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Coordinates

Volume XIX, Issue 12, December 2023

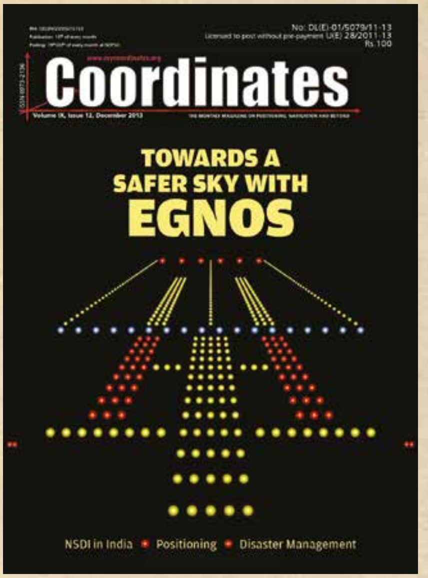
THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

Collecting volunteered GEOGRAPHIC INFORMATION from the GNSS

A review of land information management systems

In Coordinates

10 years before...



mycoordinates.org/vol-9-issue-12-December-2013

Towards a safer sky with EGNOS

F Javier de Blas
Service & Business Development Manager, Service Provision Unit, ESSP SAS, Madrid, Spain

As most of the Satellite Based Augmentation System (SBAS) systems around the world, EGNOS was dened, designed and developed to be used primarily for aviation. Therefore the SoL Service is "the service" that EGNOS was originally meant to provide, justifying its very existence. Thus, the introduction of the EGNOS SoL Service in the EATMN (European Air Trafc Management Network) was, maybe, the most important milestone for the whole EGNOS project.

Single frequency GPS/Galileo precise point positioning

Akram Afifi and Ahmed El-Rabbany
Department of Civil Engineering, Ryerson University Toronto, Ontario, Canada

Single-frequency PPP algorithms were developed in this research to combine the E1 Galileo and L1 GPS signals. A short baseline test was performed to determine the stochastic characteristic of the E1 Galileo signal. It has been shown that Galileo satellite system can offer more satellites at 45° cut-off elevation angle to the GPS system, which makes the PPP solution possible at this high cut-off angle. The results showed that a sub-decimetre positioning accuracy and up to 30% improvement in the convergence time can be obtained with single-frequency GPS/Galileo PPP.

NSDI in India: Status and the road ahead

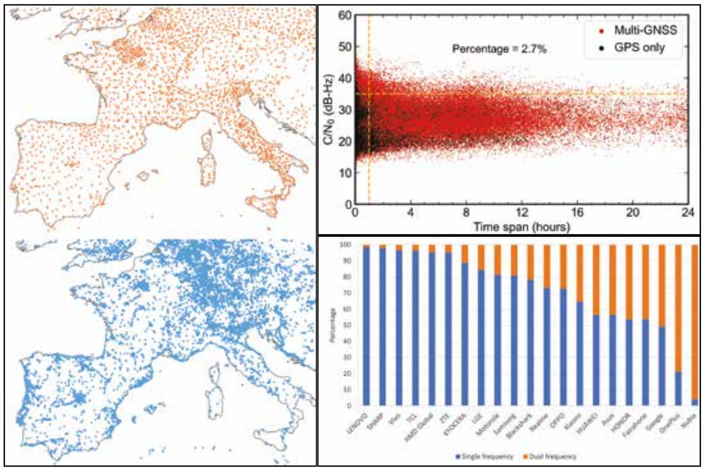
Maj Gen Dr R Siva Kumar and PS Acharya
Department of Science & Technology, Government of India

Utility of Geo Portals, Standard Specifications, Spatial Data Re- engineering, Interoperability etc. has been demonstrated with the involvement of the Advanced Laboratory on Geo- Information Science & Engineering at IIT Bombay and the network of R & D Institutions of Natural Resources Data Management System (NRDMS). These are being adopted and used by the NSDI Shareholders. Required capacities are being built in various organisations and agencies at the National and State levels to operationalise Spatial Data Nodes for provision of web-based Data Services.

Integrated disasters and risk management policy, legislation and regulations

Wafula Luasi Nabutola
Consultant – In - Chief MYRITA CONSULTANTS Chair FIG Commission 8

The management of disasters by government departments at various spheres of engagement is almost entirely reactive in nature. It is also clear that the full continuum necessary for disaster management, such as prevention, mitigation, preparedness, response and rehabilitation is not an integral component of current disaster management systems. Rather, each disaster is treated as a crisis, and preparations are conducted to deal only with emergency situations.



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Coordinates Volume 19, Issue 12, December 2023

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Columns

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Editor Bal Krishna
Owner Coordinates Media Pvt Ltd (CMPL)

This issue of Coordinates is of 36 pages, including cover.

Time is running out

The projected achievement of COP28, Dubai

Need to transition away from fossil fuels in energy system,

In a just, orderly and equitable manner,

Neither has any binding nor the timeline to adhere to.

Tripling the global target of the capacity of renewable energy,

Doubling the rate of energy efficiency improvements by 2030

Are the other welcome highlights.

However, how close we are to limit

long-term global temperature rise to 1.50C,

That was agreed upon at COP21 Paris,

Remains crucial.

There are warnings that the time is running out.

Well intending postures are to be backed by the actual positions.

Bal Krishna, Editor
bal@mycoordinates.org

Collecting volunteered geographic information from the GNSS

This paper presents results from data collection campaigns using the CAMALIOT mobile app.

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Abstract

Raw observations (carrier-phase and code observations) from the Global Navigation Satellite System (GNSS) can now be accessed from Android mobile phones (Version 7.0 onwards). This paves the way for GNSS data to be utilized for low-cost precise positioning or in ionospheric or tropospheric applications. This paper presents results from data collection campaigns using the CAMALIOT mobile app. In the first campaign, 116.3 billion measurements from 11,828 mobile devices were collected from all continents. Although participation decreased during the second campaign, data are still being collected globally. In this contribution, we demonstrate the potential of volunteered geographic information (VGI) from mobile phones to fill data gaps in geodetic station networks that collect GNSS data, e.g. in Brazil, but also how the data can provide a denser set of observations than current networks in countries across Europe. We also show that mobile phones capable of dual-frequency reception, which is an emerging technology that can provide a richer source of GNSS data, are contributing in a substantial way. Finally, we present the results from a survey of participants to indicate that participation is diverse in terms of backgrounds and geography, where the dominant motivation for participation is to contribute to scientific research.

1. Introduction

Citizen science, crowdsourcing and volunteered geographic information (VGI) are all terms that relate to the production of knowledge, often in the form of data collection (See et al. 2016). Citizen science has emerged largely from the fields of biodiversity and conservation (Bonney et al. 2009), where species observations are one area in which citizen science has, and continues to make, substantial contributions (Chandler et al. 2017; Sullivan et al. 2009). Crowdsourcing originates more from a business domain, defined as the outsourcing of tasks to the crowd that would otherwise be impossible with only the current resources of an organization (Howe 2006), e.g. a range of different tasks that have been allocated via systems such as Amazon's Mechanical Turk (Bergvall-Kåreborn and Howcroft 2014) and can earn volunteers micropayments. VGI, a term coined by Goodchild (2007), comes from a geographical domain and focuses on the locational aspect of the data, where OpenStreetMap (OSM) is the most successful example of VGI to date (Jokar Arsanjani et al. 2015).

Although these terms (and many other similar ones, c.f. See et al. 2016; Eitzel et al. 2017) have different nuances that partly reflect their domain origins, the elements that unite them are the volunteers who take part, and increasingly the technology that enables participation, in particular mobile devices. Smartphones have become one of the key tools for data collection by volunteers, which takes advantage of the GNSS (Global Navigation Satellite System) receiver for pinpointing location in real-time, based on the navigation solution utilizing code measurements (L-band pseudorange measurements) to at least four visible GNSS satellites, as well as other features of the phone such as the camera (for taking geo-tagged and date/time stamped photographs), the gyroscope for determining if the phone is moving or tilted, and the compass for direction, among others. More recently, some models of Android-based smartphones have chipsets with dual-frequency GNSS receivers (Dabove and Pietra 2019) while Google has made it possible to access the raw GNSS data in Android smartphones from Version 7.0 of the Android operating system onwards (EGSA et al. 2017). Together these two developments have opened up the possibilities for employing such IoT (Internet of Things) data in many new applications. In this context, the raw GNSS data should be understood as epoch-wise carrier-phase and code (pseudorange) observations carried out between a GNSS receiver (smartphone) and a single GNSS satellite. Therefore, at each epoch, the receiver collects multiple observations based on the visible set of GNSS satellites, and such observations are then used in the processing of the location. The amount of collected observations per epoch may reach twenty or more, but it varies as it depends upon the performance of the GNSS chipset and the in-built antenna, the number of supported GNSS constellations, and the measurement environment in which the receiver is present, e.g. urban canyons or rural areas. The clear benefit of leveraging raw GNSS data is the possibility of using carrier-phase observations that can improve the positional accuracy of smartphones from several meters to decimeters (Psychas et al. 2019; Critchley-Marrows et al. 2020; Darugna et al. 2021;Lietal.2022), for spoofing and jamming detection (Miralles et al. 2018), and in seismological applications related to earthquake and tsunami detection (Fortunato, Ravanelli, and Mazzoni 2019). However, they can also be used for applications such as more precise augmented reality (Fu, Khider, and van Diggelen 2020) or other types of scientific applications that go beyond navigation.

GNSS is considered as an important tool in the field of atmospheric research thanks to its high accuracy and all-weather capability. The GNSS signal is delayed by water vapor as it passes through the atmosphere, which can provide information related to the current weather conditions (Guerova et al. 2016). GNSS can also deliver a very precise estimation of the total electron content(TEC),whereslantTEC isthelinearintegral of the electron density along any satellite-receiver ray path (Davies and Hartmann 1997). The performed GNSS parameter estimation and dedicated processing (Takahashi et al. 2016; Zhangetal.2018; Fermi, Realini, and Venuti 2019) allows changes in ionospheric and tropospheric states to be quantified with a high temporal resolution at a global scale. The capability of modern smartphones to precisely measure parameters of the atmosphere has, for example, been demonstrated by Stauffer et al. (2023). These subjects have been investigated within the framework of the CAMALIOT project (ESA NAVISP-EL1-038.2). It consisted of a set of activities related to the development of cloud-native software dedicated to processing of diverse GNSS datasets (high quality observations collected with the use of static geodetic receivers, and smartphone observations), the application of Machine Learning (ML) for spatial interpolation and forecasting of troposphere and ionosphere-related parameters as derived with the use of GNSS, and acquisition of GNSS observations from the modern generation of smartphones with the use of a dedicated Android application. ML or deep learning (DL in this context can be used to interpolate GNSS-derived time series (acquired at specificlocations) in space and time. Incorporating information from different and rather complex domains (e.g. solar and weather data) can be beneficial, but also challenging as a direct physical relation is usually difficult to formulate mathematically. However, ML-enabled processing allows large amounts of data to be combined of various origins and types, including relevant parameters or models that are acquired with the use of various instruments and methods (Bao Zhang and Yao 2021). In addition, a subset of ML architectures related to recurrent neural networks and their variations, or other state-of-the-art approaches including transformers, tend to be especially powerful in terms of temporal extrapolation of target parameters. Given the above, ML tends to be an appropriate solution in terms of data fusion, classification or forecasting tasks. In relation to GNSS and the atmosphere, among others, recent examples include the utilization of DL for spatio-temporal interpolation of tropospheric parameters

(Lu et al. 2023;Shehajetal.2023) and the development of models for TEC forecasting (Cesaroni et al. 2020;Natras, Soja,and Schmidt 2022).

Although there is a global network of geodetic stations that receive GNSS data on a continuous basis, there are large gaps in these networks, e.g. in Africa, South America and Asia. Hence, in this paper, we address one of the key research questions behind the CAMALIOT project: can we motivate volunteers to help collect VGI in the form of raw smartphone-based GNSS data for scientific applications? These data could help to fill the gaps in areas where there is a lack of stations, or the data could provide a denser set of measurements.

The starting point for this investigation was the availability of raw GNSS data, which can be accessed directly using an Application Programming Interface (API) provided by Google (2022). Note that such an API is not available for iPhones. Alternatively, it is possible to download an existing mobile application such as Geo++ RINEX Logger or Google's GNSS Logger, which allows users to download the raw data as CSV files or in a format specific to the field of geodesy and land surveying, i.e. Receiver Independent Exchange Format (RINEX; IGS and RTCM-SC104 2013). Receiver-specific RINEX files form the main input to various GNSS analysis software packages that perform calculations in post processing and utilize both carrier-phase and code observations. Such software packages (e.g. Bernese GNSS Software (Dach et al. 2015) or GipsyX/RTGx (Bertiger et al. 2020)) employ advanced processing schemes with the consideration of long observation periods and global GNSS networks to determine various target parameters (e.g. station coordinates, tropospheric delays, Earth rotation parameters, satellite orbits) with utmost accuracy. GNSS observations collected with the use of a global network of high performance receivers and antennas are utilized on an operational basis for realization of the international terrestrial reference frame (Altamimi et al. 2016) or investigation of global-scale geodynamical phenomena (e.g. Bevis et al. 1994; Hammond, Blewitt, and Kreemer 2016; Takahashi et al. 2016; Beutler et al. 2020), both of high importance for society and crucial for revealing the signals of a changing climate. When converted to files in the RINEX format, smartphone-based GNSS data can also be processed with such state-of-the-art GNSS software packages, which is the reason why commonly used GNSS logger apps support such a feature. However, there are two main issues with using Google's GNSS Logger app: (i) it does not support data download in the latest version of RINEX, and more importantly, (ii) there is no way to access the data from other users; e.g. even if the data were collected from Android phones by a company like Google, it would not be possible to share the data due to laws on data protection and data privacy. In addition, some stability issues were identified with prolonged use of the GNSS Logger app, so it did not represent a viable solution for the CAMALIOT project. There are other similar mobile apps available, but they are more geared towards viewing the satellite data (e.g. GPS Satellites Viewer and GNSS Compare), displaying positional accuracy (e.g. GPSTest) or are of a commercial nature (e.g. GNSS Surveyor). Hence, it was decided to develop a dedicated CAMALIOT Android application as a VGI tool to support meeting the goals of the project. This paper provides an overview of the application developed and a description of the campaigns that were launched to support data collection by volunteers.

2. Overview of the CAMALIOT mobile app and data collection campaigns

2.1. The CAMALIOT mobile app

At the beginning, we identified two main target audiences: (i) the general public, who might be interested in helping science, and (ii) the GNSS community, which might be interested in using the data for practical or research purposes. Hence the design was intentionally simple to encourage participation, including some gamification elements, while also providing data download and conversion (RINEX ver. 3.03) capabilities targeted at the GNSS community.

In building the app, we used a layered approach by first creating a very stable base application, similar to Google's GNSS Logger app that also collects raw GNSS data. However, in contrast to GNSS Logger, which often crashed on our test devices after running it for some hours, we designed the CAMALIOT

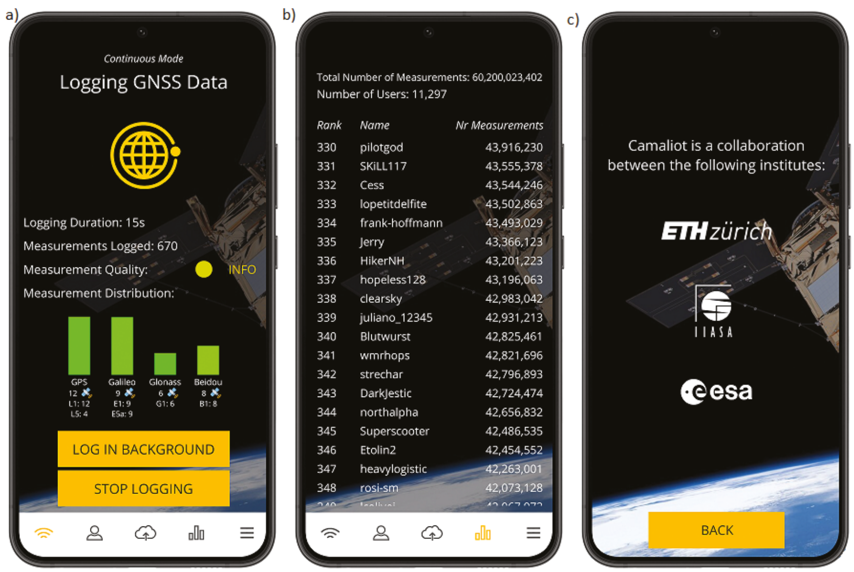

Figure 1. Screenshots from the CAMALIOT mobile app (from 20 May 2022) showing (a) the data collection page, (b) the leaderboard and (c) the information page with the partners involved in the project.

app to be as stable as possible. In addition, the base app was able to upload the data to the CAMALIOT server (ingestion micro-service comprising the CAMALIOT software that was running on Kubernetes), and export the data collected by users in RINEX-3 file format, which, as previously mentioned, would make the app very useful for researchers in the GNSS community as such smartphone-based single- or dual-frequency GNSS observations can be used directly in sophisticated analysis packages. The base app was written in Java, using the Google API to directly access the raw GNSS data from Android mobile phones as well as open-source code by Rokubun for conversion of the data to RINEX files (Rokubun 2020).

On top of this first base app, additional pages, written in Unity, were added. The example pages of the user interface (UI) of the CAMALIOT Android application are shown in Figure 1. The first page consists of simple instructions and an explanation of why users should participate in the project, which is shown when the user starts the app. The second page is the main screen (shown in Figure 1a), from which users can start the process of data collection. On top of this page, statistics and a leaderboard were added (Figure 1b); such a gamification element was intended to create competition, which could appeal to the motivations of some participants (Thiel and Fröhlich 2017). The leaderboard also acts as a form of feedback so that users could see their collective contribution in relation to other users. In addition, logos of participating partners were displayed (Figure 1c) as well as an FAQ (Frequently Asked Questions) targeted at those users interested in learning more about the project, the GNSS, and the scientific use cases in the project.

Once users download the app from the Google Play Store, they create an account and supply an alias for the leaderboard (Figure 1b), which is displayed along with how many measurements they have collected in relation to others. Users are also asked to agree to a set of Terms and Conditions with a link to the Privacy

Table 1. The variables collected by the mobile phone with their descriptions.

Name of Variable Collected	Meaning
Manufacturer	The manufacturer of the product/hardware
Model	The end-user-visible name for the end product
Elapsed Real time Millis	Elapsed milliseconds since boot
Provider	The name of the provider that generated this fix
Latitude	The latitude, in degrees
Longitude	The longitude, in degrees
Altitude	The altitude if available, in meters above the WGS 84 reference ellipsoid
Speed	The speed if it is available, in meters/second over ground
Accuracy	The estimated horizontal accuracy of this location, radial, in meters
(UTC) Time In Ms	The UTC time of this location fix, in milliseconds since epoch (January 1, 1970)
Time Nanos	GNSS receiver internal hardware clock value in nanoseconds
Leap Second	The leap second associated with the clock's time
Time Uncertainty Nanos	The clock's time Uncertainty (1-Sigma) in nanoseconds
Full Bias Nanos	The difference between TimeNanos and the true GPS time in nanoseconds
Bias Nanos	The clock's sub-nanosecond bias
Bias Uncertainty Nanos	The clock's bias uncertainty (1-Sigma) in nanoseconds
Drift Nanos Per Second	The clock's drift in nanoseconds per second
Drift Uncertainty Nanos Per Second	The clock's drift uncertainty (1-Sigma) in nanoseconds per second
Hardware Clock Discontinuity Count	Count of hardware clock discontinuities
Svid	The satellite ID
Time Offset Nanos	The time offset at which the measurement was taken in nanoseconds
State	Per-satellite-signal sync state
Received SvTime Nanos	The received GNSS satellite time, at the measurement time, in nanoseconds
Received SvTime Uncertainty Nanos	The error estimate (1-sigma) for the received GNSS time, in nanoseconds
Cn0DbHz	The Carrier-to-noise density in dB-Hz
Pseudorange Rate Meters Per Second	The Pseudorange rate at the timestamp in m/s
Pseudorange Rate Uncertainty Meters Per Second	The pseudorange's rate uncertainty (1-Sigma) in m/s
Accumulated Delta Range State	This indicates the state of the AccumulatedDeltaRangeMeters measurement
Accumulated Delta Range Meters	The accumulated delta range since the last channel reset, in meters
Accumulated Delta Range Uncertainty Meters	The accumulated delta range's uncertainty (1-Sigma) in meters
Carrier Frequency Hz	The carrier frequency of the tracked signal
Carrier Cycles	The number of full carrier cycles between the satellite and the receiver
Carrier Phase	The RF phase detected by the receiver
Carrier Phase Uncertainty	The carrier-phase's uncertainty (1-Sigma)
Multipath Indicator	A value indicating the 'multipath' state of the event
SnrInDb	The (post-correlation & integration) Signal-to-Noise ratio (SNR) in dB
Constellation Type	The constellation type
AgcDb	The Automatic Gain Control level in dB

Policy for the data, which explains how any personal data are stored and used within the project. Both documents are also available from the CAMALIOT website (https://www.camaliot.org). The user database is housed at a separate location to the CAMALIOT infrastructure (cloud-native micro-service-based software running on Kubernetes); in this way we separated the GNSS data collected from any user details, ensuring that users could not be identified, thereby complying with the EU's General Data Protection Regulation (GDPR). With a similar regulation in mind, the CAMALIOT software has been deployed and tested on the resources provided by EXOSCALE (https://www.exoscale.com), where all the infrastructure is located in Switzerland. Once users agreed to the Terms and Conditions and Privacy Policy, they could begin collecting GNSS data. In addition to the username, an encrypted password, an email address and the total number of measurements collected by the participant, the GNSS-relevant data collected by the mobile phone are listed in Table 1.

Data collection occurs via the main screen of the app (Figure 1a), which shows an example of ongoing data collection after a user has pressed the START LOGGING button. The information on the screen indicates how much data have been collected, but also from which satellites and how many satellites per constellation (i.e. GPS, Galileo, etc.) are available. If the phone has dual-frequency capabilities, this is also shown on the screen. For example, in Figure 1a, data are being collected using GPS satellites in L1 and L5 bands, whereas for Galileo satellites, measurements in the corresponding E1 and E5 bands were recorded.

The app's main data collection screen also has a real-time Measurement Quality indicator, which in the measurement UI is represented as a color-changing circle. This indicator reflects how well the phone is situated for data collection. In the case of the CAMALIOT project, the most beneficial measurements would be from a phone that is stationary and has an unobstructed view of the sky, i.e. located outside. Conversely, if the phone is moving or has a completely obstructed view, e.g. inside a building, the measurement quality indicator will change color from yellow (decreasing quality) to red (poor quality), depending upon the quantity of recorded phase and code observations. The approach for an epoch-wise classification of the quality of observations was derived empirically, taking into account all frequency bands (either one or two), several factors, and two threshold values. In general, the application checks whether the phone is moving or not based on the input from the motion sensors (accelerometer and gyroscope) and speed recordings acquired via Android`s LocationListener interface (values below 0.1 m/s are ignored), while utilizing the number of carrier-phase and code observations collected (per epoch) to assess the measurement epoch. The classification algorithm is described below:

- .gray color: no GNSS observations at all
- red color:
    - in general, if the number of code observations (from all bands) < 7
    - a case where carrier-phase observations were recorded, but the number of carrier-phase observations (from all bands) is < 7
- orange color:
    - in general, if the number of code observations (from all bands) is < 15
    - a case where carrier-phase observations were recorded, but the number of phase observations (from all bands) is < 15
- yellow color:
    - in general, the number of code observations (from all bands) is at least 15, but the smartphone is moving
    - a case where carrier-phase observations were recorded, and the number of phase observations is at least 15, but the smartphone is moving
- green color:
    - similar to yellow, but the smartphone is not moving.

The motivation behind the utilization of the number of GNSS observations is that they can be a good proxy for the environmental context (indoor, outdoor, obstructed view) in which the smartphone is present, similarly to the observed satellite-specific C/N_0 values. Although such an algorithm could be refined, for instance by leveraging additional factors such as the aforementioned C/N_0 or orientation of the phone (vertical/horizontal), the real-time Measurement Quality Indicator was, nevertheless, helpful to direct the users to some extent towards collection of a greater fraction of data that could be of use for the use cases investigated within the framework of the CAMALIOT project.

The INFO link on the right (in Figure 1a) provides more information about what the colors mean. Figure 1a shows two further options: the first is the ability to log data in the background, activated by clicking on the LOG IN BACKGROUND button. This means that the app will run completely in the background and use less resources. Finally, the app can run in continuous mode as indicated at the top of Figure 1a. This means that the user can tell the app to upload data quasi-continuously to the server (with an upload frequency chosen by the user), thus avoiding the need to manually upload the data. This latter feature was added based on user feedback. In addition, the user can also choose whether only the WiFi connection should be used for data uploading instead of mobile data. In case the WiFi connection is not available, all of the pending uploads will be resumed once the WiFi is available. Details of how to obtain the app are provided on the *camaliot.org* website or by searching the Google Play Store for CAMALIOT.

2.2. The CAMALIOT data collection campaign

We launched the first campaign on 17 March 2022, which ran until 31 July 2022. The length of the campaign was chosen to provide adequate time for demonstrating GNSS data collection by volunteers as a proof of concept. The campaign was advertised through various media channels, newsletters, magazines and mailing lists. To encourage participation, we offered prizes including a dual-frequency mobile phone, Amazon vouchers and branded goods from various companies. Although we announced that there would be prizes during the launch of the campaign, the details were only released as the campaign progressed. This allowed us to feed information to the volunteers via the website, social media and notifications in the app regarding the prizes. In the end the first prize consisted of a dual-frequency mobile phone, 2nd to 5th prizes were Amazon vouchers ranging from 50 to 200 Euros, and the prizes for the 6th to 20th ranked winners consisted of goodie bags containing swag from various companies. We also provided a clear set of prize rules posted on the website in which we stated that the 20 prizes would be awarded based on a random draw but weighted according to the number of measurements made by each participant. Hence, the more data collected, the more likely a participant would be to win a prize. During the campaign, we introduced a map showing the global distribution of data collected (Figure 2) so that users could see their contributions as part of a larger collective effort, updated in near real time. We also added a dashboard showing the top 10 contributing countries by number of devices and the number of measurements collected.

At the end of the first campaign (31 July 2022), the random prize draw was held, and the prize winners and all participants were asked to fill out a questionnaire. We then launched another campaign, called the Autumn campaign, due to the success of the first data collection campaign (see Section 3), which ran from 1 August until 30 November 2023.

3. Results from the data collection campaigns

3.1. Overview of the data collection

Table 2 summarizes the total amount of data collected by absolute number of GNSS measurements (epoch-wise satellite-specific GNSS observations, where carrier-phase and code observations are treated here as a single measurement) and the total number of devices (as a proxy for number of participants). These results indicate that the first campaign had a very good level of participation, with a large number of measurements contributed by the volunteers. Although there were less observations collected in the Autumn campaign, it still demonstrated a continued interest in collecting data.

Figure 3 shows the distribution of the data collected across the entire time period by the total number of GNSS measurements collected each day and the number of devices. Right after the launch, there was an abrupt increase in the number of measurements and participants, which coincided with a campaign launch that was marked by a press release, announcements on social media, the release of the video produced for the campaign and a news

Table 2. The total number of measurements (in billions) and total number of devices in the first campaign (17 March to 31 July 2022) and in the subsequent months of the Autumn campaign.

	First campaign	Autumn campaign (2022)			
	17 March to 31 July 2022	August	September	October	November
Measurements	116.3 billion	17.7 billion	12.2 billion	11.0 billion	11.1 billion
Devices/Users	11,828	1,241	791	880	835

Figure 2. Screenshot of the global map shown on the CAMALIOT website during the campaign (for data collected up to middle of June 2022).

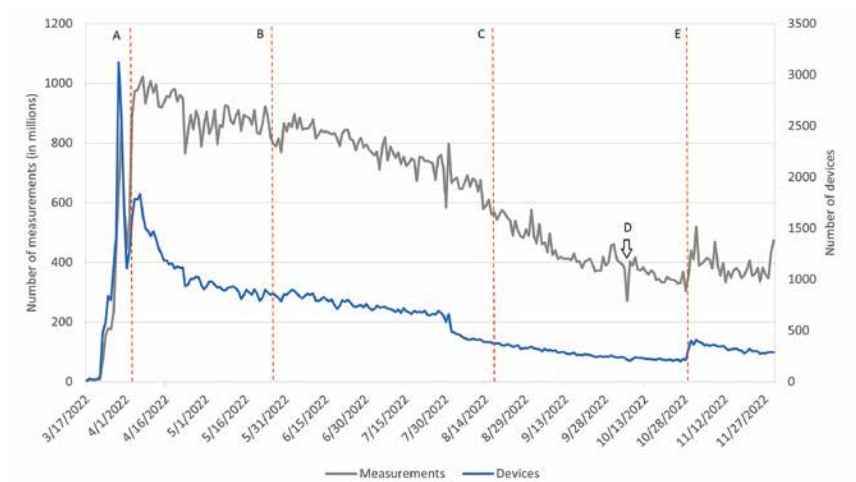

Figure 3. Volume of data collected (grey line) and the number of devices (blue line) from 17 March to 30 November 2022. The letters A to E correspond to events, described in more detail in the text.

item that appeared on the web pages of the European Space Agency. After the campaign was advertised in various newspapers (including the Guardian in the UK) and on SciTech Daily (marked by the red dotted line and A in Figure 3), there was a marked increase in the measurements and mobile usage. A second event occurred around 20 May 2022 (marked B in Figure 3), when a major update to the CAMALIOT mobile app was released in which users could now upload data on a continual basis rather than manually uploading data. There were some small peaks just after this event occurred. The event marked as C in Figure 3 denotes the end of the first campaign, which showed a slight increase in measurements as the Autumn campaign began, possibly due to advertising via the website and social media. A similar pattern can be seen again at the end of October (marked by E) with some additional social media activity. There was a decline in participation as the Autumn campaign progressed although numbers stabilized during the month of November. Moreover, a good amount of data is still being collected by volunteers (Table 2). Finally, one can see an example of where the server had issues (marked D on Figure 3), but volunteers alerted us to these issues, which were then promptly fixed.

3.1.1. Geographical distribution of the data collected

One of the key goals of the campaign and the CAMALIOT project was to try to determine whether the data gathered can either fill gaps in the network of geodetic stations (Blewitt, Hammond, and Kreemer 2018) around the world (Figure 4a) or provide a denser contribution in areas where the geodetic network is already good such as North America, Europe, or Australia. Note that some of these stations might have outages or are no longer operational, and the network with GNSS stations of the highest quality, which is run by the International GNSS Service (https://www.igs.org/network), is significantly smaller than that shown in Figure 4a (i.e. having approx. 500 stations). In contrast, Figure 4b shows the spatial distribution of data collected from the campaigns (17 March 2022–30 November 2022). One can see that the main VGI contributions are from Europe and North America, but that there are some notable areas in which the density of contributions is clearly higher, i.e. Brazil, some parts of India and Pakistan.

Figure 5 provides a more in depth view of the distribution of measurements across South America and demonstrates clear gap filling, with some measurements collected in the Amazon basin. However, the majority is concentrated in more populated areas of Brazil. A more in depth view is also provided in Figure 6, showing the southern part of Europe.

Although the network of geodetic stations is relatively well distributed across many European countries, the distribution of the

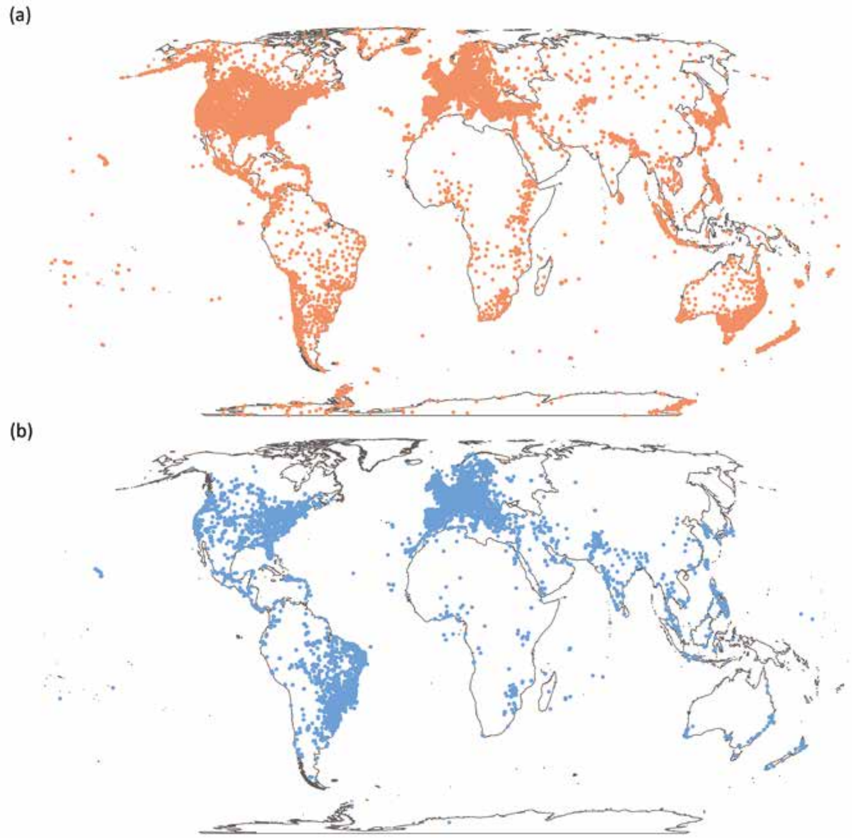

Figure 4. Spatial distribution of (a) publicly available GNSS stations of geodetic grade in orange and (b) crowdsourced data collected between 17 March 2022 and 30 November 2022 in blue.

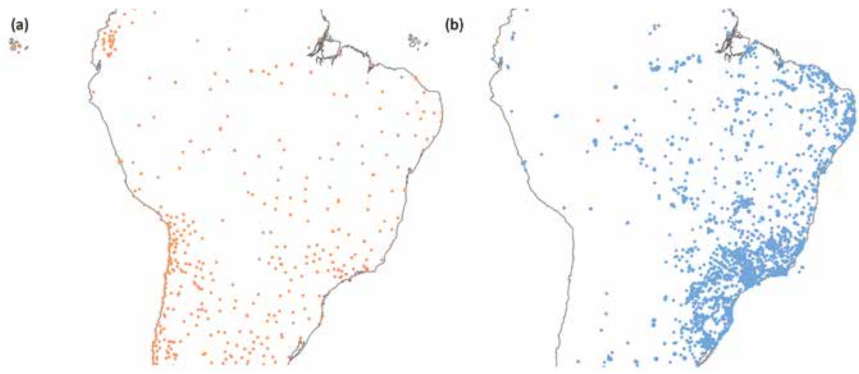

Figure 5. An example of gap filling of measurements in Brazil showing (a) publicly available GNSS stations of geodetic grade in orange and (b) data collected via the CAMALIOT app in blue.

VGI demonstrates how denser samples have been collected in many areas, e.g. in urban areas, shown clearly in Spain, while more rural areas still show gaps. However, the density of VGI in Germany is very high in comparison to the geodetic network. Moreover, gaps in the geodetic station network in areas such as the Alps have been partly filled by VGI.

3.1.2. Retention of participation in the Autumn campaign

To examine the issue of retention, we considered participation only from the Autumn campaign since we expected that many volunteers would be those already recruited from the first campaign. To do this, we calculated the number of days from the start of the Autumn campaign (1 August 2022) until 30 November 2022 during which contributions were received from the same device (as a proxy for participants). We then calculated the amount of participation as a percentage of the total time as well as the total number of measurements collected. The results are shown in Figure 7. The first three categories are participation for 1, 2 and 3 days, which are likely participants who tried out the mobile app, but did not continue to make any substantial contributions. In total, these three categories account for 56% of the participants, implying that we still continued to onboard participants during the Autumn campaign.

Looking at the contributions of participants who collected data for more than one month (or what we might term as 'active' participants), they collected data in 32 countries around the world. As a percentage of the total number of active contributors, the highest participation was from Germany (25.4%), USA (13.1%), Brazil (9.8%), Spain (6.5%) and the UK (5.2%). Of the remaining countries, most are European, but there are also active contributors in Asia and Australia.

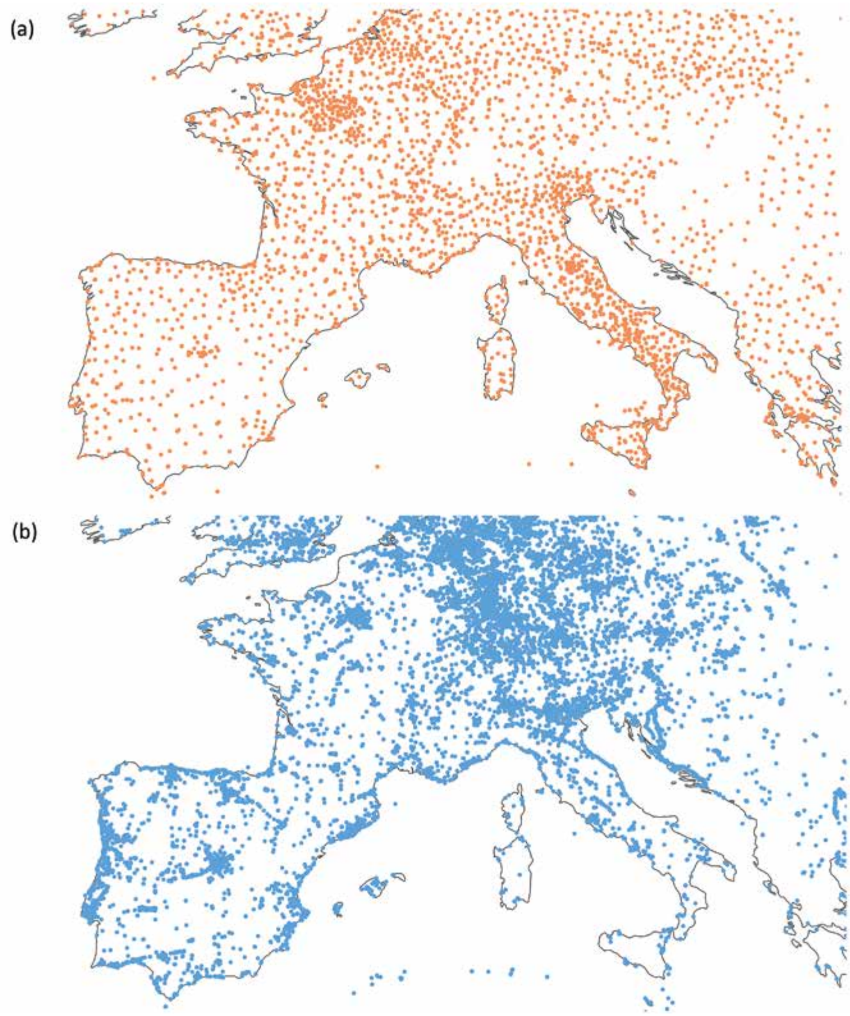

Figure 6. An example of densification of measurements in Europe showing (a) publicly available GNSS stations of geodetic grade in orange and (b) data collected via the CAMALIOT app in blue.

3.1.3. Types of mobile device used and presence of dual-frequency phones

As part of the data collection, we recorded the type of phone used by each participant and whether the phone was single or dual-frequency since one of the purposes of the CAMALIOT project was to collect GNSS data from dual-frequency phones, specifically for a scientific use case related to space weather modeling and forecasting (Natras, Soja, and Schmidt 2022). Figure S1 in the Supplementary Material shows the breakdown of the type of phone used as a percentage of all phone types while Figure 8 shows the percentage of dual-frequency phones (i.e. GNSS chipset models/versions that can support dual-frequency observations) compared to single-frequency ones for all phone manufacturers that offer both types of GNSS chipsets. Although Samsung represents the largest number of phones used in the two campaigns (Figure S1), less than 20% have a dual-frequency capability. However, the next two largest manufacturers (Xiaomi and Google) have a larger percentage of phones with dual-frequency capabilities, with Google at roughly half. Both OnePlus and Nubia have mainly dual-frequency phones although the number of Nubia phones used was quite small (around 50). Information about the distribution of phone types by continent is provided in Figure S2 in the Supplementary Material. In total, the percentage of phones with dual-frequency capabilities used to collect data across both campaigns was 27.1%.

Finally, Figure 9 shows the distribution of single and dual-frequency phones by continent to determine the feasibility of gathering dual-frequency measurements spatially. Overall, there is a relatively even distribution between mobile phones with these multi-frequency GNSS recording capabilities although single-frequency mobile phones are slightly more prevalent in Asia and South America.

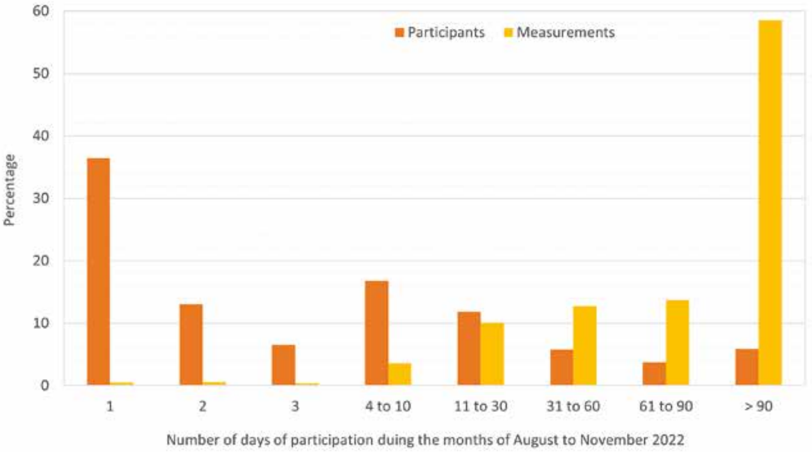

Figure 7. Participation by the number of days the participants took part in the autumn campaign as a percentage of the total number of days along with the percentage of measurements collected

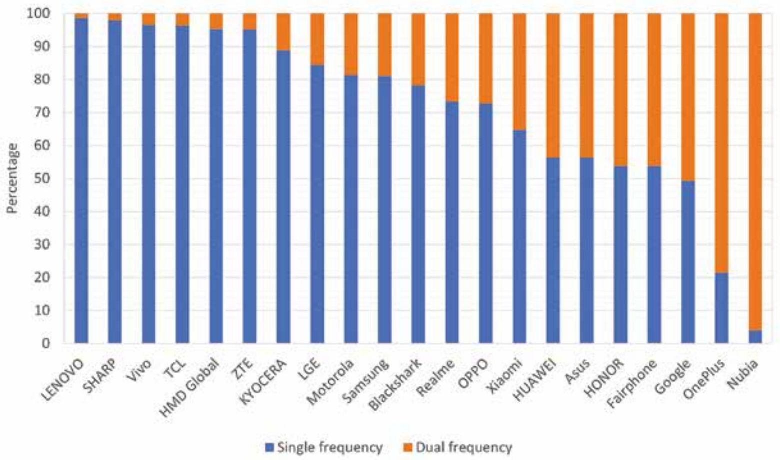

Figure 8. Distribution of mobile phones by single- and dual-frequency GNSS recording capabilities.

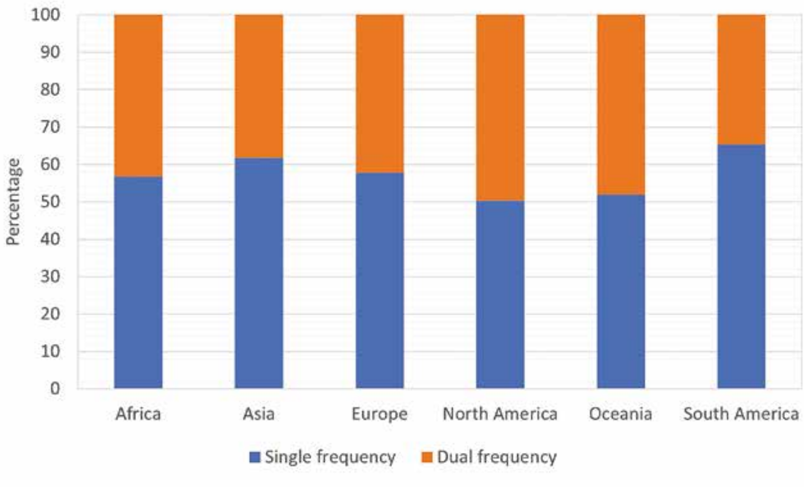

Figure 9. Continental distribution of mobile phones by single- and dual-frequency GNSS recording capabilities

3.1.4. Brief analysis of data quality

In addition to data quantity, data quality plays a crucial role in determining the usefulness of crowd-sourced data for scientific applications. In this study, we considered three important indicators observation continuity, C/N_0, and the capability of multi-GNSS to analyze the quality of the data collected. The distribution of the data collected along these dimensions is illustrated in Figure 10. To obtain high-precision tropospheric or ionospheric delays from GNSS data, it is necessary to have a sufficient time span of observations to enable solution convergence during parameter estimation. Typically, smartphone GNSS data require a longer duration for convergence due to their higher measurement noise. Our analysis reveals that 51.2% of the data had observation durations longer than 1 h, which offers the potential for achieving converged solutions. Additionally, a noteworthy portion of data collected during the campaign exceeded longer durations, with approximately 18.4% and 4.9% of data having durations longer than 6 and 12 h, respectively. The quality of the data, as indicated by C/N_0 values, is directly influenced by the observation environment. Higher C/N_0 values generally correspond to better data quality, with values larger than a certain threshold implying data collection in open sky. The mean C/N_0 of the data collected during the campaign was 27.4 dB-Hz, suggesting that the majority of data was collected indoors. Only 7.4% of the data potentially originated from outdoor environments when a threshold of 35 dB-Hz was used. If both observation continuity and C/N_0 are considered, 2.7% of the data holds potential for contributing to troposphere and ionosphere monitoring in the CAMALIOT project. Interestingly, we found that 94.6% of the data contained not only GPS observations but also observations from at least one other GNSS constellation, such as GLONASS, Galileo, or Beidou. This indicates that most modern Android smartphones have the capability to track multiple GNSS systems, thereby enhancing their potential contribution to scientific studies.

3.2. Participant profiles and motivations

The prize winners were asked to fill in a questionnaire as a condition for receiving their prize (clearly outlined in the rules of the campaign). This consisted of 21 responses (due to one

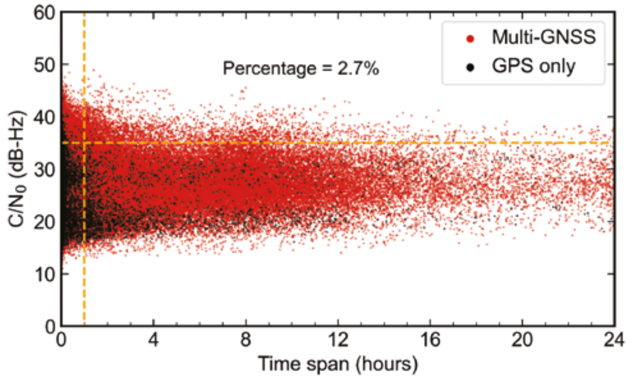

Figure 10. Distribution of time span and C/N0 of collected data. Each dot represents a data file containing GNSS observations from a single session. Black dots indicate files with GPS observations only, while red dots represent files with multi-GNSS observations. The horizontal dashed line denotes the C/N0 threshold of 35 dB-Hz, while the vertical line denotes the time span threshold of 1 h.

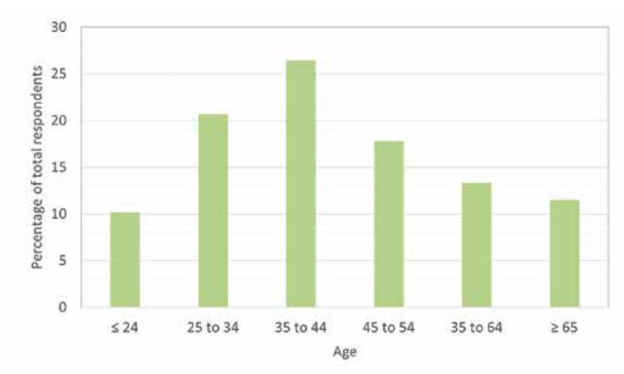

Figure 11. The distribution of respondents by age classes as a percentage of total respondents.

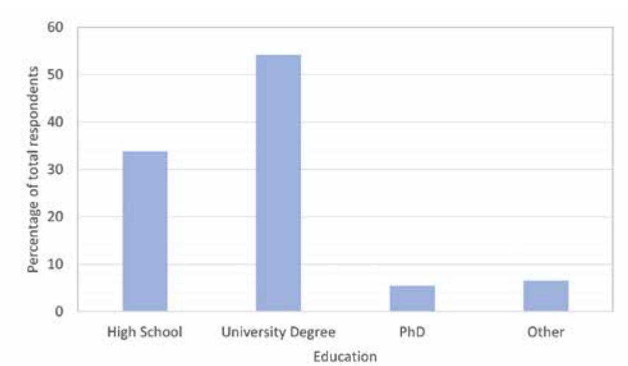

Figure 12. The distribution of respondents by type of education as a percentage of total respondents.

prize being unclaimed in the first campaign and the August prize winner having already won a prize in the first campaign). Due to EU's GDPR, we were not able to email all participants to ask them to fill in the questionnaire more generally. Instead, we advertised the link to the questionnaire on the front of the *camaliot.org* website, and notifications were pushed through the app asking participants to fill it in. As a result, we collected an additional 361 responses from non-prize winners, resulting in a total of 382 responses to the questionnaire. Note that the majority of these responses are from the participants in the Autumn campaign. The results are summarized in the sections that follow.

3.2.1. Socio-demographic profiles

The first part of the questionnaire was focused on gathering sociodemographic data about the participants, where we first asked about gender. All prize winners were male, but when all 382 responses were considered, 94.8% were male, 5.0% were female and one person chose non-binary.

After gender, we asked participants to indicate their age from a range, which is summarized in Figure 11. The results indicate that participants were from all ranges, but that just over a quarter were aged between 35–44. The next question was focused on education as shown in Figure 12. Although the majority had a university degree (bachelor or masters), roughly a third of participants had

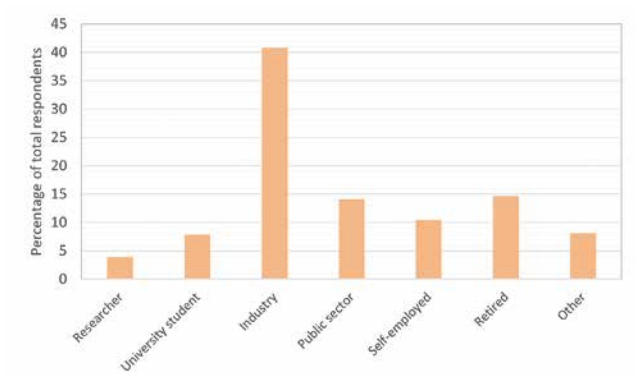

Figure 13. The distribution of respondents by the employment type as a percentage of total respondents.

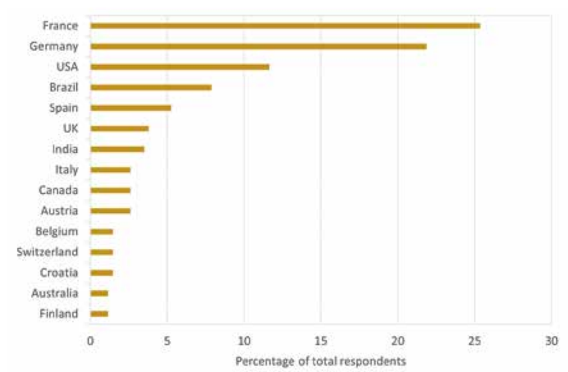

Figure 14. The geographical distribution of respondents ranked by country where the number of responses is greater than 1% of the sample.

a high school education as the highest level of attainment. Hence, the educational profile is quite diverse, where the campaign reached not only those with a higher education background.

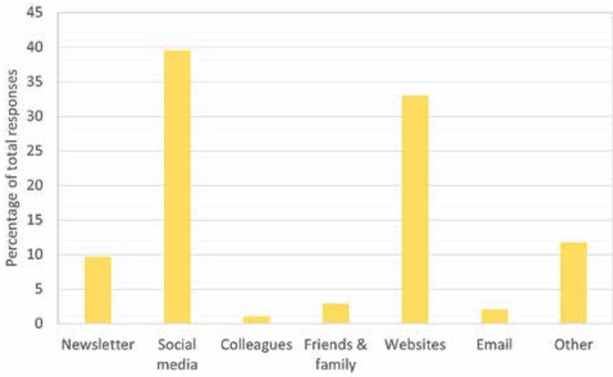

Figure 15. The distribution of channels through which participants learned about the campaign as a percentage of the total respondents.

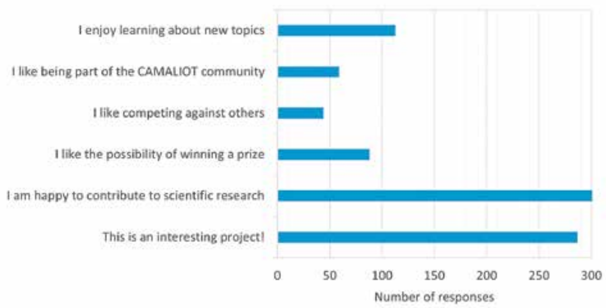

Figure 16. The motivations for participation where respondents could choose more than one motivation from a list.

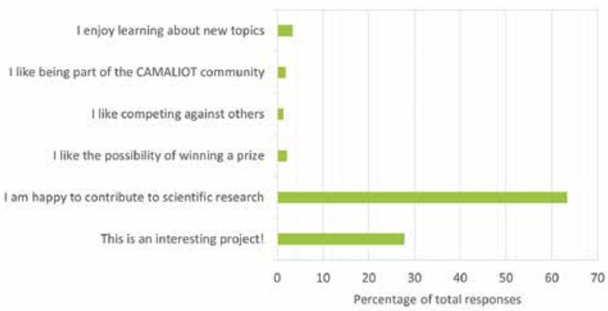

Figure 17. The dominant motivation for participation in the CAMALIOT campaigns as a percentage of the total responses.

Table 3. Responses to questions regarding interest in using data from the campaign.

Question on data usage	Response	Percentage of respondents
Are you using GNSS data collected by the app for your own purposes?	Yes	15.5
	No	84.5
Are you interested in getting access to the data collected in the project?	Yes	31.2
	No	26.8
	Maybe	42.0

Next, we asked about the type of employment of the participants (Figure 13), which shows that the majority are working in private industry, but that there is a range of diverse employment types including students and retired people. In fact, researchers make up only a small proportion of the respondents, which indicates that the campaign has appealed to many people outside of academia.

Finally, in the category regarding general information about participants, we asked them to tell us in which country they reside. Figure 14 shows this geographical distribution, focusing on only those countries with at least a 1% representation in the sample. The majority of respondents were from European countries with France and Germany as the top countries. However, there were also responses from outside Europe including USA, Brazil, India, Canada and Australia. Table S1 in the Supplementary Material shows the geographical location of respondents in other countries where data were collected.

3.2.2. How respondents learned about the campaign

In the next section of the questionnaire, we asked participants how they found out about the campaign, shown in Figure 15 as a percentage of total responses. The two main sources are social media and websites, e.g. news pieces or internet searches. The 'Other' category included responses such as radio, weather forecasts, various YouTube channels, podcasts, etc. Newsletters, emails and word of mouth played a much smaller role in reaching the participants.

3.2.3. Motivations for participation

The next part of the questionnaire addressed the motivation behind why participants took part in the campaign. Figure 16 shows those motivations that were selected by the respondents, where more than one motivation could be chosen. The most frequently selected motivation was that participants are contributing to science followed by the project is interesting, but all motivations were selected by at least some of the respondents. Hence, in addition to contributing to science, gamification and competition did appeal to some of those taking part. There was also an 'Other' category with free text to capture other motivations, but no additional responses were received.

We then asked respondents to choose the dominant motivation from those they had selected, which is summarized in Figure 17 as a percentage of all motivations. Here the desire to contribute to scientific research is clearly in the majority, with the fact that participants found the project interesting also acting as a key driver for participation.

3.2.4. Data usage

Table 3 summarizes the responses from two questions regarding data usage. We wanted to understand if users were downloading the data for their own purposes and whether participants would be interested in accessing all the data collected from the campaign, e.g. because they were GNSS professionals. The results indicated that the majority were not interested in downloading their own data (i.e. 84.5%) but a larger percentage were interested in the full data set (i.e. 31.2%). Thus, it is clear that the majority of participants were volunteers who were interested more generally in the project, which is supported by both educational backgrounds and the motivations for participation.

3.2.5. Overall user ratings of the campaign

At the end, the questionnaire had two questions related to the overall experience in the CAMALIOT campaign and the quality of the information on the CAMALIOT website. Ratings were made using a star system from 1 (worst) to 5 (best). The average rating for the overall experience in the CAMALIOT campaign was 4.35 while the quality of information on the CAMALIOT website was rated as 4.19 overall. Both indicate general overall satisfaction.

4. Discussion

Here we have shown that the CAMALIOT data collection campaigns have been successful in terms of the amount of data collected as well as the geographical distribution, where data have been collected across all continents, including even Antarctica where one device has collected measurements. Although this exercise was intended as a proof of concept as part of a scientific research project to examine how a modern generation of smartphones with GNSS capabilities can contribute to scientific applications beyond navigation, it has also demonstrated the willingness of citizens to take part in collecting GNSS data. In many ways this application is similar to the SETI (Search for Extraterrestrial Intelligence) project in which participants were willing to provide their processing power for scientific research (Anderson et al. 2002) and the Weather Signal app, in which users passively collected temperature data from their mobile phones from around the world (Sosko and Dalyot 2017). Based on responses from the questionnaire, the overwhelming motivation for participation was helping science, which we have found in similar citizen science applications involving volunteers, even when small payments were provided (Laso Bayas et al. 2020), and more generally in the literature (West, Dyke, and Pateman 2021). Although gamification and prizes were added to the campaign to appeal to different motivations of the crowd, it appears as if these elements were not considered to be as important as helping science or even selected all that often by questionnaire respondents as one of the underlying drivers of motivation.

As mentioned in the introduction, GNSS data can be used to provide valuable information on the presence of water vapor or on the ionospheric state. Hence, an important outcome of the campaigns has been to demonstrate that the data collected has the potential to fill gaps in the current network of geodetic stations (e.g. in Brazil), but that they can also provide a denser sample in other parts of the world (e.g. in Europe). The large contributions from Brazil were very surprising, but another citizen science project in which 10 million battery temperature measurements were collected in Sao Paulo, Brazil (Droste et al. 2017), indicates that there is clearly a willingness to take part in such projects. We acknowledge that greater participation in the countries of Africa and Asia is desirable, but has not been fully achieved in this project, which was originally designed as a proof of concept. To increase participation in these regions, one would need to work with partners in these countries, e.g. space agencies, meteorological services and non-governmental organizations, to help promote the app and the concept of crowdsourcing GNSS observations. Translation of the app and website into local languages, information campaigns to raise the awareness of the value of GNSS data beyond positioning or navigation, and other types of incentives such as micropayments could be avenues for exploration to improve the worldwide data collection coverage.

Another geographical pattern in the contributions was the concentration of data collected in populated areas versus more rural, which is a bias seen in other crowdsourcing projects like OpenStreetMap (Thebault-Spieker, Hecht, and Terveen 2018). However, in the CAMALIOT project, this urban-rural bias could be an advantage because one of the aims is to improve local weather forecasting of precipitation events, e.g. across a city, and this would require a dense set of observations. However, in this case one needs to be more specific upon the preferable location of the smartphones while taking measurements. GNSS radio signals used for precise positioning remain vulnerable to interference, jamming, and local variations in demanding environments such as dense urban areas, tunnels/bridges or thick vegetation. As a result, this leads to unwanted blockages, multipath interference, and reflections of GNSS signals before they reach the receiver antenna (Kubo, Kobayashi, and Furukawa 2020). Due to the low suppression level of such errors in the case of in-built GNSS smartphone antennas (G. Li and Geng 2019), this is an important aspect to consider in the future in relation to the science use cases examined throughout the course of the CAMALIOT project. Therefore, an open field with no obstructions from buildings or other large features would be favorable in this case. In general, one would also need to communicate clearly that the preferred orientation of smartphones is an upward orientation, as this tends to be the most beneficial in terms of the quantity and quality of raw GNSS observations that can be collected from smartphones (Li et al. 2022). The proposed concept would also require relatively continuous observations, at a specific location or area where tropospheric and ionospheric conditions are still identical, if these were to be assimilated into numerical weather prediction models in near real-time, or used in ionosphere-related studies, and therefore have an impact. Although such a data collection campaign

We demonstrated the potential of the data in terms of filling spatial gaps and increasing the density of observations relative to permanent geodetic GNSS networks.

can potentially contribute if more users could be convinced to collect GNSS data, there is also an argument that the intervention of big technology companies is needed such as Google, who could provide this information in the same way that IBM's Weather Channel has provided pressure data in the past for weather forecasting purposes (Cliff Mass Weather Blog 2022) as a form of corporate social responsibility.

In terms of contributions to the campaign over time (Figure 3), the pattern follows many other typical VGI and citizen science contribution patterns, i.e. large increases in participation following the launch of a campaign (due to advertising) and then increases linked to any subsequent major advertising events, e.g. being picked up by the Guardian newspaper and SciTech Daily, followed by a decrease in participation as the campaign progresses. Retention of participants is a well-known issue in VGI, citizen science and user generated content such as Wikipedia (Frensley et al. 2017; He 2012). Referred to as the 90-9-1 rule for online communities, 90% of users never contribute, 9% of users contribute a little bit and almost all of the content is generated by only 1% of participants (Nielsen 2006). In the case of OpenStreetMap, 3.5% of volunteers have generated more than 98% of the content in the past (Neis, Zielstra, and Zipf 2011). To investigate this phenomenon, we examined retention in participation during the four months of the Autumn campaign (1 August 2022–30 November 2022), with the argument that these participants would most likely have been recruited during the first campaign and hence be more likely to continue collecting data. How-ever, we showed that 56% of participants only collected data for one to three days so we clearly continued to onboard new participants that we did not retain. More active participants, i.e. those that contributed for more than one month, represent 15.4% of the participants who contributed 85% of the data. Hence, the ratio of contribution is not as extreme as that of the 90-9-1 rule or what was found in OpenStreetMap, but it still follows this type of typical skewed contribution pattern.

The results from the questionnaire provided insights into the backgrounds of the participants. There is a clear gender bias towards male participation, which is also seen in applications like Open-StreetMap (Gardner et al. 2020). However, the questions on age, education and employment indicate a diversity of backgrounds, which is often not the case with citizen science projects, e.g. a recent survey showed that participation was highest amongst those currently in education while in the CAMALIOT campaigns, a much larger proportion were employed in industry (West, Dyke, and Pateman 2021). This also demonstrates that the target audience reached by the campaigns was citizens interested in the project and much less from the GNSS community. Moreover, advertising the campaign in the GIM international online magazine, aimed at professionals, also showed little impact on the numbers of participants when this advertising event occurred.

The distribution of Android mobile phones in 2022 in terms of market share (Curry 2022) largely follows the relative distribution of the types of mobile phones that were used to collect data in the campaigns. Although this is not unsurprising, the number of devices capable of receiving GNSS signals in dual-frequency mode was higher than expected and was also well distributed globally, especially given that this is an emerging technology. This further demonstrates the potential of collecting raw GNSS data at scale for scientific applications of a global nature. However, it should be noted that even if a phone model is theoretically capable of dual-frequency GNSS signal reception, this is not always the case with all GNSS chipset models and versions as demonstrated by Barbeau (2021).

5. Conclusions

This paper provided an overview of the CAMALIOT mobile app for the collection of GNSS data along with results from two data collection campaigns, an intrinsic part of the CAMALIOT project (ESA NAVISP-EL1-038.2). We demonstrated the potential of the data in terms of filling spatial gaps and increasing the density of observations relative to permanent geodetic GNSS networks. We also showed that there has been a relatively substantial contribution from mobile phones with dualfre-quency capabilities, which are still an emerging technology. We then presented results from a questionnaire showing the diversity of participation and the drivers motivating the data collection. As the CAMALIOT project has now ended (as of 31 October 2022), plans for how to sustain the data collection are still under discussion. However, for the time being, we will continue to encourage data collection via the app and participation in the development of the CAMALIOT community.
The science use cases related to CAMALIOT that integrate the GNSS VGI will be presented in future papers.

Acknowledgements

We would like to acknowledge all the participants who took part in the CAMALIOT crowdsourcing campaigns for their valuable contributions to new data sets and science.

Data availability statement

Due to issues related to data protection and the potential to identify individuals from GNSS location information, the full data set collected through the project is not currently available. Once an anonymization process has been devised and applied, we will make the data available publicly through ESA's GNSS Science Support Center (GSSC) portal (https://gssc.esa.int/portal/). For the GNSS community interested in using the data for scientific research purposes, we suggest that you contact us directly.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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A review of land information management systems

The study provides an overview of contributions made so far on land information management systems, with the sole purpose of ascertaining the progress recorded and inherent challenges to the existing system.

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Abstract

The need to improve on a system must begin with glare lapse(s) in the existing system yearning for redress. The desire for a much better way of going about the business evokes intensive search for possible available alternatives. The process ultimately leads the relevant stakeholders to discovery or fashioning of a pragmatic model that will not only serve the purpose more effectively and efficiently but will also have the approval of the majority of the stakeholders and stand the test of time. This study provided an overview of contributions made so far on land information management systems, with the sole purpose of ascertaining the progress recorded and inherent challenges to the existing system. Nigerians suffer unnecessary delays in obtaining land title and land title information. The scenario has caused failure and abandonment of many developmental projects. A more robust and integrated land information management system that will provide timely land information for the stakeholders in Nigeria is imperative.

Introduction

Information management is critical for sound decision making in every facet of life. Harrison, as cited by Obongo (2003), opined that information is the lifeblood which flows into and out of an organization. The success of any enterprise or organization to a large extent depends on the accuracy and timing of the information supplied and its effective use. The Ministry of Lands, Survey and Town Planning especially in Anambra State, Nigeria, being the custodian of the state land wealth, should effectively tap the potentials of communication and information technology to improve on its service delivery, revenue collection and physical land use planning.

A Land Information Management System (LIMS) is essentially a computerized tool for legal, administrative and economic decision making for land use planning and development. It consists of a structured database with spatial referenced land related attributes and spatial data for a defined area as well as procedures and techniques for systematic collection, processing, updating and distribution of the data to aid in solving land management problems (Pindiga, 2012).

Currently, the world has more or less become a global village and information on a particular phenomenon at one part of the globe may be required by someone at another part, at any point in time. The need for land information computerization and land titling procedure automation is more crucial now than ever before. A functional land information management system should not only ensure that all data relating to land are consistent, correct and up-to-date but should also avail different users their required information without necessarily engaging in generation of new datasets. This entails the availability of land information to government, industry, business, academia and citizens to meet their needs through easy and simple access solutions (Akingbade, 2005).

In many countries, improvements to the existing land administration systems are driven by developments in technology. Land and property datasets grow larger in volume as population expands. Consequently, the need for a reliable means of storage and easy retrieval of land information in support of development becomes critical and ever more urgent. Both the administrators and users of land information need accurate and up-to-date data (Dale & McLaughlin, 1999).

Additionally, information technology is dynamic; new ideas and inventions are released almost on a daily basis and this should equally reflect in the land information management system. In 2007, Anambra State Government of Nigeria developed and started the use of the Land Information Management System (commonly referred to as ALIMS) hoping to reduce corruption, delays in title registration and enhanced internal revenue generation from state land management. However, challenges of the state land management are still prevalent despite the system which has remained the same. Similar stories are obtained in different states of the federation. A scale up of the existing system may reasonably solve our problem. A holistic land information management system that captures the needs of all relevant stakeholders is expedient.

Statement of the problem

Effective land information management not only provides the necessary information on the land title and records for the use of the stakeholders but also does that with dispatch. The current systems and practices of land administration in the states of the federation and Federal Ministry of Works, Land and Housing are mainly analogue systems. The systems are fraught with bureaucratic bottle-necks and human-engendered hiccups that inhibit timely completion of land title perfection. The systems are frustrating and seriously put off prospective investors; they invariably militate against national economic development. Though some states and the Federal Ministry of Works, Land and Housing have ventured into computerizing their cadastral records, their levels so far very much fall below what a good land information management system should provide to the stakeholders. Ukaejiofor (n.d) noted with dismay that despite the benefits of computerization of land information, only about 20% of the states in Nigeria have commenced the application of ICT in their land administration system. The need to leverage and improve on the land information management system cannot be overemphasized especially in the contemporary age of information and communication technology (ICT) driven global economy. Computerizing land administration can ensure speedy processing of first registration of title, prevention of unnecessary duplications, and facilitation of access to land-related data as well as in-built quality control measures, among others.

Securing land title in Nigeria today is still shrouded in secrecy; prospective investors outside the country can hardly contemplate investing in Nigerian real estate due to this obvious predicament. Access to land information is still very difficult and the government is invariably losing enormous revenue from the sector. The few states that have ventured into computerization of their land information system only automated a fraction of the entire sector which still makes them face challenges of delays and hiccups in processing and perfecting land titles. There is therefore a dire need in today's Nigeria to reduce the time it takes to process land titles and their documentation. The Ministry of Lands and Urban Development in most states comprises different departments which complement each other in the discharge of their core functions to the public. Improvement in their working relationships is imperative for better service delivery. But before such improvement is considered, review of present processes is very necessary. Such a review will identify the existing gaps and likely areas that require improvement. This study captures the aim and objectives of the existing land information management system and on that basis proposes recommendations of enhancement in the system that will cater for the needs of the present and future generations.

Aim and objective of the study

Improvements in information systems are essential due to constant changes in the ways activities and outputs are carried out and expected. Land information is very crucial for any meaningful investment; investors must determine location choice of investment and many a time, the time taken to arrive at a consensus contributes to the overall successes or failure of a project.

Delays in obtaining land information in Nigeria is a serious challenge even with skeletal land information systems in use in some states; therefore, improvement on the existing system is imperative. This study is aimed at proposing factors that should be considered based on the existing systems while articulating improvement or developing another LIM system for effective and efficient land administration in Nigeria. Other objective include:

1. To ascertain the nature of the existing land information management systems.

Conceptual framework

Land records and title registration

Maintenance of comprehensive and robust land records which are easily accessible by stakeholders is one of the most important issues facing governance today. "Land Records" itself is a general term and can include records such as the register of lands, Records of Rights (RoRs), tenancy and crop inspection register, mutation register, disputed cases register, etc. It can also include geological information regarding the shape, size, soil type of the land, and economic information relating to irrigation and crops (Ministry of Electronics and Information Technology India [MeitY], 2015).

Indian land records currently seek to accomplish the following across the country:

- Completion of all data entry relating to digitization of land records,
- Provision of legal sanctity to computerized Records-of-Rights (RoRs),
- Stopping further operation of manual RORs,
- Setting up computer centers at Tehsils, and
- Enabling web access.

In Nigeria, the federal government developed a land information management system which is not only a land records system but its features also include:

- A central control and monitoring of remote sites from the headquarters via the internet,
- Large data storage capacity of 10,000,000 records within an expandable system,
- Multi-user functionality: Up to 1000 users sharing same database,
- System entities are linked together within the relational database system,
- C of O to land to owner and to other transactions,
- Appropriate statistics and reports in both textual and map forms for policy action.

Land records are very important because they form the basis for assignment and settlement of land titles issues. The records kept at Tehsil office in India are of two types:

- Alphanumeric data containing record of rights details, crop statistics of individual plots, and
- The cadastral maps depicting the boundaries and extent of the plots.

These are maintained in the form of village maps or Field Measurement Book (Thakur, Khadanga, Venkatesh, Shukla, & Meena, 2003).

On the other hand, UNFIG (1999) defined land registration as the process of recording rights in land either in the form of registration of deeds or the registration of title to land, and adjudication as the process whereby the ownership and rights in land are officially determined. Dale and McLaughlin (1999) averred that land registration provides the means for recognizing formalized property rights, and for regulating the character and transfer of these rights. Registries take note of certain interests in land including information about the nature and spatial extent of these interests and the names of the individuals to whom these interests relate. In Lesotho, the registration system focuses on the land with the unique identifier obtained from cadastral surveying (Selebalo, 2004).

Title registration systems is an authoritative record of the rights to clearly defined units of land as vested for the time being in some particular persons or bodies, and of the limitations, if any, to which these rights are subject and kept in a public office. With certain unavoidable exceptions, known in the English system as 'overriding interests', all the material particulars affecting the title to the land are fully revealed merely by a perusal of the register which is maintained and warranted by the State (Simpson, as cited by Selebalo, 2004).

To ensure that the land records under the title registration systems are authoritative and warranted by the State requires the lengthy processes of adjudication and surveying to cadastral standards, which are usually rigorous. The processes of land registration in many African countries can be quite time consuming; it still takes over six months to obtain a registered title (Steyn, 2003). It is therefore not surprising to find that there have been a number of initiatives to bypass the formal land registration system and to create land records that can be used for development projects.

In Nigeria, land instrument registration is the predominant land record. The Land Registration Act No. 36 of 1924 as variously amended is the major law regulating land registration in Nigeria, and it has been adopted and re-enacted in most states under different nomenclatures (Nuhu, 2009). The Land Instruments Registration Laws of the various states and the federation have been expressly ratified by S. 48 of the Land Use Act of 1978 to the extent of their conformity with the Act. Section 315(5)(d) of the 1999 Constitution provides for the sanctity of the Land Use Act. The Constitution thus gave the Land Use Act a strong footing. These laws prescribe for the establishment of a land registry in the respective state under a land registrar charged with the responsibilities of registering instruments affecting land in the state and keeping the registers, books and files in relation thereto safe.

Types of land registration systems

There are three main types of land registration systems:

1. Private Conveyancing,
2. Registration of Deeds, and
3. Registration of Title.

Private conveyancing

In a private conveyancing system, land transactions are handled under private arrangement. Interests in land are transferred by the signing, sealing and delivery of documents between private individuals with no direct public notice, record, or supervision. The pertinent documents are held either by the individual to the transaction or by an intermediary such as a notary. In such a system, the state has little control over the registration process (save for regulating the intermediaries), and there is little if any security for errors or fraud. This system is known to be invariably slow and expensive (Dale & McLaughlin, 1999). Despite these serious limitations, notarial versions of private conveyancing are still in operation in some parts of Latin America.

Registration of deeds

Under this system, a public repository is provided for registering documents associated with property transactions (deeds, mortgages, plans of survey and so forth). There are three basic elements in deeds registration: the logging of the time of entry of a property document, the indexing or referencing of the instrument, and the archiving (i.e., storing) of the document or a copy thereof.

Many versions of deed registration system exist today; however, they all center on three core principles (Nichols, 1993), which are:

- Security: Registration of a document in a public office provides some measure of security against loss, destruction, or fraud.
- Evidence: Registered documents can be used as evidence in support of a claim to a property interest (although they cannot provide an assurance of title).
- Notice and priority: Registration of a document gives public notice that a property transaction has occurred and, with exceptions, the time of registration provides a priority claim.

Deeds registration provides a means for registering title documents only; it does not register title to a property. Registration is often not compulsory and, as a general rule, many rights are not registered. Reviewing and assessing all the documents required to determine the validity of a claim to ownership can often be extremely tedious and expensive to undertake, and sometimes open to disputes (Dale & McLaughlin, 1999).

Registration of deeds is the predominant system of land registration in Nigeria today. Each state in Nigeria has its own Land Instruments Registration Law (Imhanobe, 2007).

Registration of title

In this system, the register describes the current property ownership and the outstanding charges, obligations and liens. Here, registration is usually mandatory, and the state plays an active role in examining and warranting transactions. In most countries where this system obtains, the entry in the register becomes the proof of ownership. This is because in most cases, once a title is issued, it becomes irreversible. If someone with a better claim to the land resurfaces and establishes his claim, he does not recover 'his property' but rather has a remedy against the state in indemnity (Burdon, 1998).

There are various types of title registration system; the best known is that introduced by Sir Robert Torrens in Australia in the latter half of the nineteenth century. The Torrens registration system is based on three well known principles, namely:

a. The mirror principle: The register reflects accurately and completely the current state of title; hence, there is no need to look elsewhere for proof of title.
b. The curtain principle: The register is the only source of title information, which means a curtain is drawn blocking out all former transactions; there is no need to go beyond the current record to review historical documents.
c. The insurance principle: The state handles the veracity of the register and for providing compensation in the case of errors or omissions, thus providing financial security for the owners.

Title registration systems show a significant improvement over the rudimentary deeds registration systems. However, these title registration systems have been criticized for being often too expensive and cumbersome to implement and also for the length of time required for state examination and approval of the title and survey evidence. Some overriding interests that are not specifically registered gradually diminish the significance of the mirror principle. The details on the title certificate may not reflect all the rights as they exist on ground (Dale & McLaughlin, 1999).

The title registration system is unfortunately not popular in Nigeria (Olubodun & Onukwuli 2010). It was operated only in some parts of the old colony of Lagos, which include the present day Lagos Island, Victoria Island, Apapa, Ikoyi, Yaba, Surulere and some parts of Mushin (Imhanobe, 2007). Despite this, registration of titles is still valid under our laws.

Survey / Cadastral records

The efficient and effective administration of land and its associated resources depends on the availability of sound land information. Many nations are computerizing their cadastral records and creating large, national databases. Land-related data are now being integrated, analysed, and distributed in ways that until recently were not possible (Zegeye, 2019).

Kurwakumire (2007) submitted that without functional and up-to-date land information, it is difficult to implement planning, development and exploitation of land resources sustainably for the betterment of the communities. Land is unarguably one of the most valuable resources of any nation and land information management forms a major part of urban development. Likewise, the increasing growth in rural population and the massive migration of people to the cities (especially in the developing countries) have put increasing pressure on rural and urban lands and facilities (Dale & McLaughlin 1988). Therefore, a systematic record and rational use of the land should be of prime importance to planners and policy makers.

Cadastre, as defined by the International Federation of Surveyors FIG. (1995), is a parcel based and up-to-date information system containing a record of interests in land (e.g., rights, restrictions, and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of interests and ownership or control of those interests. It may also include the value of the parcel and its improvements. More aptly, a cadastral system consists of collection, recording and storage of all information relating to individual land parcels. Cadastral surveying is that which establishes and records the location, boundaries and features thereon, and ownership of land and property. This is one of the data sources in the Geographic Information System (GIS).

According to Nwilo, Omotilewa and Alademomi (2010), GIS is a system for capturing, storing, manipulating, analyzing and presenting geographically referenced data. It is a multidisciplinary concept because it cuts across virtually every profession. They however stressed further that basically, a GIS consists of a set of tools that professionals in various disciplines use to improve the way they work. It allows many different types of data to be geographically viewed, organized and analyzed. This information can be used to computerize the Cadastral register.

Egbenta, Ndukwu and Adisa (2012) opined that GIS technology can potentially lead to the development of efficient and organized land markets, guarantee tenure security among land owners, increase revenue generation by government, reduce disputes among land owners, and as well foster prudent land management by establishing efficient system of land administration.

Computerized land information system through GIS is therefore seen as the most appropriate technology in the reformation of cadastral systems and land administration all over the world (Siriba & Farah, 2014). GIS according to Nuhu (2009) is one of the modern methods that could be used in the computerization of land records as well as enhancing the process of land registration in Nigeria. This underscores the reason why many state governments in Nigeria are beginning to adopt GIS in their land administration processes. With the success story of the Abuja Geographic Information System (AGIS), other states such as Lagos, Niger, Bauchi, Benue, Cross River, and Nasarawa have also established their respective GISs.

Land use / Physical planning

Land use or physical planning can be described as a process aimed at achieving orderly physical development with the overall aim of evolving a functional and liveable environment where individual and common goals can be achieved. In urban centres, the essence of land use planning is to ensure that urban activities are organized and developed in physical space with due consideration for the protection of the public interest which include health, safety, convenience, efficiency, energy conservation, environmental quality, social equity, social choice and amenity (Adeagbo, 1998; Nnah et al., 2007).

It can also be described as the systematic assessment of land and water alternative patterns of land use and other physical, social and economic conditions in such a way as to encourage land users to select options that increase productivity and meet societal needs in a sustainable manner (Onibokun, 1985). This means that it is an art and science of organizing the use of land for the greater good of the society. Land use planning could therefore be expressed as physical planning. This is because physical planning attempts to achieve an optimal spatial coordination of different human activities for the enhancement of quality of life (Olajuyigbe & Rotowa, 2011).

Summarily, physical planning involves the reconciliation of land uses; provision of the right site for the right use; control of development; provision of facilities, services and public goods; preservation, protection and conservation of resources; and preservation of heritage sites, among others (Oduwaye, 2009).

The use of information communication technology (ICT) in physical planning is not new; it has been in fact contemporary with the development of computers themselves. The investment in research on urban models around the 1950s and 1960s was very intense and led to the development of some important models that were applied for the first time to real world case studies. An example is the Lowry Model (Lowry, 1964). These complex, aggregated models were aimed not only to research but also to help some highly capacitated public agencies to start understanding urban and regional areas as systems that could be controlled as machines. The period was described as the era of systems planning.

The 1980s brought to the limelight three instrumental features that were decisive for rebounding the interest of planners on new tools that from then on were beginning to be named as ICT:

i. Microcomputers which made the use of powerful computational and visualisation resources cheap and available to everyone,

ii. More capable database technology, which allowed the use of larger and better datasets, and

iii. The development of GIS as the first powerful tool to deal with data and cartography in an explicit visual manner.

The 1990s and the 2000s were the coming to age decades of the development of new ICT in planning. After a rapid diffusion of the use of GIS among all levels of planning agencies, professionals understood that they could take the next step towards exploring new tools and new approaches that would not only make use of GIS but also benefit from their popularity to interest the practitioners, a wide set of new tools and decision support systems based on many different concepts coming from different areas of knowledge—from physics to mathematics, from life sciences to economic theory. At the same time, computation became increasingly more visual, and brand new technology was used to create the first feasible virtual environments.

During these years, spatial and urban systems came to be regarded as complex ones; new disciplines were summoned, with researchers from all backgrounds becoming involved in the study of urban matters. This brought an entire new perspective to the field. Complexity became a central perspective in urban research, spanning from the more perceivable social, institutional and governance perspectives (closer to planning practitioners) to the mathematical and geographical perspectives (closer to researchers). The scenario gave birth to a wide set of ICT tools that are currently available for planning and policy design. They range from the use of advanced

GIS, with new and more sophisticated methods of spatial analysis, to the enhanced capacity of providing valuable visualisation (both on 2D and on 3D), to the development of new modelling tools based on several approaches, from cellular automata (Pinto & Antunes, 2010) and agent-based simulation (Wise & Crooks, 2012), to discrete choice based models (Kakaraparthi & Kockelman, 2011), and to simulations based on optimization (Koomen et al., 2011). The development of 3D environments is also experiencing a significant increase based on the LIDAR technology (Yu et al., 2010) but mainly driven by the industry from which many platforms emerged, allowing the creation of highly realistic virtual environments (for example, the ESRI City Engine and the widely used Google Earth).

Additionally, the application of GIS in land use planning is well established (Fedra, 1995; Alshuwaikhat & Nassef, 1996; Brazier & Greenwood, 1998; Cromley & Hanink, 1999; Bojorquez-Tapia et al., 2001; Ball, 2002; Hoobler et al., 2003; Malczewski, 2004 and Trung et al., 2006). Notably however, Trung, Tri, Mensvoort, and Bregt (2006) applied GIS in three different land planning approaches:

- The participatory land use planning (PLUP) which strongly considers the local people perceptions and beliefs for land utilizations,
- The guidelines for land use planning by FAO enhanced with multi-criteria evaluation (FAO-MCE), and
- The land use planning and analysis system (LUPAS) using interactive multiple-goal linear programming.

GIS plays a crucial role in the application of these approaches. In PLUP for instance, GIS helps to integrate the acquired spatial entities and attribute data from farmer discussions and analyzes the changes not only in biophysical land cover but also in farmers' perception on land utilizations. In FAO-MCE, GIS is used to combine biophysical and socio-economic characteristics and to perform multi-criteria evaluation. In LUPAS, an optimization model was developed. The model is linked with a GIS for data input and results presentation. The land use planners can (as has been established) use the model to explore different land use scenarios with different objectives and constraints, both biophysically and socio-economically.

Empirical review on land information management systems

In this review, we identified existing land information management systems that will at a glance display contributions made so far in this sector. However, since timely completion of activities involved are yet to be achieved with existing models especially in land registration; stakeholders still yearn for further improvement in the systems. It still takes weeks and months to secure approval from any government agency in Nigeria on land registration; an improvement on the system is imperative.

Ducker (1987) studied technical, economic and institutional issues surrounding the multipurpose land information system. His focus was on ways of modernizing land records through application of geographic information systems in land administration and possible problems the proposed system may face in implementation. The study noted institutional and economic constraints as major barriers in the implementation of the multipurpose land information system.

Enemark and Sevatdal (1999)—on their work titled Cadastres, Land Information Systems and Planning: Is decentralization a significant key to sustainable development?—evaluated the interrelationships of different land systems: land tenure system, land value system, land use control and land development system. They noted that the design of adequate systems in the areas of *land tenure* and *land value* would lead to the establishment of an efficient land market. On the other hand, the design of adequate systems in the areas of *land-use control* and *land development* would lead to an effective land-use administration. They averred that the combination of an efficient land market and an effective land-use administration would consequentially form the basis for a sustainable approach to economic, social and environmental development. The cadastral identifications of land parcels permeate through the land administration and land management systems and provide the basic infrastructure for running the interrelated systems within the areas of land tenure, land value and land use.

As a result of this development, the traditional surveying, mapping and land registration focus moved away from being primarily provider-driven to now being clearly user-driven. However, each of the systems (involved in the interrelated systems) includes tasks and processes that impose quite different demands on the cadastral system. The success of a cadastral system is a function of how well it achieves these broad social and economic objectives.

Fourie (1999) looked at developing cadastre and land information systems for decision makers in the developing world. The study emphasized that African countries should design land information management systems without a cadastral layer due to the cost implications associated with putting up such a structure. He therefore recommended a national spatial framework solely for visualization.

Due to challenges such as cadastral maps problems and the insufficiency of paper maps and land registers, Ibraheem (2012) proposed the development of computerized land and geographic information systems (LIS/GIS). The system is poised on digital cadastral maps and digital cadastral data bases (DCDB). The methodology involved several phases which include data collection and conversion, LIS structure and analysis, and the assessment of the accuracy of the digital maps. The results showed that the developed system can present the structure and information content of the digital maps as well as its differences with analogue maps. This digital cadastral map can be the basis for additional thematic layers, successively converting it into a complex system for management of administrative units. Ibraheem developed a large-scale land information system (LIS) by using geographic information systems (GIS) and field surveying. His work portrayed the problems of analogue cadastral maps, observing that the existing cadastre which consists of paper maps and land registers was highly insufficient. He recommended the creation of a land information system and a digital map.

Pindiga and Orisakwe (2013) developed a land information system of Tumpure residential and commercial layout in Akko Local Government Area of Gombe State. They created and tested a multimedia relational database of the attributes of the individual parcels and properties and linked them to the polygonized spatial positioning GIS software. On the other hand, video clips of properties within the studied neighborhood were obtained and linked to GIS software and the system developed afterwards was found to be efficient. The study recommended the use of Arc 3.2 GIS software in land administration.

Chiemelu and Onwumere (2013) noted that the manual land administration system has been in use by the Ministry of Lands and Survey, Port Harcourt since its inception and it has not meaningfully assisted the government in physical planning and revenue generation. Manual land registration from their findings is prone to abuses, time consuming and inefficient. The study discovered that since the implementation of integrated land information management in Rivers State, the government's internal revenue in the land sector improved and delays associated with land administration greatly reduced.

Abbas, Ben-Yayork and Muhammad (2014) developed a Land Information System (LIS) for providing a better and more efficient system for land management in Tsaunin Kura Residential Layout in Chikun Local Government Area of Kaduna State, Nigeria in response to the absence of an electronic way of land administration. The system developed can maintain and track changes, detect errors and make online corrections.

Kurwakumire (2014) made conceptual contributions to digital cadastres facilitating land information management. According to his work, modernization of cadastral systems in municipalities through technological reforms to improve access to cadastral information, as well as modernization of deed generating processes, can greatly reduce time required for land transactions.

Delays in land registration encouraged Wanjohi and Mutua (2015) to develop a Web Based Integrated Land Information System (WBILIS) for ownership, value and taxation using the Ministry of Lands, Housing and Urban Development, Kenya to demonstrate the application of the system. The system aimed at providing an effective land information collection, storage and dissemination platform for the Ministry of Lands, Housing and Urban Development. The WBILIS contained information on parcel ownership, land use, taxation, location boundaries, land value, encumbrances and many more. It demonstrated a streamlined flow of land information within the Ministry ensuring there was a well structured process of collecting, storing and disseminating land information.

Deane, Owen, and Quaye (2017) summarized all the required activities on "The Ghana enterprise land information system (GELIS) as a component of national geospatial policy" that can enable Ghana to develop a comprehensive land administration system that will ultimately lead to a national spatial data infrastructure. The policy implementation plan was not an academic exercise; it was rather a practical and operational solution to well known and acknowledged sets of problems designed to ensure greater effectiveness and efficiency across many units within the land sectors. The study carried out an extensive review of the current GELIS (under land administration project 1) noting all the inherent problems and current public needs; on the basis, an integrated comprehensive Ghana land information management system was developed (under land administration project 2). Critical stakeholders and their individual roles were identified; the linkage of all units and demonstration of the systems functionality was vividly elucidated.

Emengini, Akpata and Ejikeme (2017) developed a Cadastral Information System (CIS) which can be used to organize land records, holdings and descriptions of both spatial and non-spatial entities of parcels and land information. The (CIS) has the capabilities that allow recording, storage, update and retrieval at any time of all land related information.

3D Land Administration: A Review and a Future Vision in the Context of the Spatial Development Lifecycle by Kalogianni, Oosterom, Dimopoulou and Lemmen (2020) looked at the possibility of improving 2D based systems used to define legal and other spatial boundaries relating to land interests. The study noted that the built environment is increasingly becoming spatially complex; land administrators are presently challenged by the unprecedented demand to utilize the space above and below the earth's surface and the relationship between people and land in vertical space can no longer be unambiguously represented in 2D. They further submitted that in order to integrate different standalone systems for optimal service delivery, 3D data collaboration, sharing and reuse across sectors and disciplines in the life cycle is very crucial to enable new ways of data harmonization and use in any complex environment. Web-based system architecture was proposed in the study for a future 3D Land Administration System.

From the above studies, it is evident that land information management systems (LIMS) still function at different units especially where they are obtainable and no holistic and nationalistic view has been taken, especially in Nigeria. Most LIMS in place did not specify the actual information system adopted for its design but noted the importance of such systems in the land market.

More so, the human computer interaction perspectives of automation were not considered. This can be traced to the fact that most of the authors are not software specialists and/or land management experts. This review exposed the fact that specific activities that constitute the mandate of the Ministry of Lands have not been holistically covered in LIMS developed in Nigeria. The existing automations are only within specific units of the ministry and this explains the delay still experienced in completing documentations in the Ministry. Inter departments' or units' relationships in the Ministry have not been integrated in the systems; hence, undue time is wasted to link departments or units especially when there is a need for their professional opinions on the subject applications.

This review reveals that available land information management systems are yet to solve the problem of delay in land title registration process; obtaining real time information for effective physical planning and reliable decision making is not only important in Nigeria but also across the globe. Indeed there is a need to fill this existing gap through the development of a robust system that can integrate and run the activities for the Ministry. Such a system must be web based for global accessibility and use.

Conclusion and recommendations

Land management information system is a critical component of nation building. It is positioned to assist policy makers in making decisions that are evidenced based for effective physical planning and policy making. On the other hand, it also enables citizen's access land title information with ease. This review revealed that Nigeria is still far behind in this regard; some states of the federation have introduced a working automated land information management system in their relevant ministry, but delays in processing land title applications are predominant. Aside from delays in getting consents from the chief executive officer of the state or the designee, completing the documentation is still an issue that should be addressed with a functional system in place.

Additionally, land title registration procedure is still shrouded in secrecy in Nigeria and many citizens still lose their allotted plots due to the poor documentation system. Based on these findings, the study recommends the following:

i. Streamlining land management activities of the Ministry of Lands to serve as a benchmark for operations of the ministry in Nigeria.
ii. Integrating the activities of all the departments or units in the Ministry of Lands in their interrelatedness for easy automation as a process.
iii. Developing national land information management system which integrates the states' land management systems as answer to the quest for national land database.
iv. Training of all relevant officers on modern ICT skills to increase their dexterity in the prosecution of automated land management systems.

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Ireland successfully launches its first satellite into space

EIRSAT-1, a student-built satellite from University College Dublin, has been successfully launched into space, officially becoming Ireland's first-ever satellite.

The miniature cube satellite, or cubesat, designed, built, and tested at UCD under guidance of the European Space Agency (ESA), took flight at the Vandenberg Space Force Base in California aboard a Falcon 9 SpaceX rocket Friday evening (IST), 1st December. *www.ucd.ie*

Collaboration on Sustainable Lunar Economy

ispace and Orbit Fab agreed to collaborate on in-space propellant harvesting and delivery for future missions to the Moon.

The partnership will leverage each company's unique and complementary capabilities to develop effective propellants and fuels from resources in space, such as water, ice, and lunar regolith or fine and rocky soils found on the surface of the Moon.

The MoU signed by both the companies sets the stage for a series of innovative demonstrations, including resource mapping and in-situ resource utilization (ISRU) missions aimed at drastically reducing the reliance on supplies from Earth. *www.orbitfab.com*

India and US to launch joint satellite for earth observation

India and the US will launch the joint microwave remote sensing satellite for Earth observation, named NASA-ISRO Synthetic Aperture Radar (NISAR) in the first quarter of next year.

NISAR is targeted for launch onboard India's GSLV. Data from NISAR will be highly suitable for studying the land ecosystems, deformation of solid earth, mountain & polar cryosphere, sea ice and coastal oceans in regional to global scale. It was informed that ISRO's S-band SAR was integrated with NASA's L-band SAR at JPL/NASA and integrated L & S band SAR is currently undergoing testing with the satellite at URSC, Bangalore with participation of NASA/JPL officials. *https://pib.gov.in*

NASA helps study one of the world's most diverse ecosystems

NASA satellite and airborne tools aid an international team studying biodiversity on land and in the water around South Africa.

An international team of researchers spent October and November 2023 in the field studying one of the world's most biologically diverse areas – South Africa's Greater Cape Floristic Region. As part of the effort, researchers used NASA airborne and space-based instruments to gather complementary data to better understand the unique aquatic and terrestrial ecosystems in this region. Their findings will inform the capabilities of future satellite missions aimed at studying plants and animals.

Known as the Biodiversity Survey of the Cape (BioSCape), the effort is a large collaboration led in the U.S. by NASA, the University at Buffalo in New York, and the University of California, Merced. It is led in South Africa by the University of Cape Town and the South African Environmental Observation Network. *www.jpl.nasa.gov*

China launches Egypt's remote-sensing satellite

China helped Egypt send a remote-sensing satellite into orbit from the Jiuquan Satellite Launch Center in northwestern China. The satellite MISRSAT-2 was launched on 4th Dec'23 using a Long March-2C carrier rocket. Its purpose is to contribute to various applications in Egypt, including land and resource utilization, water conservancy, and agriculture. *www.aa.com.tr*

Geospatial AI to address climate change

IBM has released its latest geospatial artificial intelligence (AI) initiative to address climate change. These efforts involve collaborations across various regions and uses advanced AI models designed for geospatial applications.

Central to these initiatives is IBM's geospatial foundation model, developed jointly with NASA. These models aim to generate environmental insights and solutions related to climate change. These use a vast amount of climate-relevant data to accelerate the analysis of various environmental aspects that are affected by climate change.

IBM and the Mohamed Bin Zayed University of Artificial Intelligence (MBZUAI) have partnered to map urban heat islands in Abu Dhabi using a fine-tuned version of IBM's geospatial foundation model. The goal of the project is to understand the impact of local landscapes on temperature anomalies. The initial results show a decrease in heat island effects, which can provide valuable insights for future urban design strategies.

IBM and NASA have partnered to develop an AI foundation model dedicated to weather and climate applications. The collaboration aims to enhance the accuracy and speed of weather forecasting, predict wildfire conditions and understand meteorological phenomena. *https://newsroom.ibm.com*

Climate change threatens Australia's low-lying coral reef islands

University of Sydney researchers have found 25 percent of Australia's coral islands, land masses formed by reefs, currently face high to very high risk of being wiped out by climate change.

The findings, published in the latest edition of the journal Science of the Total Environment, identified that all of the 56 investigated Australian coral islands are exposed to some degree of climate risk but that three small, unvegetated coral islands in Western Australia, on Scott, Clerke and Imperieuse reefs, are the most vulnerable

The research introduces an innovative method to evaluate and categorise coral reef islands based on their risk from and resilience to climate change.

The risk system, built using open-access ocean climate data and satellite imagery that could be applied globally, provides decision-makers with a tool to prioritise protection efforts for vulnerable coral islands in the era of rapid climate change. *www.sydney.edu.au*

Commission welcomes Political Agreement on AI Act

The European Commission welcomes the political agreement reached between the European Parliament and the Council on the Artificial Intelligence Act (AI Act), proposed by the Commission in April 2021.

Ursula von der Leyen, President of the European Commission, said, Artificial intelligence is already changing our everyday lives. And this is just the beginning. Used wisely and widely, AI promises huge benefits to our economy and society. Therefore, I very much welcome today's political agreement by the European parliament and the council on the Artificial Intelligence Act.

"The EU's AI act is the first-ever comprehensive legal framework on artificial intelligence worldwide. So, this is a historic moment. The AI Act transposes European values to a new era. By focusing regulation on identifiable risks, today's agreement will foster responsible innovation in Europe," Ursula emphasized.

"By guaranteeing the safety and fundamental rights of people and businesses, it will support the development, deployment, and take-up of trustworthy AI in the EU. Our AI act will make a substantial contribution to the development of global rules and principles for human-centric AI," she added. *https://ec.europa.eu*

NASA, partners launch US Greenhouse Gas Centre

NASA Administrator Bill Nelson, U.S. Environmental Protection Agency (EPA) Administrator Michael Regan, and other United States government leaders unveiled the U.S. Greenhouse Gas Center recently held 28th annual United Nations Climate Conference (COP28).

The U.S. Greenhouse Gas Centre will serve as a hub for collaboration between agencies across the U.S. government as well as non-profit and private sector partners. Data, information, and computer models from observations from the International Space Station, various satellite and airborne missions, and ground stations are available online.

As the lead implementing agency of the center, NASA partnered with the EPA, National Institute of Standards and Technology, and National Oceanic and Atmospheric Administration. Science experts from each of these U.S. federal agencies curated this catalog of greenhouse gas datasets and analysis tools.

The centre's data catalog includes a curated collection of data sets that provide insights into greenhouse gas sources, sinks, emissions, and fluxes. *www.nasa.gov*

Union Bank of India and Accenture to accelerate data-driven transformation

Union Bank of India is collaborating with Accenture to design and develop a scalable and secure enterprise data lake platform with advanced analytics and reporting capabilities.

Using predictive analytics, machine learning and artificial intelligence, this platform will leverage structured and unstructured data from within the bank as well as from external sources to generate business-relevant insights. *accenture.com*

NavIC L1 signal tracking now operational on JAVAD GNSS latest receivers

JAVAD GNSS announced that its latest receivers are successfully tracking the NavIC L1 signal broadcast from the first of its second-generation navigation satellites, launched May 29, 2023. As additional satellites with L1 frequency (1575.42 MHz) capability are launched, JAVAD will include their measurements into the navigation solution through firmware updates. The NavIC L1 capability is available on all TRIUMPH-2 ASIC and TRIUMPH-3 ASIC-based receivers, ensuring seamless availability for customers through firmware. *www.Javad.com*

Qualcomm support India's NavIC

Qualcomm Technologies, Inc, in collaboration with the Indian Space Research Organisation (ISRO), has announced support for the new and recently launched L1 signals of India's navigation satellite system NavIC (Navigation with Indian Constellation) in select chipset platforms. Qualcomm Location Suite now supports up to seven satellite constellations concurrently, including the use of all of NavIC's L1 and L5 signals for more accurate location performance, faster time-to-first-fix (TTFF) position acquisition, and further improved robustness of location-based services. *www.qualcomm.com*

Airbus starts Galileo second generation satellite production

Full production has begun on the six Galileo Second Generation (G2) satellites at Airbus' site in Friedrichshafen, Germany, with the arrival of the first satellite Flight Model structure from Beyond Gravity in Zurich. After initial preparation the panels will be dispatched to other Airbus sites before final integration and testing at Friedrichshafen. The Galileo G2 satellites are scheduled for launch in the coming years to support the initial deployment and validation of the G2 System. *www.airbus.com*

GNSS menace: DGCA unveils action plan for Indian airlines

India's Civil aviation regulator the Directorate General of Civil Aviation (DGCA), recently issued an advisory to Indian airlines about interference with the Global Navigation Satellite System (GNSS) in airspace.

This circular comes amid uncertainties due to emerging threats of GNSS jamming and spoofing. It delivers clear guidance to all stakeholders, presenting a roadmap and action plan to tackle the menace of GNSS interference in airspace effectively.

Besides, it highlights growing threats, and identifies specific geographical areas where the incidents have been observed and outlines their potential impact on both aircraft and ground-based systems. Considering the increasing instances of GNSS interference over airspace in the Middle East in the recent past, DGCA had formed an internal panel on 4th October to take stock of the situation, sensitize operators, and start discussions with experts. The circular is based on the panel's recommendations and International Civil Aviation Organisation's guidance on it.

The circular is applicable to all Aircraft operators and Air navigation service provider (ANSP) Airports Authority of India. It establishes roles and responsibilities of each stakeholder in monitoring and mitigating the threat in a coordinated manner in addition to highlighting the reporting obligations as per regulatory requirements.

Furthermore, the circular provides comprehensive mitigation measures and action plan for aircraft operators, pilots, ANSP and air traffic controllers which includes development of contingency procedures in coordination with equipment manufacturers, and assessing operational risk by conducting a safety risk assessment.

It also provides for a mechanism for ANSP to establish a threat monitoring and Analysis network in close coordination with DGCA for preventive as well as reactive threat monitoring and analysis of reports of GNSS interference to generate valuable insights with data and new developments so as to have a robust and immediate threat response. *https://Livemint.com*

EASA updates SIB on GNSS Outage and Alterations

The European Union Aviation Safety Agency (EASA) has updated the Safety Information Bulletin (SIB) on Global Navigation Satellite System (GNSS) Outage and Alterations Leading to Navigation / Surveillance Degradation. SIB 2022-02 was first published on March 17, 2022 and then updated to Revision 1 (R1) on February 17, 2023. Revision 2 has been published on November 6, 2023 on the EASA SIB Tool. This follows EASA analysis of recent data from the Network of Analysts and open sources that has concluded that GNSS jamming and/or spoofing has shown further increase in the severity of its impact, as well as an overall growth of intensity and sophistication of these events.

This revision provides the following updated information:

- Examples of symptoms of suspected GNSS spoofing for aircraft <no change>.
- The list of the most affected flight information regions (FIR) <no change>.
- . Examples of issues that a degradation of GNSS signal (including Satellite Based Augmentation Systems (SBAS) and Ground Based Augmentation Systems (GBAS)) could generate with the addition of references to Terrain Avoidance and Warning Systems (TAWS).
- Revised recommendations for civil aviation authorities (CAAs), air traffic management/ air navigation services (ATM/ANS) providers and air operators (including helicopter operators – with specific information on both jamming and spoofing that flight crews and relevant flight operations personnel should be aware of). New for this revision are also recommendations for aircraft and equipment manufacturers.

RIEGL launches three airborne survey systems

RIEGL has released three airborne survey products, which are are designed to enhance sensor performances and capabilities in various segments, from terrestrial, to mobile and airborne applications.

The VQX-2 helicopter pod is designed for airborne data collection. It integrates a RIEGL laser scanner, a high-performance IMU/GNSS unit, and up to five cameras. It also can be easily mounted and dismounted onto UAVs.

The VQ-680 compact airborne lidar scanner OEM is designed to be integrated with large-format cameras or other sensors in complex hybrid system solutions.

The VUX-180-24 offers a wide field of view of 75º and a high pulse repetition rate of up to 2.4 MHz. These features – in combination with an increased scan speed of up to 800 lines per second – make it suitable for high-speed surveying missions and applications where an optimal line and point distribution is required. *www.riegl.com*

Furuno introduces dual-band GNSS receiver chip

Furuno Electric Co. has released its dual-band GNSS receiver chip, eRideOPUS 9, which can achieve 50cm position accuracy without correction data.

The product is designed to provide absolute position information and can be used as a reference for lane identification, which is essential for services such as autonomous driving. It also serves as a reference for determining the final self-position through cameras, lidar and HD maps. *www.furuno.com*

Inertial Labs receives SBIR Phase III contract

Inertial Labs has been awarded an SBIR Phase III contract by the Army Applications Laboratory of Army Futures Command. It supports Inertial Labs development, design, and fabrication of the Cannon

Artillery Pointing and Sighting System (CAPSS) for potential use on the US Army's Paladin and the Extended Range Cannon Artillery (ERCA) vehicles.

The CAPSS mission is to dramatically reduce weight on the target vehicle platforms by providing a digital replacement for the vehicle's current panoramic telescope (PANTEL). The CAPSS prototype is being designed to replace the PANTEL physically. This state-of-the-art CAPSS system amalgamates a collection of cameras, inertial measurement units (IMUs), advanced electronics, and an intuitive tablet-based user interface. *https://inertiallabs.com*

Point One Navigation launches real-time INS

Point One Navigation has introduced the Atlas inertial navigation system (INS) designed for autonomous vehicles, mapping and other applications. It can provide users with ground-truth level accuracy in real-time, which can streamline engineering workflows, significantly reduce project costs and improve operational efficiency. *https://pointonenav.com*

Enhancing GPS technology on Eurofighter

BAE Systems Digital GPS Anti-jam Receiver (DIGARTM) has been selected to continue into the next phase of the Phase 4 Enhancements (P4E) capability program on the Eurofighter Typhoon aircraft. DIGAR will boost the protection of the aircraft from GPS signal jamming, spoofing, and Radio Frequency (RF) interference, so that pilots can execute their missions in the most heavily contested RF environments.

DIGAR uses advanced antenna electronics, high-performance signal processing, and digital beamforming for significantly improved GPS signal reception and superior jamming immunity. *www.baesystems.com*

CHC Navigation launches Apache 3 Pro

CHC Navigation has launched the Apache 3 Pro, an advanced compact hydrographic drone designed for autonomous bathymetric surveys in shallow waters. It has lightweight carbon fiber hull, IP67 rating, and semi-recessed motor. *https://chcnav.com*

ComNav introduces 3D laser scanning system

ComNav Technology has released the LS300 3D laser scanning measurement system. It utilizes SLAM technology, and advanced real time and mapping techniques. It operates autonomously, independent of GNSS positioning, which makes it ideal for harsh conditions in both indoor and outdoor environments. *www.comnavtech.com*

Enhancing NATO Navy's AUV Capabilities

L3Harris, Voyis and Wavefront collaborate to deliver advanced technology to enhance NATO Navy's autonomous underwater vehicles (AUV) capabilities. Its area of expertise is the development of AUVs for a variety of maritime applications. AUVs are designed to operate in harsh environments, including deep water and can be used for a range of missions, including search and rescue, surveillance, mine countermeasures and oceanography. *www.voyis.com*

Seamless cm-level accuracy via satellite and cellular

Trimble announced stream switching - a new feature allowing farmers to seamlessly stream Trimble CenterPoint® RTX, RangePoint RTX and ViewPoint RTX, over IP or satellite. Available for farmers using a NAV-900 or NAV-500™ receiver, this new feature delivers less down time and performance comparable to RTK without the complexity of base stations.

Given the importance of uptime in farming operations, this solution was designed to provide farmers with the optimal GNSS corrections stream, delivered via IP or satellite, depending on signal strength. In areas prone to satellite cutoffs due to elevation changes or canopy, the signal switches to the modem and stays on IP. For regions with bad cellular connection, the streaming automatically switches to satellite. *Trimble.com*

MARK YOUR CALENDAR

February 2024

Geo Week 2024
11 - 13 February
Denver, CO, USA
https://www.geo-week.com

MENA Geospatial Forum
14 - 15 February 2024
Dubai, UAE
https://menageospatialforum.com

March 2024

Geo Connect Asia
06 - 07 March 2024
Singapore
https://www.geoconnectasia.com

DGI 2024
11 - 13 March
Londone, UK
https://dgi.wbresearch.com

Munich Satellite Navigation Summit 2024
20 - 22 March
Munich, Germany
www.munich-satellite-navigation-summit.org

April 2024

GISTAM 2024
02 - 04 May
Angers, France
https://gistam.scitevents.org

IGRSM Conference 2024
29 - 30 April
Kuala Lumpur, Malaysia
https://conference.igrsm.org

May 2024

FIG Working Week 2024
19 - 24 May
Accra, Ghana
www.fig.net/fig2024/Welcome.htm

June 2024

GEO Business 2024
05 - 06 June
London, UK
https://www.geobusinessshow.com

July 2024

Esri User Conference
15 - 19 July 2024
San Diego, CA, USA
www.esri.com

August 2024

International Geographical Congress 2024
24 - 30 August
Dublin, Ireland
https://igc2024dublin.org