, this study provides an in-

depth literature review of its application in the supply and logistics chain. The importance of this GNSS system provides services that basically facilitate the information flows between logistics providers for traceability, collaboration, and interoperability between different actors in the supply chain.

KEYWORDS: Supply chain management, traceability, seamless positioning

Finland

Aviation GNSS users’ view in the workshop

Klaus SIEVERS

Aircraft navigation is performed with the help of systems that use

- terrestrial radio signals, like VOR, DME or ILS
- inertial navigation sensors of various kinds
- GNSS systems

While nominally many systems make up the GNSS, in many aircraft it is GPS that is used, which is also the case for GBAS and SBAS augmentation systems. Issues with GPS are mostly man-made interference and spoofing, and they make navigational use of GPS more and more unreliable. Areas mostly affected are the conflict zones along the eastern part of the Eurocontrol area of responsibility, Israel, Turkey, Irak. Recent, preliminary reports of complete loss of navigational capability due to spoofing over Irak have been seen, involving GPS positions being off by 60 nm and inertial sensors becoming unusable, too. This situation involved several aircraft, could luckily be resolved by radar vectors.

Another concern is the influence of space-weather on the SBAS systems. ICAO Space Weather advisories are designed to advise on GPS, not specific SBAS issues, but they provide an indication of possible trouble. At present, usage of SBAS in airline operations in Europe is minimal, however, this will change as by 2030 the EU prescribes use of PBN, which means mostly SBAS, the European EGNOS. In the USA and Canada, SBAS in the form of WAAS is used by many, especially smaller operators and in remote regions. Recent Space Weather reduced coverage of both EGNOS and WAAS systems. Inaccessible databases and scant use of EGNOS in flight operations have combined for no reports of issues being available. For the USA, a good and searchable database exist, but for unknown reasons no impact reports could be found. For Canada, however, things are different. The CADORS reporting system contains reports of multiple aircraft simultaneously experiencing loss of WAAS approach capability.

Multi frequency, multi system receivers are but a promise on the far horizon, they haven´t been approved for use and it will be many, many years until a sizeable portion of the worlds´ aircraft fleet has been retrofitted with such systems.

Pilots generally like to fly with GPS, GNSS, as it offers many advantages over traditional, terrestrial systems, however, jamming, spoofing and space weather are concerns that need to be addressed.

France

Role of GNSS in the space weather research

Christine AMORY-MAZAUDIER
Sorbonne Université, Ecole polytechnique, Institut Polytechnique de Paris, Université Paris Saclay, Observatoire de Paris, CNRS, Laboratoire de Physique des Plasmas (LPP), 75005 Paris, France
christine.amory@lpp.polytechnique.fr

Space weather develops a systemic approach of the Sun-Earth system to study the impact of all the phenomenon of this system on our new technologies and on living. Space weather is essential for daily life.

GNSS plays an essential role in the study of Space weather because it makes possible the study of disturbance of the satellite signals due to ionosphere and atmosphere and as a consequence to develop physics of ionosphere and atmosphere.

There are more and more satellites in the GNSS (GPS, GALILEO, GLONASS, BEIDOU etc...) useful for scientific studies The GNSS receivers are not very expensive tools. GNSS help in development of Space Weather in developing countries.

We will present the great advances made in space weather during the last decade with the use of GNSS more particularly at low latitudes.

KEYWORDS: Space weather-GNSS-Ionosphere

Germany

S2VSE - System and Service Volume Simulation Environment

Sebastian BERNHARDT, Florian Georg EISELBRECHER
DLR, DLR
Sebastian.Bernhardt@dlr.de, Florian.Eiselbrecher@dlr.de

Our team at the Galileo Competence Center is currently developing a System and Service Volume Simulation Environment (S2VSE) to support activities with the focus on analysing the performance and capabilities of existing and future Global Navigation Satellite Systems (GNSS) and their impact on various users.

S2VSE enables the testing and validation of new ideas in system design and employed technologies by simulating the functional and processing architecture of GNSS. This includes service volume simulation (e.g. user segment analysis, navigation performance, integrity, and link budgets) as well as system volume simulation (e.g. orbit determination, ephemeris generation, inter-satellite links, intra-system synchronization, etc.).

In both cases, the software environment allows the determination and presentation of key performance indicators (e.g. DOP, DOC, SISRE, UEE, UERE, SPP, PPP) through the combination of in-house developed modules for parsing and conversion of data, error corrections, KPI calculations, general utilities for data handling and the possibility to include external software functionalities.

In this way, workflows can be adapted to specific application cases. These scenarios include the provision of performance analysis due to changes in system design, such as the use of LEO constellations or multi-layer systems. Additionally, the use-cases can show the impact on different sectors such as maritime, aviation, road or rail, and different user environments at global, regional, or local levels, like the performance of navigation solutions in urban canyons.

Currently the simulation environment is among other things used for an analysis of different orbital configurations for LEO PNT constellations, a study regarding the effects on user performance when using new technologies such as optical inter-satellite links and an evaluation of the impact of atmospheric and space weather effects on orbit determination and signal propagation.

KEYWORDS: Performance Analysis, System & Service Volume Simulation, System Evolution

Germany

A low cost product (prototype) for ADSB big data analysis

Narayan DHITAL
Nepal Astronomical Society (NASO)
na.dhital@gmail.com

Automatic Dependent Surveillance - Broadcast (ADS-B) is an avionic in the aircraft that periodically broadcasts state vector estimates and additional information of the aircraft to the traffic control centers and other nearby airspace users. The sate vector estimates are based on the navigation system such as the GNSS and multitude of avionic sensors, which means that the quality of ADS-B broadcast is highly based on the quality of aircraft navigation and communication systems. This project aims to analyse the performances of relevant matrix such as the navigation accuracy, integrity, source integrity level and avionics system assurance level. Using the real data, it highlights the benefit of GNSS derived geometric altitude over the barometric altitude. Besides, the project also focuses on characterising the quality and pattern in the ADSB data and identifying any errors or anomalies coming from potential failure modes. Statistical analysis and machine learning is used to correlate the data with Required Navigation Performance (RNP) Specification, flight levels and flight phases. As the global uptake of the ADSB in the airspace is ever increasing, it is important to understand the quality and performance of the ADSB surveillance in various airspace where aircraft types and supporting ATM/CNS services are different. For this reason, the data retrieved by installing a low cost ADSB ground station in the Flight Information Region in Kathmandu, Nepal is compared against highly advanced airspace in Munich, Germany. Based on the mechanisms developed for ADSB data retrieval, monitoring, performance analysis, and anomalies detection, the project envisages to develop a low cost product which offers the features to support relevant stakeholders in the decision making process.

KEYWORDS: ADS-B, accuracy, low cost product

Germany

Model-based analysis of ionospheric effects in grazing angle reflectometry from space

M. MORENO[1,3], M. Semmling[1], M. Hoque[1], and J. Wickert[2,3]*
[1] *German Aerospace Centre, Institute of Solar-Terrestrial Physics (DLR-SO), Germany*
[2] *German Research Centre for Geosciences (GFZ), Germany*
[3] *Technische Universität Berlin (TUB), Department of GNSS Remote Sensing, Navigation and Positioning, Germany*
** mario.moreno@dlr.de*

The ionosphere constitutes a layer within the Earth's upper atmosphere that becomes ionized due to solar radiation. It plays a pivotal role in the propagation of signals from the Global Navigation Satellite System (GNSS), as these signals traverse the ionosphere while traveling from GNSS satellites to receivers. The irregularities in ionospheric electron density can exert a significant impact on GNSS signals, leading to signal delays and scintillations.

Ground-based atmospheric sounding techniques, involving continuously operating reference station (CORS) networks, combined with GNSS receivers positioned on low Earth orbit (LEO) satellites to measure refracted radio signals through GNSS Radio Occultation (GNSS-RO), constitute the foundational framework of GNSS meteorology. GNSS Reflectometry (GNSS-R) presents a promising technique for atmospheric and ionospheric sounding, particularly in locations lacking GNSS ground stations or GNSS-RO observations. In anticipation of the ESA CubeSat Reflectometry mission "PRETTY," this study aims to characterize ionospheric effects by analyzing varying grazing elevation angles, distinct latitude-based regions, and diurnal temporal variations. The investigation employs simulations using authentic metadata from Spire Global Inc.'s Lemur-2 CubeSat constellation for the orbits on March 1, 2021. The first-order ionospheric delays are estimated along each ray path (incident, reflected, and direct) by deriving the slant total electron content (sTEC) from the Neustrelitz Electron Density Model (NEDM2020) and the NeQuick Model.

The study findings reveal significant fluctuations in crucial ionospheric parameters. Specifically, the slant Total Electron Content (sTEC) displays variations of up to approximately 300 Total Electron Content Units (TECU), underscoring the dynamic nature of electron density in the ionosphere. Moreover, the relative ionospheric delay exhibits variations of 19 meters, providing insight into the influence of ionospheric effects on signal propagation paths. Additionally, Doppler shifts demonstrate deviations of 2 Hz, accentuating the frequency changes resulting from ionospheric interactions.

The investigation delves into the spatial dimension by exploring the height of the electron density peak. The results depict variations spanning from 215 to 330 kilometers, signifying the diverse altitudinal effects of the ionosphere on GNSS signals. These variations are intricately influenced by various parameters, including the grazing elevation angle of the signal, the geographical location of the event, and the time of day during which the observations occur.

KEYWORDS: GNSS-R, ionospheric effects, grazing angles.

Hungary

GPS Type Tracker Based on LoRa Transmission for Small Satellites

Yasir Ahmed Idris HUMAD
Institute of Space Research and Aerospace (ISRA)
Budapest University of Technology and Economics (BME)
Yasirahmedidris.humad@edu.bme.hu

The utilization of GPS-type trackers has emerged as an up-and-coming and dynamic field encompassing technology, social engagement, and security considerations over recent years. The GPS manufacturing industry has experienced rapid growth and evolution during this time. Numerous innovative GPS tracker experiments have been conducted within the Microwave Remote Sensing Laboratory at Budapest University of Technology and Economics (BME). The central objective of this presentation was to delve into the robust foundation and coherent concept underlying the utilization of the 70 cm UHF (Ultra High Frequency) Band within the communication subsystem of small satellites. This enables the transmission and reception of NMEA data from GPS trackers stationed on the Earth's surface, employing LoRa modulation. The novelty of the ”GPS Tracker system as a beacon” is the realization of the LoRa type GPS beacon as the ground segment and the onboard communication system (satellite segment), which can receive under noise power level of LoRa modulated signals containing GPS information to be able to track objects on the Earth surface monitored by the small satellites.

KEYWORDS: Small Satellite, LoRa, GPS Tracker

NavIC-Reflectometry Receiver Development for Remote Sensing Applications

Bushra ANSARI
Indraprastha Institute of Information Technology, Delhi
bushraa@iiitd.ac.in

The Global Navigation Satellite System (GNSS) is an integral part of the space industry. GNSS is a generalised term that refers to the collection of all global and regional navigation satellite systems. It includes GPS by the USA, Galileo by Europe, Russia's GLONASS, Beidou by China and two regional navigation satellite systems, NavIC by India and QZSS by Japan. GNSS signals are now used everywhere, from mobile phones and smartwatches to navigation services for the aviation industry and many others. Besides the conventional navigation information, GNSS signals are also used for space-based remote sensing, and this technique is termed GNSS-Reflectometry (GNSS-R). Space-based remote sensing is a promising technique that can provide critical data for studying the Earth's Surface and land geophysical parameters. GNSS-R utilises the GNSS signals reflected from the Earth's sur-face to estimate the land geophysical parameters. GNSS-R is potentially helpful for measuring soil moisture, vegetation-water content, snow monitoring, sea state estimation, and predicting droughts or floods. Until now, the GNSS-R research has mainly focused on using GPS, Galileo or BeiDou satellite constellation signals. In addition, the existing research on NavIC reflectometry is majorly restricted to the analysis of multi-path signals acquired using commercial NavIC navigation receivers, which restricts the scope of the research. In our research work, we are mainly focused on developing and assessing the capability of a Software Defined Radio (SDR) based NavIC-Reflectometry (NavIC-R) receiver for esti-mating soil moisture using the NavIC-L5 satellite signals.

The presentation will mainly discuss the development of a Software Defined Radio (SDR) receiver-based NavIC-Reflectometry (NavIC-R) receiver and verification of its efficacy in soil moisture estimation using a Hardware-In-Loop (HIL) simulation testbed and numerical simulation. The NavIC-R receiver consists of two hardware blocks, a BladeRF SDR board and a Raspberry Pi (RPi) single-board computer. The BladeRF SDR front-end is used for receiving the NavIC-L5 signal, and it is reprogrammable and can be programmed to any of the GNSS frequency bands of interest. The Raspberry Pi model 4b is used as a single-board processing unit, which is used to interface the BladeRF SDR. The RPi is used to store the signal and generate the DDM onboard. The NavIC L5 signals stored in the RPi can also be downloaded to the remote server in the binary format. The NavIC signals are then processed into the Delay-Doppler Map (DDM), which is the 2D representation of the power/amplitude distribution of the received GNSS signal. According to the bistatic radar equation, the DDM peak power is a function of underlying surface properties, which in turn is related to soil moisture. Hence, the trend of DDM peak power is studied to estimate the surface dielectric constant, which will further determine the soil moisture. The comparison of the DDM peak power with the theoretical values will also be presented. The surface dielectric constant and soil moisture measured using the TechDemoSat (TDS)-1 derived Delay-Doppler Map (DDM) are compared with the same generated from the numerically simulated NavIC-R scenario to validate the numerical simulation. The results from the numerical simulation are further compared with those computed from the DDM output of the developed NavIC-R receiver in an HIL simulation to verify the receiver's capability.

The main goal of this presentation is to demonstrate the possibility of using spaceborne NavIC-L5 satellite signals transmitted from the geostationary and inclined geosynchronous satellites to perform land surface monitoring using a spaceborne or airborne NavIC-Reflectometry receiver. Further, GNSS-R can provide a high-resolution map that can provide precise statistics of surface geophysical properties. Real-time monitoring and the possibility of on-demand estimation of Earth's surface geophysical parameters is feasible using the GNSS-R technique.

KEYWORDS: NavIC, GNSS-Reflectometry, SDR receiver

India

NavIC/GNSS applications in India

Kalpesh Kumar BORSADIYA
Space Applications Centre (ISRO), India
kalpesh@sac.isro.gov.in

NavIC/GNSS applications for societal and scientific purposes in the country are increasing at a faster pace. The availability and accuracy of position solution improves with use of multi-constellation systems like NavIC and other GNSS systems like GPS, Galileo, GLONASS etc. Also, the techniques to obtain sub-meter accuracies has enabled use of satellite based navigation systems in high accuracy applications like surveying, mapping etc.

The NavIC/GNSS enabled chipsets in smartphones opens up plethora of GIS and other commercial applications.

NavIC/GNSS applications are being developed and deployed in India in various sectors. The vehicle tracking and transportation rely on NavIC/GNSS based devices for their tracking, routing and fleet management related operations. The government's Automotive Industry Standard (AIS)-140 mandates use of NavIC enabled tracking devices for public transport vehicle operations.

In addition to their primary functionality, the capability to transmit text messages in NavIC satellites allows broadcasting of additional short messages. These messages can be related to alerts, forecast and directives on the occurrence of natural disasters like Floods, Earthquake, Tsunami, Cyclones, Landslides etc. and dangers for the safety of life in areas with poor or no communication infrastructure. The NavIC Messaging Receivers with message reception capabilities can be helpful to fishermen going to deep sea by communicating the required information and alerts.

The use of NavIC system time for time dissemination and synchronization is proliferating in the country. The NavIC based Timing systems are used in national power grids, railway networks, public time displays, earth stations, mobile base stations and organizational network synchronizations.

The Aadhaar numbers are used for unique identification of Indian citizens. The NavIC based location and time tagging is used by Aadhaar Enrolment centres to prevent malpractices and forgery while generating these unique identification numbers known as Aadhaar number.

The high accuracy techniques like differential GNSS and RTK are being developed for various applications like surveying, mapping, precision farming, drone tracking. The high accuracy with integrity requirement for safety critical applications like in train protection systems is being developed.

Also, use of NavIC/GNSS in various scientific, environmental and atmospheric studies is proliferating. The space weather phenomenon also affect our communication systems. The study of ionization and charged particles in the upper atmosphere (ionosphere) is required to understand this phenomenon. The availability of NavIC signals in three bands (L5, S, L1) will aid in improved diversity of observations and better modelling of ionospheric phenomenon. The NavIC/GNSS has also found a significant role in applications of ocean study and reflectometry.

The NavIC/GNSS receivers are also increasingly used in launch vehicles and satellites for tracking and orbit determination purposes. The establishment of CORS network for land survey being undertaken by various agencies. The use of NavIC/GNSS in surveying will improve the efficiency and lower the surveying cost.

KEYWORDS: NavIC, GNSS, Timing, Tracking, Atmospheric

India

Classifying GNSS Signals in Terrestrial Environments using Deep Learning

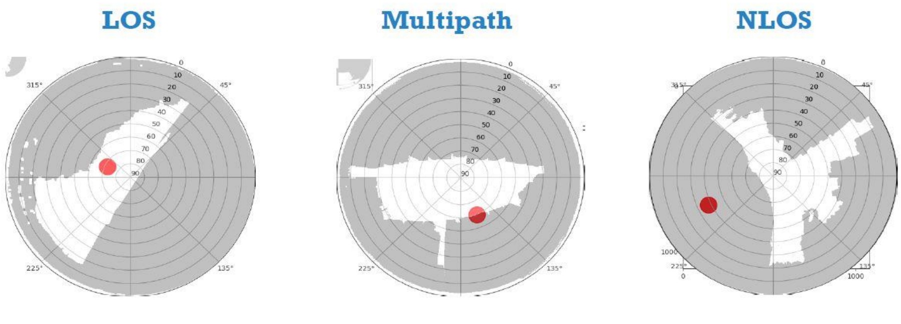
Dr. Shweta N. SHAH
Department of Electronics Engineering, SVNIT, Surat, Gujarat, India.
snshah@eced.svnit.ac.in

The Global Navigation Satellite Systems (GNSS) have become an essential part of our daily lives and are widely used worldwide. They serve various purposes, from civilian applications like precision farming and navigation to military applications. However, achieving precise positional accuracy in real-time scenarios poses several challenges. The satellite signals encounter atmospheric obstacles as they travel long distances. When they reach the Earth's surface, they can be affected by Reflection, Diffraction, Scattering, and Multipath Propagation (MP). This can result in signals with a clear Line of Sight (LOS) and signals that have encountered obstacles, leading to Non-Line of Sight (NLOS) and MP conditions. It is crucial to distinguish between these types of signals accurately.

To address this issue, Artificial Intelligence (AI) is integrated into GNSS technologies to classify LOS, NLOS, and MP signals effectively. Considering different terrestrial environments, a Deep Learning / Convolutional Neural Network (CNN) is used for this purpose. The basic idea behind using Deep Learning/CNN for satellite signal classification is to extract features from the skyplot image of a single satellite (ref. figure is given) and use them to classify the signal type. CNNs are well-suited for this task because they can learn and identify patterns within image data. The convolutional layers of the CNN extract features from the skyplot image, while the pooling layers reduce dimensionality and create a feature map. The feature map is then fed into fully connected layers to classify the signal.

A large dataset of labeled skyplot images of a single satellite signal is required to train the CNN. This dataset should include examples of LOS, NLOS, and multipath signals. The CNN is trained using backpropagation, adjusting the network weights to minimize classification errors. The dataset is divided into training (65%), validation (15%), and testing (20%) sets. To prevent overfitting and minimize unnecessary computation, the training process incorporates the concept of early stopping halting when necessary.

In this study, the accuracy of the CNN model is tested using datasets from the global GPS, regional NavIC, and combined constellations of these systems. The model demonstrates good performance across all these datasets.



KEYWORDS: GNSS, Deep Learning, Signal Classification

Indonesia

Integration of GNSS receivers with External Environmental Sensors for Mobile Air Monitoring Applications

Dr. Lin YOLA
School of Strategic and Global Studies, Universitas Indonesia
lin.yola.ui.ac.id

GNSS technology has been rapidly developed to meet users' needs. The high accuracy and precision of the GNSS technology have been the main forte offered to the market. Integrating GNSS applications with other technologies maximizes the objective to accommodate the navigation data associated with other non-navigation data, such as demographic and environmental data. One of the environmental data is air quality. Rapid urban development has caused complex issues in big cities. One of the issues is massive traffic congestion in the city center, which causes high carbon emissions. Air pollution has caused a burden on the range of environmental, social, and economic sectors, especially the development of climate change. Research on the relationship between urban traffic and air pollution is expected to generate a reliable tool to support the holistic study. An experimental study was conducted on two main roads in Jakarta, one of the most polluted cities in the world. It developed technology integration of RTK GNSS U-Blox F9P with GNSS Trimble NetR9 receiver and the external CO2 MH-Z19C sensor. The experiment resulted in new findings on 'the process of time synchronization' and 'the error technique removal' from the data processing analysis of integrating two technologies. The field observation using the integrated technology pinpointed the significant spatial correlation between urban traffic and air pollution. This finding is a preliminary stage of developing prototype integration of GNSS receivers with external environmental sensors for mobile urban air monitoring Jakarta Bus Rapid Transit facilities.

KEYWORDS: integrated GNSS, environmental sensor, air monitoring

Ireland

Building a National Timing Grid of Ireland – Lessons Learned

Zdenek CHALOUPKA
Timing Solutions Ltd
zdenek.chaloupka@timingsolutions.ie

David Fleming
National Standards Authority of Ireland's National Metrology Lab
david.fleming@nsai.ie

Security and resiliency of Critical Infrastructure have recently become focus of companies and governments due to geopolitical issues around the world. Since time and its distribution are key components that underpin Critical Infrastructure's systems, companies and governments are looking for systems that can introduce a level of resiliency for time and its distribution.

Time and timing distribution are recognized to be fundamental services in Critical Infrastructure sectors such as: communications, energy, transportation, emergency services, financial services, and cloud data centers. Telecom systems, for example, require time and phase synchronization of base stations to fully utilize available spectrum and mitigate interference. Energy (or power utilities) sector uses time & frequency sources to monitor stability of power transfer network. Financial sector is required to maintain time synchronization due to regulatory requirements.

The most common time distribution methods for Critical Infrastructure are nowadays based on packet distribution methods over wire/fiber media (IEEE 1588v2 PTP or NTP protocol), or Global Navigation Satellite System (GNSS) using Radio Frequency signals. These two methods are usually used in combination as, for example, PTP/NTP is most often traced to a GNSS receiver.

The actual source of time information for the PTP/NTP server is most often provided by the so called "Grandmaster clock", which is essentially a high-quality frequency source (atomic clock) combined with a steering GNSS receiver to produce legally recognized UTC time. Now, such high-quality Grandmaster clocks provide great value to their owners, but in case they receive inaccurate or wrong information from the steering GNSS receiver, their stability could become unpredictable. To increase resiliency of timing sources in Ireland we have proposed to combine, or rather interlink as many of Ireland's atomic clocks as possible to establish a National Timing Grid (NTG).

To fulfill the above goal Timing Solutions has partnered up with National Standards Authority of Ireland's National Metrology Lab (NSAI NML) and Data Edge Ltd to provide a complete monitoring and alert system that observes fundamental time and timing distribution components and provides near real time tracking of the time distribution system performance and stability.

The system, called National Timing Grid (NTG) of Ireland, is currently being deployed in Ireland since February 2023 as a cooperation between multiple entities: Timing Solutions Ltd, NSAI NML, Data Edge Ltd, Vodafone, Eir, Irish Rail, ESB Networks, and Microchip's Cork Laboratory.

The NTG system offers a degree of resiliency by interconnecting and measuring sources of time against a selected reference (physical representation of UTC – UTC(NSAI)). Since the measured devices and selected reference can be very far from each other, we need a measurement technology that works over a very large distance (tens to hundreds of kilometers).

In the very first phase of the NTG project we decided to use a Common View Time Transfer (CVTT) technology in combination with GNSS signals due to their reach and availability (we are aware of the vulnerabilities, though). Note that the NTG system is ready to use other time transfer signals (wire or wireless) with CVTT technology as soon as they become available (planned for second phase of the project) to increase the system's resiliency.

Our paper will discuss the overall architecture design choices for NTG system, lessons learned throughout the roll out of the system, and next steps to further increase the resiliency of National Timing Grid of Ireland.

For live NTG system results please see https://ntg.ie.

KEYWORDS: Timing resiliency, Timing Distribution, GNSS resiliency

On the development of multi-instrument arrays for ionospheric studies over West Africa to support the implementation of SBAS

O. K. OBROU
Université Félix Houphouet
olivier.obrou@univ-fhb.edu.ci

The main technical issue concerning the implementation of SBAS in sub-Saharan Africa is the limitation of its performance in the equatorial region over Africa. The main problem for SBAS deployment in Africa over the Sahara is the ionospheric variability in the equatorial region over Africa. Uncorrected propagation delays of GNSS satellite L-band signals due to the ionosphere can significantly limit the performance of a satellite-based augmentation system (SBAS) for a vertical guidance approach (VGA) and a precision approach (PA).

This possible limitation of SBAS in Africa is the subject of debate as to whether Africa can truly benefit from SBAS services using current technology. The reality is that the current EGNOS technology (EGNOS V2 single frequency) currently used in Europe may not meet the performance criteria required in some parts of Africa as noted above. However, it is recognized that the issue of limiting SBAS performance in the equatorial zone over Africa is being addressed by multiple dual-frequency constellation (DFMC) SBAS systems. The next generation of EGNOS (EGNOS V3) will provide dual-frequency signals on the L1 and L5 bands and will augment both the GPS and Galileo constellations as part of the regional multi-constellation system concept (EUSPA, 2023). If the ionospheric effect on the equatorial zone over Africa can be mitigated, this will allow Africa south of the Sahara to be easily included in the ongoing deployment of SBAS as a global system. To achieve this goal a network of GNSS infrastructure has to be deployed to collect data for intense research work on these issues.

This present work is an overview of the GNSS networks covering the west African region. During those last two decades a series of GNSS networks have been deployed in the region of west Africa. Among others are the CORS network in Burkina Faso composed of 9 GPS stations covering the whole country as well as in Benin, where a network of 7 stations is established crossing from the south to the north.

KEYWORDS: SBAS, GNSS, Ionosphere

Japan

GPS and Galileo Signal Authentication using Quasi-Zenith Satellite System (QZSS) Signal

MANANDHAR Dinesh
Center for Spatial Information Science (CSIS)
dinesh@csis.u-tokyo.ac.jp

GNSS has been used in several safety-critical applications such as autonomous driving, ITS, UAV, UMV, Drone and timing applications. However, spoofing attacks on the GNSS receivers used in these applications make the system vulnerable to safe and secure operation. Civilian GNSS signals were not designed to detect spoofing attacks. Recently, Galileo and QZSS have implemented signal authentication functions to detect spoofing attacks.

QZSS has implemented signal authentication to authenticate QZSS signals, GPS signals and Galileo signals. QZSS signal is authenticated by broadcasting a digital signature of the navigation message that has to be authenticated. The digital signatures are generated for LNAV (L1C/A/B), CNAV (L5) and CNAV-2 (L1C) messages.

QZSS also authenticates GPS and Galileo signals by broadcasting the digital signatures using QZSS L6E signal. QZSS authenticates GPS LNAV (L1C/A), CNAV (L5), CNAV-2 (L1C/A) and Galileo I/NAV(E1B) and F/NAV (E5a) signals.

QZSS has been broadcasting test signals for GPS and Galileo signal authentication since 31st July 2023. In this presentation, we present signal authentication procedures and test results of GPS and Galileo signal authentication.

KEYWORDS: Spoofing, Jamming, Authentication

Japan

Low-Cost GNSS Receiver System for Space Weather: Comparison of results from low-cost vs. high-end receivers

MANANDHAR Dinesh
Center for Spatial Information Science (CSIS)
dinesh@csis.u-tokyo.ac.jp

The performance of a low-cost GNSS receiver system for high-accuracy positioning has improved to a level comparable to a high-end GNSS receiver. Dual and triple frequency GNSS receivers are available at a price of less than one thousand US dollars including an antenna.

In order to evaluate the performance of low-cost GNSS receiver systems for the computation of TECU and ROTI, we have made observations from four different receivers by connecting them to the same antenna. Two of these receivers are high-end (Trimble NetR and Septentrio PolaRx5) and the other two are low-cost GNSS receiver (u-blox F9P and Septentrio MOSAIC) systems. Data were logged for several days and analyzed using two different types of software independently. The results from both processing outputs have shown that low-cost GNSS receiver systems also provide results that are in line with the outputs from the high-end GNSS receivers. Further studies will be done by logging data using different types of antennae, adding additional receivers and using different types of software as well.

KEYWORDS: Space Weather, TECU, ROTI

Japan

GNSS signal spoofing tests

MANANDHAR Dinesh
Center for Spatial Information Science (CSIS)
dinesh@csis.u-tokyo.ac.jp

GNSS spoofing has become a major issue for the safe and secure use of GNSS in critical infrastructure systems. In this presentation, we show video demos of spoofing a GPS watch, spoofing a mobile phone and spoofing of a car navigation system (simulation). We also discuss briefly spoofing targets, spoofing types and spoofing methods. The spoofing attack differs depending on the target type, attacking methods and the state of the target during the attack period.

KEYWORDS: Spoofing, Authentication, Jamming

Kenya

Operational Space Weather Programme in Kenya: Space Weather Monitoring and Forecasting Using GNSS Receiver Data and Magnetometer Data

Zipporah Njeri MARGARET
Kenya Space Agency
Zipporah.njeri@ksa.go.ke

Space Weather is a dynamic and ever-changing phenomenon in the GeoSpace environment, including the Sun, interplanetary medium, and magnetosphere-ionosphere-thermosphere system that can have a significant impact on our planet. These impacts can range from minor disruptions of communication systems to large-scale geomagnetic storms that can damage satellites and power grids resulting in social economic losses hence the need for monitoring and forecasting of space weather. The emerging science of Space Weather is striving to comprehend the cause of solar storms and their impact on the Earth's societal, technological and social-economic impacts with the hope of forecasting Space Weather and mitigating damage. Space Weather forecasting is among the rapidly developing fields in the world, with a growing interest in the use of GNSS receiver data and magnetometer data to improve forecasts.

Kenya is located in the equatorial region, where Space Weather effects make the ionosphere more variable and highly unpredictable. However limited efforts have been made to study the impact of space weather in the equatorial region owing to lack of the requisite infrastructure. Kenya, through the Kenya Space Agency is contributing to fill this gap through the Operational Space Weather programme. This programme entails issuing research grants to Kenyan Universities with the aim of establishing a Space Weather monitoring system in the country. A consortium of three Universities benefitted from this initiative: Taita Taveta University, University of Eldoret and Dedan Kimathi University of Technology.

The consortium is in the process of setting up an operational space weather network that has nodes at Eldoret (Western Region), Nyeri (Central Region) and Voi (Coastal Region) with a view of expanding the network towards the crest of the geomagnetic equator (-150 geomagnetic latitude). The consortium is also in the process of developing an effective Space Weather early warning system to safeguard people, infrastructure and land cover, as well as conduct research into space weather-related activities, technologies and mitigation. It has also developed a Master of Science programme in Space Weather to address the national gap for specialists in Space Weather in addition to the global unemployment challenges.

In addition to the research grant, the Kenya Space Agency procured and set up a PolaRx5S ionospheric monitoring GNSS receiver in Nairobi and a Spectramag-3 magnetometer in Wajir to enhance Space Weather monitoring in the country. A GNSS receiver outputs Total Electron Content (TEC) and iono-scintillation indices on all GNSS L-band frequencies and also monitors interference in the ionosphere. The KSA GNSS receiver collects and logs data in Rinex format. The data collected entails observation files "O" and mixed GNSS navigation files "P". The data can be used to calculate the Total Electron Content in the ionosphere. The Agency also has a magnetometer installed in Wajir. The magnetometer does simultaneous collection of magnetic field, vibration and acoustic data in three axes in micro-Tesla with a sensitivity of 0.001 nanotesla (nT). The Agency is in the process of organizing for a magnetic survey of the installation sites of the instruments so that they can be fully operational.

GNSS receivers and magnetometers are two important tools that can be used to monitor and forecast space weather events. GNSS receivers measure the time it takes for signals from GPS satellites to reach the Earth. This information can be used to track changes in the ionosphere, which is the layer of charged particles that surrounds the Earth. Magnetometers measure the strength and direction of the Earth's magnetic field. Changes in the Earth's magnetic field can be caused by solar flares and other space weather events leading to ground induced currents. By combining data from GNSS receivers and magnetometers, The Agency can forecast the likelihood of space weather events such as solar flares and geomagnetic storms. This information can be disseminated to relevant stakeholder and used to protect critical infrastructure such as power grids, aviation, satellites and GPS systems, with the aim of improving their resilience and developing mitigation strategies. The KSA's Operational Space Weather Programme is an important step in ensuring that Kenya is prepared for the challenges of space weather.

KEYWORDS: Space Weather, forecasting, GNSS

Lao People's Democratic Republic

Lao satellite development

Dr. Vithaya SAYVISITH
Department of Radio Frequency, Ministry of Technology and Communications of Lao PDR
vithaya@mtc.gov.la

Lao PDR is the only landlocked country in Southeast Asia covering a total of 236,800 square kilometers. Nearly three-quarters of Laos is covered in mountains and forested hills where normal terrestrial communications facilities are difficult to be deployed. Satellite Communication plays an important role in promoting the social development of Lao PDR and improving Lao people's living standards. Lao PDR attaches great importance to the LAOSAT-1 satellite project.

The Lao Satellite Project is a great strategic choice of the Lao government for the enhancement of overall national strength, technological capabilities, and further socioeconomic development to ensure that Lao people have equal opportunity to be able to receive television and education channels as well as more importantly allow for the wide and immediate dissemination of critical and safety of life information to not only Lao population but also to those of neighboring countries. It will be a break-through for the first time for Laos for peaceful use of outer space, narrowing the technological distance and to eliminate the digital division in our country's communications field, we are committed to a variety of ways to promote the development of the Lao satellite communications industry.

And LAOSAT-1 satellite was launched on 21st November 2015. It deploys 22 transponders including C band and Ku band frequency.

As a developing country, however, Lao PDR has less experience in the satellite industry and lacks of satellite communication professionals who are familiar with the Satellite technical and Radio Regulation provisions, and the LAOSAT-1 is this country's first satellite, and we are learning more from the International Satellite Organization and the ITU expertise.

In 2021, our Ministry changed its name by combining the Ministry of Post and Telecommunications and the Ministry of Science and Technology, currently, one of the important works is GNSS.

We use GPS for positioning, Mapping, Air traffic navigation, Land Management, Vehicle Safety protection Vehicle traffic navigation, etc.

Many organizations used GNSS in Laos, and they are developing by cooperating with many companies and organizations from many countries. So, this is very challenging work for us to learn the technical and regulations of GNSS from advanced countries and International Organizations to become the central of GNSS management Ministry in Laos.

KEYWORDS: Satellite Communication, Navigation, Positioning

Mexico

Potentialities identified by the Mexican Space Agency for the use of GNSS applications in aviation, agriculture and other sectors in Mexico

Antonio de Jesús Serrano Arellano
Mexican Space Agency
serrano.antonio@aem.gob.mx

The Mexican Space Agency (AEM) has been actively engaged in promoting Global Navigation Satellite System (GNSS) solutions, in alignment with governmental objectives. The focus lies on:

- The 2020-2024 National Space Activities Program prioritizes the development of space infrastructure for telecommunications, **navigation, global positioning, and related applications**. This initiative aims to accelerate digital transformation and the delivery of services that contribute to social inclusion, economic development, and overall welfare.
- In 2019, AEM introduced its "Orbit Plan 2.0.", a roadmap for the industrial development of Mexico's space sector. It addresses converging public and private market needs, including **GNSS applications for positioning, synchronization, management, and monitoring**.

Consequently, AEM has pursued the following lines of action during its actual administration:

1. **Collaborative efforts with the Galileo Information Center of Mexico, Central America and the Caribbean (GIC Mexico) to promote EGNSS technologies across Latin America**. This engagement extends to national triple helix stakeholders within working groups dedicated to agriculture, aviation, and transportation. Notably, an Industry Workshop was jointly organized within the Aerospace Fair Mexico 2023 (FAMEX) showcased GNSS opportunities, and potential initiatives with key stakeholders, including Thales Alenia Space, Safran/Orolia, Semtech, and Mexican companies like Thrusters Unlimited and the National Association of Vehicle Tracking (ANERPV), governmental entities belonging to the Ministry of Infrastructure, Communications and Transportation: the Federal Civil Aviation Agency (AFAC) and the Navigation Services in the Mexican Airspace (SENEAM). Themes covered included aviation, SBAS, navigation, semiconductors, tracking services, remote sensing, and others.
   Likewise, the AEM is in contact with representatives from the Latin American and Caribbean Space Agency (ALCE) for GNSS application promotion in the region, involving countries such as Argentina, Mexico, Colombia, among others.

2. **Exploration of SBAS technology potential for collaboration with Mexican government entities**. Dialogues commenced between AEM, SENEAM, AFAC and international stakeholders regarding the operation of these technologies in Mexican airports.

3. **Advancement of GNSS-based applications and services, particularly in precision farming proof-of-concept projects**. This initiative integrates technologies such as Internet of Things, satellite communications, remote sensing, and GNSS applications in a precision farming project. Key stakeholders include the State of Guerrero, Eutelsat, Autonomous University of Guerrero (UAGRO), Thrusters Unlimited, Aquosmic, and agrotech start-ups. The project aims

to enhance agricultural practices, encompassing guided agricultural machinery and asset monitoring.

4. **Collaboration between the National Center of Metrology (CENAM) and the European Space Agency (ESA)**. ESA provided AEM and CENAM with Septentrio receivers and GNSS data, to conduct base tests for support a pre-feasibility analysis for the development of a national synchrony national network.

Within Mexico, AEM has identified significant opportunity areas and potential fields of application for the GNSS services:

I. Aviation and Drones

National Stakeholders: AFAC, SENEAM, Ministry of Defense, Aerospace Clusters, Private enterprises.
Applications: SBAS, air traffic control, approach procedures, drone navigation and monitoring.

II. Precision Farming

National Stakeholders: State governments, Ministry of Agriculture, National Institute of Forestry, Agricultural and Livestock Research (INIFAP), agricultural producers and local farmers, universities, agrotech companies.
Applications: Automated machinery guidance, crop monitoring and sensors, livestock tracking, virtual fences.

III. Application Development

National Stakeholders: Technology and software clusters, software development companies, research centers, universities.
Applications: GNSS-based solutions including navigation, LBS commerce, mobile apps, environmental monitoring, transportation, logistics.

IV. LATAM Collaboration

Stakeholders: ALCE, Space Agencies, Ministry of Foreign Affairs, Embassies
Projects: Medium-term roadmap for regional and local technology development projects, applications, or services within LATAM.

AEM would serve as a liaison between Mexican private, academic and governmental entities and potential international counterparts, fostering collaborative engagements.

KEYWORDS: Mexico. Agriculture. Aviation.

Mongolia

GNSS Efficient management and collaboration with private and public partnerships in a pilot project

Zolzaya LKHAMSUREN[1], *Otgonjargal.Terbish*[2]
[1] *Agency for Land Administration, Management, Geodesy and Cartography*
[2] *Mongolian Geospatial Association]*
zolzaya@gazar.gov.mn, otgoomgl88@gmail.com

Currently, out of the total 65 GNSS-CORS (Continuously Operating Reference System) stations established by state institutions for research and geodetic purposes in Mongolia, 43 stations are actively engaged in providing continuous high-precision data to the Agency for Land Administration and Management Geodesy and Cartography.

These 43 CORS stations provide real-time kinematic (RTK) corrections to various users, including surveyors, engineers, and other professionals, enabling them to achieve centimeter-level accuracy in positioning. The CORS stations are situated in the capital city, districts, and provinces, and are accessed by around 70-100 users daily, working approximately 3-8 hours per session.

The data from these CORS stations are utilized in various applications such as geodetic surveying, cadastral mapping, infrastructure construction, and other spatial data-related activities.

The continuous 24-hour static data collected from the CORS stations is made available to the public through the MonPOS online platform, allowing users to access high-precision coordinates for their needs without any charges.

In recent years, Mongolia has faced natural disasters such as earthquakes (e.g., a 6.7M magnitude earthquake in Khankh soum of Khuvsgul province, on January 12, 2021), which have led to various environmental and social disruptions. These disruptions include landslides, flooding, and subsequent soil erosion, affecting livestock, people, property, and infrastructure.

To address these challenges, we have established a collaboration with the Institute of Astronomy and Geophysics to conduct research on the long-term impact of environmental changes caused by earthquakes.

For enhancing the performance of the GNSS CORS network, technical upgrades are necessary to mitigate potential risks. We need to obtain licenses for integrating the firmware update of GNSS CORS stations and other institutions into a unified management system. (25 stations)

In the face of changing natural hazards before and after seismic activity, it is essential to conduct thorough studies, analyze the impacts of disaster-induced changes, and assess the vulnerability of urban and rural areas. Providing accurate information and raising public awareness about disaster resilience is crucial.

Our research aims to provide actionable information to the public and stakeholders through a well-prepared and experienced team of researchers, advanced equipment, technical support, and financial resources.

We have successfully installed and utilized the UB01 CORS, a part of the International GNSS Service (IGS) network, to ensure the reliability and accuracy of data collection for research purposes.

Managing the vast amount of data (Big Data) collected from the 43 operational CORS stations across Mongolia requires robust solutions for data analysis, storage, and dissemination. These solutions should be equipped to handle changes in station positions, antenna changes, and land use dynamics, among other factors. The establishment of high-capacity servers with advanced capabilities for data processing and monitoring will contribute to the efficient management of the CORS network.

To conduct daily basis monitoring we need to equip the technical room in terms of integration and monitoring as well as improve coordination among the CORS users. That's why equipping the technical room is an important step in conducting comprehensive coordination.

KEYWORDS: Public-Private partnership, GNSS-CORS, Management

Nepal

Low-Cost GNSS Receiver System for Multi-Purpose Applications

Avinab MALLA
Department of Civil Engineering, Institute of Engineering, Tribhuvan University
078phce103.avinab@pcampus.edu.np

Dinesh Manandhar
Center for Spatial Information Science, The University of Tokyo
dinesh@csis.u-tokyo.ac.jp

This paper discusses the design and implementation of a multi-purpose low-cost GNSS receiver system.

The low-cost system developed includes Wi-Fi and Bluetooth connectivity, data-logging capabilities and a battery management system. The receiver system utilizes a modular design that allows it to be used with dual or triple-frequency low-cost GNSS receivers from different manufacturers.

The receiver can be configured as a data recorder to record GNSS data and upload to remote servers which allows it to be used in many applications such as space weather observation (TEC/ROTI), land subsidence measurements, and structural health monitoring. The device can also be used as a low-cost base-station for high-accuracy surveying and mapping applications.

KEYWORDS: Low-Cost GNSS, Space Weather, CORS

Netherlands

FUTUreNAV In Orbit Demonstrator – A First Step Towards a European LEO-PNT component

Miguel CORDERO LIMON
European Space Agency
miguel.cordero.limon@ext.esa.int

Position, Navigation and Timing (PNT) services are critically important for various aspects of modern society, being the backbone of various applications. GNSS and regional space-based PNT augmentation systems are the main providers of PNT services thanks to their ubiquity, performance and free-of-charge use for final users. These systems have continued evolving over the years with the improvement of ground and space segments and the introduction of new signals which has led to a continuous improvement of the PNT service's performances. In this context, the exploitation of signals from LEO satellites for PNT services has become a major trend of evolution for space-based PNT systems thanks to the potential benefits that LEO orbits can bring to complement GNSS systems. Because LEO satellites are closer to Earth, they experience faster geometry change with respect to a user on Earth which is beneficial for the convergence of sequential filters (e.g., for PPP). This also enables the use of alternative frequency bands as well as possibly two-way services for small user terminals thanks to the lower propagation losses with respect to satellites at higher orbits, as well as lower latencies. Using orbits below MEO also allows new Orbit Determination and Time Synchronization (ODTS) concepts with reduced complexity of the onboard clock and the ground monitoring segment. All this at the cost of increasing the number of satellites in orbit to be able to provide the required coverage. Thanks to new industrial and business models in Space sector (the so-called New Space) the deployment of such constellations is nowadays feasible both technically and in terms of cost. ESA's FutureNAV LEO-PNT programme will develop an in-orbit end-to-end demonstrator with the objective to demonstrate the benefits of LEO-PNT to end users in terms of performances and new added-value services and to validate associated key enabling technologies for LEO-PNT systems, paving the way for future satellite navigation systems.

KEYWORDS: LEO-PNT, ESA, FutureNAV

Nigeria

Update on Augmented Navigation for Africa (ANGA)

Lasisi Salami LAWAL
Nigerian Communications Satellite Ltd/Usmanu Danfodiyo University; Nigeria
lasisi.slawal@udusok.edu.ng

SBAS-supported operations for navigation in aviation provide more safety, enhanced navigation effectiveness, and contribute to reducing operational costs for airlines, while improving the accessibility to airports and green environment in terms of reduced carbon footprints. SBAS therefore stands out as an enabling technology, providing real opportunity for the development of aviation sector in Africa. Airlines should therefore stay abreast of its developments and be prepared to adjust their innovation strategies towards its use in Africa as it aligns with African Union's (AU) agenda for Single African Air Transport Market (SAATM), Nigerian Communications Satellite Ltd, Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA) and Partners are poised for the provision of SBAS services in Western and Central Africa, with a potential for extension in other regions multilaterally and collaboratively for the entire continent and surrounding waters. Promoting acceptance and adoption of SBAS services in Africa's aviation sector as a means of navigation continent-wide is one of the recommendations and takeaways made during Continental Cost Benefit Analysis (CBA) of implementation of SBAS in Africa organized in May, 2022 by African Union Commission (AUC) and African Civil Aviation commission (AFCAC); the specialized arm of African Union (AU) on aviation matters. We emphasized the need for specialized institutions and partners in Africa to undertake capacity building and awareness activities for the applications of SBAS in aviation and non-aviation sectors.

The paper highlights impacts and benefits of SBAS Services in Africa based on pilot projects conducted in Togo, Cameroun, Congo and Nigeria meant to encourage stakeholders to accelerate deployment of the technology in both aviation and non-aviation sectors. The last part of the paper describes real time DFMC SBAS testbed that has been set up in view of the demonstration that started this Spring in 2023. The testbed use ANGA signal broadcast by ASECNA's demonstration infrastructure to produce both valuable demonstration L1 and L5 augmentation messages. The Signal in Space (SiS) is broadcasted by NigComSat1-R GEO satellite. To our knowledge, this will be the first DFMC SBAS demonstration SIS to be broadcasted through NIGCOMSAT-1R SBAS GEO in Africa, and one of the first in the world.

KEYWORDS: ANGA, NIGCOMSAT-1R, SBAS

Norway

The Threat of GNSS Jamming and Interference

Aiden MORRISON
SINTEF Digital, Sustainable Communication Technologies Department
aiden.morrison@sintef.no

Multiple existing safety and liability critical infrastructure components including all segments of transportation (air, road, railway and sea), emergency/search and rescue, power grid system support, and even a number of banking operations depend on reliable and robust position, navigation, and timing (PNT) services. In addition, the evolution and adoption of safety critical semi- and fully autonomous operations and systems (unmanned autonomous cars, passenger ferries, aerial vehicles, construction machine guidance, etc.) depend heavily on the unobstructed access to PNT signals. Unfortunately, as it has been shown by several recent studies including the EU H2020 STRIKE3 and ESA NAVISP-EL3 ARFIDAAS projects, PNT signals are under threat from illegal interference at a level which exceeds the tolerable limit for important infrastructure systems, and which is expected to become even more common due to growing financial incentives to use signal jammers unless robust enforcement activity can discourage such behavior.

To be able to develop reaction strategies necessary to ensure continuity and availability of PNT services, in addition to enabling new system concepts/architectures which rely on multiple frequencies (e.g., involving switching between modes based on different core frequencies), knowledge of jamming signal characteristics including center frequency, bandwidth, time modulation frequency of the signal, band/bands affected, relative occurrence rates between the considered frequencies and frequency combinations, as well as their relative power levels is highly beneficial. When carrying out such analysis, it is necessary to use equipment that would not only cover the frequency bands of interest but also allow for flexible analysis of the captured raw RFI event data. To facilitate the monitoring and data analysis task results of which are the focus of this paper, SINTEF's advanced GNSS RFI detection, analysis, and alerting system (ARFIDAAS) was used. ARFIDAAS simultaneously supports all navigation bands transmitted by GPS (L1, L2 and L5), Galileo (E1, E5a, E5b and E6), GLONASS (G1, G2 and G3) and Beidou (B1, B2 and B3) for RFI events impacting any individual or multiple signal bands. To allow for the flexible analysis of the captured raw RFI event data such as the possibility to reprocess the captured events using different parameters of interest, the stations upload all events detected to centralized cloud storage for post-processing. In total, 14 stations were deployed between October 2019 and June 2023 across a growing network of international sites in Europe and Scandinavia.

In this presentation, results based on the data captured from a subset of six monitoring stations (three in Trondheim, Norway; one in Asker, Norway; one in Amsterdam, Netherlands; one in Moss, Norway) with the longest continuous operational periods which each exceed one year will be discussed. In total, about 8.5 full years of data aggregated across the selected sites were used here totaling 3116 site-days of observations. Analysis aspects such as the dominant types of RFI as observed at the various locations, the distribution of power levels of the emissions sources creating these disruptions, the derived occurrence rates of RFI and ratios between the different GNSS signals and frequency bands as well as their combinations will be presented. Evolution of the state-of-the-art jamming signal structures will be also discussed based on the events captured by the network.

KEYWORDS: GNSS, RFI, Jamming

Philippines

Using GNSS in validating the Philippine Geoid Model

Donnie T. MANCERA, Ronaldo C. Gatchalian, and Aila Leana T. Sampana
National Mapping and Resource Information Authority (NAMRIA) - Philippines
dtmancera@namria.gov.ph

The Philippines is one of the most vulnerable countries at risk from climate change, it is exposed to extreme weather events, has active volcanoes, and is highly susceptible to tectonic movements. To better respond to these challenges (e.g. sea level rise, ground subsidence or uplifts, earthquakes) NAMRIA as the central mapping agency of the Philippines, has committed to modernizing its geodetic reference frame. The modernization has two components, a geometric reference (Philippine Geocentric Datum, PGD), and a vertical reference (Philippine Geodetic Vertical Datum, PGVD). The development of a geoid model is one of the integral elements in creating a modern height system. A geoid model would make GNSS leveling possible by converting ellipsoidal height to orthometric height using the formula $H = h - N$; where H is height referred to MSL (orthometric height), h is the ellipsoidal height from the GNSS survey, and N is the geoid height derived from a geoid model.

A preliminary Philippine Geoid Model (PGM) was developed in 2014 with the assistance of the National Space Institute - Technical University of Denmark (DTU-Space) led by Dr. Rene Forsberg. This geoid was computed in a global vertical reference system and then fitted to the Local World Geodetic System 1984 (WGS84) reference system using Global Navigation Satellite System (GNSS) and leveling data nationwide, this was done to preserve the existing vertical datum tied to the mean sea level (MSL). This was named the Philippine Geoid Model 2014 (PGM 2014).

This preliminary geoid model however contains large errors, with a standard deviation (SD) of ±0.30 m and a 0.54 m root mean square (RMS) fit to GNSS/Leveling. In 2016 using new land and satellite gravity, the geoid model was reprocessed and the SD was reduced to ±0.022 m and RMS 0.054 m (PGM2016). Through continuous terrestrial gravity observations this was refined further to the latest model (PGM2018) with SD ±0.010 m and RMS fit of 0.020 m. To validate and confirm the fit of the latest geoid model (PGM2018) to the leveling network, benchmarks (BMs) were observed using GNSS observations. The GNSS data were then post-processed using Trimble Business Center (TBC) software with the PGM2018 file incorporated into it. With the PGM, TBC generates the MSL elevation of the BMs. These BM elevations (using GNSS+PGM) were compared to their geodetic leveling-adjusted elevations. The elevation differences obtained from the two methods indicated the accuracy of the PGM.

My presentation will discuss the activities and the results of this validation process in detail and the way forward towards the development of the Philippine Geodetic Vertical Datum (PGVD).

KEYWORDS: Philippine Geoid Model, GNSS-leveling, Height-systems

Poland

IGS Ionosphere Working Group Cooperation with IRI – Provision of GNSS Tec Products to Gambit Database

Andrzej KRANKOWSKI
University of Warmia and Mazury in Olsztyn (UWM), Space Radio-Diagnotsics Research Centre (SRRC/UWM)
kand@uwm.edu.pl

The current activities of IGS Iono Working Group include several different fields of development which allows for rapid increase of product's quality and usability. Great examples include the extension of ROTI maps to cover southern hemisphere and equatorial region in depiction of ionospheric irregularities as well as the development of real time GIMs. IGS Iono WG also directly cooperates with IRI group to provide the users with data fusion products allowing for thorough analysis of the ionosphere.

IGS Iono Working Group and IRI both conduct works regarding joint provision of ionosphere products, that allow for complex real time analysis of its response to changing geomagnetic conditions. Different approaches represented over the years by both groups meet on the common ground of GAMBIT Database and Explorer where currently available are several climate and weather products allowing for multi instrumental analysis. Apart from IGS- provided GNSS TEC this of course includes ionosonde and IRI model data. The addition of IGS-IRI cooperation in 2020 was the inclusion in GAMBIT of 30-day-average climate VTEC maps, depicting quiettime reference of VTEC. Now two new products are added to GAMBIT roster – IGS Real-Time and Rapid weather VTEC maps. IGS Iono WG activities are not limited to the post- processed GIMs. Great effort is currently concentrated on cooperative RTGIMs that prove their great quality and unprecedented speed of delivery, providing a great answer to user's needs expressed over the years. Another field of interest is mapping of irregularities. The pioneer northern- hemisphere IGS ROTI product is currently being developed to include the depiction of southern hemisphere as well ionospheric product.

KEYWORDS: IGS, IRI, GIMs

Republic of Korea

KPS and KASS Update in 2023

Jongsun AN, *Keonhee LEE*
KPS R&D Directorate, Korea Aerospace Research Institute
jsever@kari.re.kr

The satellite navigation system is a critical navigation method that provides high-precision PNT for autonomous driving, urban aviation, mobile networks, aviation, ships, and drones and is being operated and developed in countries worldwide. In June 2022, Korea also began developing the Korean Positioning System (KPS) to provide high-precision PNT information based on satellite navigation, focusing on the Korean Peninsula. The KPS plans to provide six navigation services (Open, Meter Level, Centimeter Level, SBAS, Public Safety, Search and Rescue) to provide PNT information required for various use fields. To this end, we are pursuing the development of a regional satellite navigation system based on satellite segment(3 GEOs, 5 IGSOs), ground segments(operation centers, satellite control centers, antenna stations, monitoring stations, Mission control stations for MLS/CLS), and user segments(research and development receiver, monitoring station receiver, test and evaluation receiver). System design is in progress, and action is scheduled to be completed in 2035 through system development, deployment, and validation stages.

In October 2014, KARI was designated the development organization to manage the KASS (Korea Augmentation Satellite System) program. The KASS program office gave the public notice of tender for cooperation development, and In October 2016, the prime contractor was selected. After these full-fledged developments began. The KASS program aims to develop and establish APV-I SBAS in Korea. The KASS started open service in May of 2023 and will achieve APV-I system qualification by the end of 2023. In the future, the KASS will provide the sky load information with GPS correction and integrity. As everyone knows, SBAS is now used in transportation, survey, timing, and aviation. So, KASS will be used in various fields in the future.

KEYWORDS: KPS, KASS

Saudi Arabia

LOS in Surface Deformation Mapping: A Case Study of the Kingdom of Bahrain

Mohamed ELHAG [*1,2,3,4] *and Khadija Diani* [5]

[1]*Department of Water Resources, Faculty of Environmental Sciences, King Abdulaziz University, Jeddah, 21589. Saudi Arabia.*

[2]*The State Key Laboratory, of Remote Sensing, Aerospace Information Institute, Chinese Academy of Science, Beijing 100101, China.*

[3]*Department of Geoinformation in Environmental Management, CI-HEAM/Mediterranean Agronomic Institute of Chania, Chania 73100, Greece.*

[4]*Department of Applied Geosciences, Faculty of Science, German University of Technology in Oman, Muscat 1816, Oman.*

[5]*Department of Geology, Faculty of Sciences, Mohammed V University of Rabat, 8007, Morocco.*

[*]*melhag@kau.edu.sa*

Land surface deformation is a phenomenon that can lead to severe consequences for urban development, infrastructure, and the environment. Active remote sensing techniques, such as Synthetic Aperture Radar (SAR) and Interferometric Synthetic Aperture Radar (InSAR), are valuable tools for detecting and monitoring land surface deformation. In this case study, a set of several algorithms were applied to analyze land surface deformation in the Northern part of the Kingdom of Bahrain. The current study's findings provide insights into the spatial distribution and temporal patterns of surface deformation in Bahrain, identifying the velocity of subsidence/uplift areas over the last 5 years ranging from 5 to -4 cm/year. Such findings can contribute to informed decision-making for sustainable development and disaster risk reduction.

KEYWORDS: InSAR, Interferometry, Spatial Coherence, Subsidence Uplift

Thailand

GNSS time and Frequency transfers and receiver calibrations: plans and implementations

Thayathip THONGTAN
National Institute of Metrology Thailand
Thayathip@nimt.or.th

National Institute of Metrology Thailand (NIMT) maintains an official atomic timescale; UTC(NIMT), providing traceability to an international timescale; UTC, through GNSS signal observations. Time and frequency information is essential for serval critical infrastructures such as electrical power distributions, telecommunication networks and financial systems. UTC(NIMT) realisation is applied in time and frequency calibrations and time information distributions services across Thailand through Internet network. Therefore, systematic and measurement errors need to be determined and modelled in order to compare remote clocks precisely.

NIMT participates in the International Bureau of Weights and Measures (BIPM) GNSS receiver calibration campaign in 2022 for GNSS signal delays determinations travelling through the antennas and receivers. The calibrated values are later transferred to the newly installed receiver at the site in 2023.

The presentation includes the receiver internal calibration delay measurements and computations using common clock and common view satellite in a short baseline scheme. The results from the calibrated receivers are later analysed in order to determine time scale differences between the UTC(NIMT), GPS system time and Galileo system time as well as the differences between the GPS and Galileo system time scales. The aim is to maintain Thailand atomic timescale of within 20 nanoseconds with corresponding determined errors are within 2.8 nanoseconds.

KEYWORDS: GNSS time and frequency comparisons, GNSS receiver calibrations, precise time determinations

Uzbekistan

Current situation and future prospects of GNSS application in Uzbekistan

Bekhruz MIRZAEV
The Space Research and Technology Agency under the Ministry of Digital Technologies of the Republic of Uzbekistan
b.mirzayev@uzspace.uz

This presentation provides an in-depth analysis of the current state of Global Navigation Satellite Systems (GNSS) application in Uzbekistan and paints a picture of the promising future possibilities. The significance of GNSS's role in sectors such as transportation, agriculture, and telecommunications cannot be understated, given its capacity to enhance efficiency and accuracy.

Drawing upon recent studies and real-world data, this presentation explores the extent of GNSS application in Uzbekistan's technological landscape today. In doing so, it sheds light on current utilizations, the advantages experienced, and the challenges faced.

Following this, the presentation elucidates the potential for future growth and development in this sphere. It highlights areas unexplored and proposes feasible strategies for utilizing GNSS services and technologies for economic growth and societal advancement. The focus will be on how innovative GNSS applications can lead to improved disaster management, precision farming, and the planning of smart cities in Uzbekistan.

The conclusion offers a perspective on how a strategic approach to GNSS application can position Uzbekistan favorably on the global space technology map. The material presented should foster discussions on avenues for international cooperation, as well as industry-academia partnerships, to bolster the GNSS application in Uzbekistan. This presentation encourages the exploration of paths to harness the full potential of GNSS for the continual growth of our country.

KEYWORDS: GNSS application, technological advancements, future growth