

## Application of high spatial and temporal resolution remote sensing data to map cropping practices in Merguellil plain (Sentinel-2/VEN $\mu$ S synergy)

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**Keywords:** Spectral harmonization, Sentinel-2, VEN $\mu$ S, Intercropping, Tillage.

multi-sensor remote sensing applications is continually rising, driven by the increasing availability of free earth observation data, enhanced computing power, and the development of more complex algorithms that require temporally dense data. The spectral harmonization approaches (transformation of one pseudo sensor data) enhance the temporal resolution, bridge data gaps, and thereby elevate the quality of land cover monitoring applications.

In this work we compare the potentiality of raw and harmonizing Sentinel-2/VEN $\mu$ S, to identify tillage and crop intercropping practices in the case of Merguellil Plain, center Tunisia. We compared the feasibility of the derived spectral indices of Sentinel-2, VEN $\mu$ S and the harmonized products VEN $\mu$ S / Sentinel-2 product, to detect intercropping: the Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Enhanced Vegetation Index (EVI), Modified Normalized Difference Water Index (MNDWI), Soil-Adjusted Vegetation Index (SAVI), and Plant Senescence Reflectance Index (PSRI).

The harmonized NDVI + PSRI provided the best classification precision, with a Kappa of 82.3 % for winter crops (Six intercropping crops were identified, mainly based on cereals and vegetable intercropping) and 76.7 % for summer crops (4 intercropping crops were identified, mainly based on cucurbits and piment intercropping).

The harmonized NDVI and Brightness Index (BI) combination allows the best identification of tillage periods. Eight tillage period were identified in winter and summer 2023. Tilled soils are more frequent in March, April, and May than in June and July.

The integration of multispectral and multi-temporal remote sensing data, coupled with ground-truth observations, facilitated the robust classification of land cover types, including the detection of tillage and intercropping practices. and data fusion techniques to map and monitor cropping practices at a regional scale. The findings can contribute to the development of decision support systems for agricultural management and the promotion of sustainable cropping practices in the Kairouan region and beyond.

# A Hybrid Approach to Groundwater Level Forecasting: Integrating Earth Observation and Machine Learning in the Medjerda Basin (Tunisia)

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**Keywords:** Groundwater level, forecasting, EO data, Machine learning, Tunisia

Groundwater is a critical resource in Tunisia, particularly in the water-scarce Lower Valley of Medjerda basin. Accurate groundwater level predictions are essential for sustainable water resource management. This study demonstrates the effectiveness of combining Earth observation (EO) data and machine learning techniques to address the challenges of groundwater forecasting in data-scarce regions. A comprehensive dataset was assembled, integrating EO data from GRACE, GLEAM, GLDAS, and CRU with in-situ measurements. Four machine learning models—Random Forest, XGBoost, Support Vector Regression, and Long Short-Term Memory—were evaluated for their predictive performance. The results consistently indicated a declining groundwater level trend, highlighting the urgent need for effective water management interventions. Random Forest and XGBoost consistently outperformed SVR and LSTM, demonstrating superior accuracy and robustness in predicting groundwater levels. Uncertainty analysis revealed the significance of Total Water Storage (TWS) as a key driver of groundwater levels, emphasizing the importance of considering this factor in future predictions. Additionally, the study highlighted the synergy between EO data and machine learning in enhancing the accuracy and reliability of groundwater level forecasting. The findings of this study can be applied to other similar case studies in Tunisia and regions with similar hydrological conditions, providing a valuable framework for improving groundwater management practices and addressing water scarcity challenges.

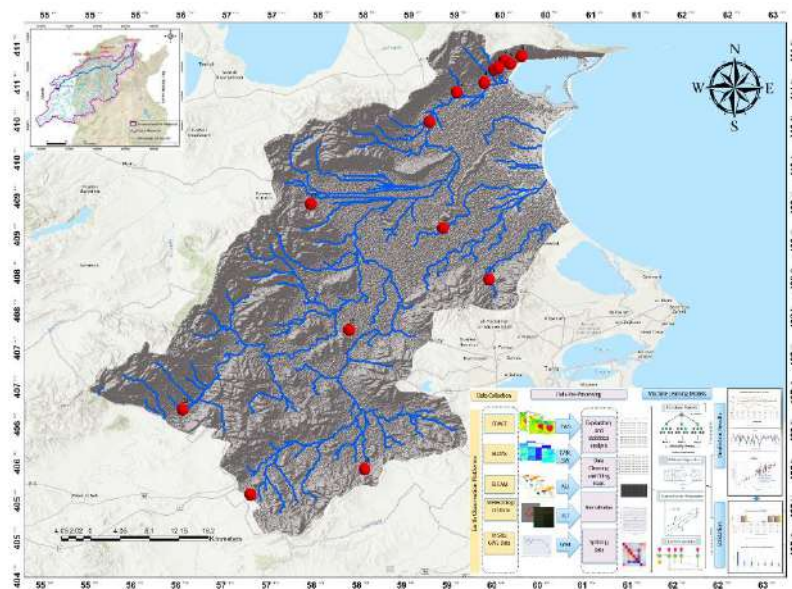


Figure 1. Location map of the Lower Valley of Medjerda and methodology flowchart

## Mapping and predicting land use change using remote sensing data: case study of Zaghouan

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**Keywords:** Land use, random forest, Markov chain, change detection, prediction

Land use change is an alteration of the Earth's surface caused by human activities. These changes are significant conversions of the Earth's surface and are important factors in environmental degradation in any landscape. Knowledge of past, current and future changes play an important role in developing decision-making. Monitoring this phenomenon can help to highlight the causes of these changes, the problems they cause and possible solutions. Earth observations, particularly when based on satellite technology, represent a valuable aid in this approach.

In this context, the aim of this study is to monitor and analyze land cover changes in the governorate of Zaghouan. the methodology used consists of analyzing the spatio-temporal variations in land cover between 1997 and 2022, using the Random Forest algorithm for classification and the Markov chain with cellular automata for predicting land cover maps until 2060. The results reveal a significant shift in land cover within Zaghouan, with a major change being the progressive transition from cereal crops to olive trees. Cereals, representing 80% of the area in 1997, decreased to 45% in 2022. The results also showed that the Olives and Field Crops classes underwent the most significant changes. This phenomenon can be attributed to various factors, such as agricultural practices, rural development strategies, and climate change. These data provide valuable insights into the distribution of different land cover classes over time, enhancing the understanding of spatial and temporal dynamics in the region. They also offer essential perspectives for land planning, natural resource management, and environmental preservation.

# Classification of Time Series Sentinel-1 Images Using Convolutional Neural Networks

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**Keywords:** Moisture, CNN, RF, Sentinels data, Classification.

Accurate classification of the satellite data relates on a key role in monitoring soil conditions, with wide-reaching applications in agriculture and management of the environment. Our study provides original soil moisture analysis for a semi arid region of Tunisia based on Sentinel-1 satellite images (TSD\_Sentinel-1) and specific trained Convolution Neural Network (CNN) classifiers which are developed and used for Time Series Sentinel-1 Data classification. The built learning database was controlled by Sentinel-2 data and the ground truth data, in order to enhance the classification accuracy and precision.

The study area is located at Kairouan province, Center of Tunisia, in the eastern part of the Tunisian Atlas between 9°30'E and 10°15'E and 35°N and 35°45'N. Measurements were performed during the 2019 campaign. In this area, different soil occupations, cultivation systems and crops are used, including cereals, fruit crops, olive trees, bare soil, fallow land, vegetables, urban areas and dams. Sentinel-1 and Sentinel-2 images were obtained from the Copernicus platform from June to October 2019. The TSD\_Sentinel-1s were pre-processed using the ESA's SNAP software. Data were treated following different steps such as terrain correction, denoising and radiometric calibration. Then, the data was segmented under the QGIS platform using the GPS specific terrain reference data. Statistical analysis was carried out with the tool R. Sentinel-1 (VH polarization) and Sentinel-2-NDVI images were used to develop sampling hypotheses for the datasets used for the training step and the testing step of the CNN, taking into account the surface soil moisture and biomass changes. The CNN classifiers were implemented under the MATLAB R2017a platform and the cross-validation method was applied to evaluate the robustness of the CNN, selecting models that minimized loss and maximized accuracy.

The best results are achieved by the CNN model with the following performances: Elapsed learning time= 503 seconds, precision =99.36%, loss=6.76%. In the training step, the CNN is parameterized by 9x9 sampling windows for the digital dataset, 15.000 samples (with data augmentation, 2/3 for training and 1/3 for testing the CNN), 5 classes, 50 filters (size 5x5), Maxpooling (window size = 4, Stride=2), Activation function='gradient descent with momentum', Learning rate=0.005, number of fully connected layers=1, Epoches=30, iterations=50. The CNN classifier showed high performance in handling data complexity (moisture, biodiversity and biomass) compared to the Random Forest (RF) approach which was applied to Sentinel-2 data.

## Identification of flood-vulnerable areas in the Nabeul region by optical and radar remote sensing

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**Keywords:** Flood, remote sensing, Sentinel-1 and 2, Landsat 8, vulnerable areas

The historic flood in Nabeul on September 22, 2018 represented a major event for Tunisia, highlighting the need to effectively manage flood risk. This event has raised particular interest in the study of flood-vulnerable areas in Nabeul, using modern approaches such as optical and radar remote sensing. The main objective of this study is to exploit high spatial resolution remote sensing data for a characterization of flood-vulnerable areas. To meet this objective, 3 approaches have been developed: (1) The first approach is based on land cover change detection before and after the event using Sentinel-2 images to identify urban and peri-urban areas at highest risk through spatial analysis. (2) Using radar images from the Sentinel-1 sensor, the second approach aims to delineate flooded areas by analyzing radar signal variations before and after the event. (3) To assess flood risk in the area of interest, the third approach tests two satellite products: one using Landsat 8 sensor images and the other using Sentinel-2 images, to evaluate flood risk in the area of interest.

The results of the first approach revealed significant changes in urban areas after the flood, marked by accumulation of mud and sediment. Before the event, urban areas covered 1228.38 hectares, but this decreased to 1114.28 hectares after the flood, indicating a reduction due to the effects of water and deposited materials. Bare soils decreased significantly suggesting that these areas were submerged or transformed by vegetation. The water surface increased from 50 hectares to 78 hectares, reflecting the accumulation of water. The variations within the different land cover classes highlight the environmental transformations that occurred following the flood event. The second approach based on the use of Sentinel-1 sensor data to detect flooded areas, revealing a total area of 1924 hectares mainly affecting urban areas and agricultural land. This approach allowed to precisely quantify the extent of flooded areas and their spatial distribution. The results of the third approach highlighted notable differences in the areas of risk areas, with better visualization by Sentinel-2. This approach highlighted the need for an accurate assessment for effective natural hazard management.



## **Synergy between optical and microwave satellite data to identify agricultural vegetation parameters and soil humidity in arid zones in Tuscany (Italy)**

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**Keywords:** satellite indexes, PRI, Sorghum, plant water content, Water Cloud Model

Climate change and extreme events such as floods and drought are increasingly affecting agricultural productivity, especially in fragile areas such as the semi-arid and arid zones of the Mediterranean basin. A frequent and accurate monitoring of crop parameters such as soil moisture and vegetation health is therefore essential to ensure food security, to support the water management and to optimize the agricultural practices. Our research aims at identifying methods capable to exploit the synergy between microwave (Sentinel-1, S-1) and optical (Sentinel-2, S-2) satellite data for the soil and vegetation status monitoring.

The goal of this research consists of an in-depth investigation of the complex interactions between soil and vegetation, by exploiting the multi-sensor synergy to provide valuable insights that approaches based on a single sensor might overlook or fail to evaluate.

Field data (vegetation leaves, Photochemical Reflectance Index – PRI, surface roughness, vegetation and soil water content and biomass) have been collected during summer seasons in 2022 and 2023 in two sorghum fields in Tuscany and electromagnetic models have been used to relate satellite derived indexes to plant conditions.

The analysis of the integrated datasets has shown that the S-1 derived Plant Water Content - PWC and the field collected PRI are well correlated each other, especially when the vegetation is well-developed, by showing how plants react to possible stress environment conditions. Time series analysis revealed a correlation between PWC variations and the xanthophyll cycle, directly connected to plants photosynthetic activities, confirming that consistent variations in PRI may correspond to changes in plant water content.

Similarly, a good correlation has been found between in-situ PRI measurements and S-2 derived indices, as the Normalized Difference Red Edge Index (NDRE), the Red Green Ratio (RGR), the Plant Senescence Reflectance Index (PSRI) and the Structure Insensitive Pigment Index (SIPI).

The findings of this study highlighted the possibility of monitoring the vegetation stress from space, with the enormous advantages of improving significantly the spatial and temporal coverage and reducing dramatically the costs with respect to carrying out experimental campaigns to collect in-situ PRI measurements.

## Early Estimation and Spatial Modeling of Cereal Yields and Water Productivity in Semi-Arid Region Using Machine Learning and Satellite-Based Drought Indices

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**Keywords:** Early Yield Prediction, Machine Learning, Cereal Water Productivity, Drought.

In response to increasing drought events due to climate change, early yield prediction models are crucial to improve crop resilience and optimize water resource management. This study develops an early yield prediction model for cereals (wheat and barley), incorporating drought indices, and assesses water productivity in Kairouan, Tunisia.

Using machine learning models, Random Forest (RF) and Support Vector Machine (SVM), along with monthly remote sensing-based drought indices (Soil Moisture Anomaly Index (SMAI), Vegetation Anomaly Index (VAI), Evapotranspiration Anomaly Index (EAI), and Inverse Temperature Anomaly Index (ITAI)), and cereal yield data from 2010/2011 to 2021/2022, an early cereal yield prediction models were developed for different periods, based on historical yield data over eight agricultural seasons. The most effective early prediction model was applied to spatially predict yields at the plot level. Then, WaPOR evapotranspiration data combined with yield results were used for spatial assessment of cereal water productivity.

Testing several spatiotemporal models at the plot level showed that the RF model combined with all drought indices until March, three months before harvest, gave the greatest early results with  $R^2=0.82$  and  $RMSE=0.6$  ton/hectare. The results highlight the strength of using RF with drought indices to early predict cereal yields, compared to SVM model. Key drought indices, SMAI and VAI, showed critical importance for yield prediction during germination and early tillering, emphasizing water availability's importance during these growth stages. However, spatial analysis of cereal water productivity showed a decline ( $<1.2$  kg/m<sup>3</sup>), mostly linked to over-irrigation and groundwater overexploitation. These low water productivity was notable in 2013/2014 and 2018/2019, severe drought years, revealing low yields despite excessive irrigation, lowering then water use efficiency.

The calibrated model demonstrates the potential of the RF model for accurate yield prediction by incorporating drought indices, supporting the adoption of effective irrigation strategies adapted to critical growth stages. These findings underscore the possibility of improved irrigation strategies in order to increase water productivity and overcome water scarcity challenges.

# Water Loss Detection and Mapping System

## Using Deep Learning and Big Data

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This study therefore poses that water being a scarce necessity is more relevant to management since loss occurs. In the past, water loss was usually identified by simple observation and checkups and basic monitoring mechanisms were not very efficient.

This project provides an enhanced system that is built with deep learning and big data engine in conjunction with data from a number of sensors to identify, locate and map the water leakage. The system focuses on two key types of water loss: pipeline leaks and surface area losses.

For pipeline detection, smart metering and sensors obtain large consumption data about the water distribution pipeline which will be passed through Long Short-Term Memory (LSTM) networks to detect deviations which suggest pipeline leakage. The nature of consuming groceries makes LSTM work well in identifying anomalies from normal usage rates thus useful in the tracking of usage patterns. To estimate surface water loss, the system relies on the information from remote sensing and drones and processes them with the help of the Vision Transformer (ViT) model.

These models then are able to differentiate between changes in water distribution and existence across large extent through the use of current and past images. Further, the system incorporates mapping and localization to accurately quantify the geographical locations of water loss and offers solutions for early mitigation. The assessment of the system will involve the generation of several pipeline leak and surface water loss scenarios, with overall detection rate, response time and localization accuracy as the parameters of assessment. The expected outcomes include: Highly accurate and timely assessment of water loss, as well as the map of water loss for proper response that is more effective than conventional kinds of detection.

Further studies will use the actual implementation and enhance the functionality to serve diverse issues in water management.

**Keywords:** Remote sensing, water loss, pipeline leak, Deep Learning, Big Data, Multiple sensors.

# UAV-Satellite data integration for forestry

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## Conference Theme: Space Applications and Utilization

### Abstract:

Notably, the data characteristics of remote sensing vary significantly between UAVs and satellites. UAV remote sensing systems typically cover smaller areas enabling operations below clouds. This allows for higher spatial accuracy in data collection and facilitates easier extraction of valuable information. On the other hand, satellites are equipped with more sophisticated sensors, and covers wide areas providing a wealth of information. To reap the benefits of both, this abstract proposes two integration approaches.

The first approach is Analysis Fusion, where each data source is processed and analyzed independently, and the results are then combined to make a final inference. In this case, the combination of information from different sources occurs at the result level, considering each modality separately. A noteworthy use case in forestry involves using UAV LiDAR data to extract height, coverage, and other structural variables, while satellite multispectral data is used to extract spectral indices. These variables can then be fed into supervised artificial intelligence models to estimate timber volume.

The second approach is Data Fusion, where a new dataset is generated by combining different sources to synthesize a new modality. For example, combining high-resolution UAV RGB imagery with satellite multispectral data to achieve spatial-spectral fusion. These fused images provide superior classification accuracy for recognizing tree types in a forest compared to using each data source independently.

In conclusion, the choice between the two approaches will depend on the available data and the objective.

**Keywords:** Forestry, UAV-satellite integration, analysis fusion, Data fusion

# **Satellite Observation of Coastal Changes in Tunisia: Addressing Sustainable Development Challenges and Marine Biodiversity**

## **Coastal Protection and Planning Agency (APAL)**

**Keywords:** Coastal zones, satellite observation, climate change, sea-level rise, invasive species, sustainable development, marine biodiversity

The Coastal Protection and Planning Agency (APAL), a public institution committed to safeguarding and promoting the sustainable development of Tunisia's coastal areas, harnesses advanced satellite technologies to effectively monitor and manage environmental changes. In emerging countries like Tunisia, where data scarcity and governance challenges often impede environmental management, satellite-based Earth observations are indispensable tools for identifying, assessing, and addressing the multifaceted challenges confronting coastal zones.

This paper demonstrates how APAL utilizes comprehensive satellite imagery analysis to detect alterations in coastal ecosystems, monitor the impacts of sea-level rise, and identify environmental hotspots requiring urgent attention. Tunisia's coastal zones, rich in biodiversity and ecological significance, are increasingly vulnerable to anthropogenic pressures and the accelerating effects of climate change. Satellite data projections indicate sea-level rises of approximately 0.5 meters by 2050 and up to 1 meter by 2100, with extreme scenarios anticipating increases up to 3 meters, posing significant risks to coastal communities and ecosystems.

By integrating satellite tools into sustainable coastal management strategies, APAL's initiatives align closely with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action) and SDG 14 (Life Below Water). This paper explores the methodologies employed by APAL to monitor environmental changes and discusses the significant impacts of climate change—including rising Mediterranean sea temperatures and the proliferation of invasive species—on Tunisia's marine biodiversity.

Leveraging data from the Copernicus Marine Environment Monitoring Service (CMEMS) and insights from the World Bank's Coastal Resilience Report, APAL illustrates how space-based monitoring can bridge critical knowledge gaps, enhance environmental assessments, and inform effective policy development. By synergizing advanced satellite technologies with robust public governance frameworks, APAL not only strengthens the resilience of Tunisia's coastal zones but also advances the broader sustainable development agenda, setting a precedent for similar initiatives in other emerging nations.

# **Bridging gaps in the provision of high accuracy positioning services on the African Continent with Galileo High Accuracy Service (HAS)**

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**Keywords:** GNSS, GALILEO, PPP, SDG, HAS, AUC

Sustainable Development Goals (SDGs) are a part of global development as they providing a detailed plan for dealing with issues like hunger, poverty, and inequality as well as climate change. Although these objectives are universal, developing countries, where sustainable development is most urgently needed, will benefit greatly from their accomplishment. Access to basic infrastructure services remains a concern in many countries on the African continent.

**Among them, SDG 9 seeks to build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.** This SDG encompasses three important aspects of sustainable development: infrastructure, industrialization and innovation.

Space technologies enabling Earth observation (EO) and geolocation using Global Navigation Satellite Systems (GNSS) have continuously supported the implementation of SDGs. Geolocation and in particular, GNSS, is used to incorporate position information to data and provide location-based services to both humans and machines (e.g. drones or self-driving cars). Geolocation is central and ubiquitous in nature as its often employed in all modes of transport (road, aviation, maritime, etc.), fleet management, high-precision and consumer applications, provision of time information in critical national infrastructures, as well as scientific applications such as measuring the impact of **space weather on the Earth**, of **earthquakes** and **climate change** on human communities, among others.

In large regions of Africa, challenges in the provision of precise positioning services to support critical applications that address the various SDGs exist, with most solutions predominantly limited to the use of Precise Point Positioning (PPP) and Real-time kinematic positioning (RTK) techniques.

From the study conducted by SATNAV Africa JPO for the African Union Commission (AUC) – “**SURVEY AND GAP ANALYSIS ON SATELLITE NAVIGATION AND POSITIONING INFRASTRUCTURE AND TECHNOLOGIES IN AFRICA**”, a number of deficiencies were observed in relation to provision of precise positioning services that are predominantly provided by sparsely distributed RTK networks in some regions of the continent and subscription based PPP services.

To address these gaps on the continent, the recently introduced GALILEO High accuracy services (HAS) can provide the precise point positioning services with guaranteed horizontal accuracy levels of up to 20cm within a convergence times of 300 secs. This paper provides outcomes of studies undertaken to assess the performance of GALILEO HAS on the African continent.

## Satellite electricity transmission from space to earth

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**Keywords:** 1 Solar satellites, wireless transmission, renewable energy, clean energy, sustainability

Solar satellites are designed to harness energy from the sun using expansive solar arrays. The energy collected depends on the solar panel size, their orbital location, and solar cell technology. These satellites convert sunlight into electricity, which is wirelessly transmitted to Earth.

This technology promises to provide clean, safe, renewable, and affordable energy reliably. Moreover, it offers a viable solution for global energy needs, delivering power to regions worldwide. This paper investigates the potential of solar satellites by examining technological advancements, economic feasibility, and environmental benefits.

Through this analysis, we aim to highlight their transformative potential in shaping future global energy systems. Our findings underscore the significant impact solar satellites could have on sustainable energy delivery, positioning them as a key player in future energy solutions.

This study focuses on the design and implementation of solar satellites, which are engineered to harness solar energy using expansive solar arrays. The efficiency of energy collection is influenced by the size of the solar panels, their orbital positions, and the advanced solar cell technologies employed. These satellites convert sunlight into electricity and transmit it wirelessly to receiving stations on Earth, promising a clean, safe, renewable, and reliable energy source.

Our research presents several key findings: firstly, we demonstrate that optimizing the orbital location and panel size can increase energy collection by up to 25% compared to current designs. Secondly, we introduce a novel solar cell technology that enhances conversion efficiency by 18%. Thirdly, we showcase an advanced wireless power transmission system that minimizes energy loss during transmission.

The contributions of this research are manifold. We provide a comprehensive analysis of the technological advancements in solar satellite design and their economic feasibility, showing that the deployment of solar satellites could be cost-competitive with traditional energy sources within a decade. Furthermore, we assess the environmental benefits, highlighting a potential reduction in global carbon emissions by 10% if widely adopted.

This paper underscores the transformative potential of solar satellites in shaping the future of global energy systems. Our findings indicate that solar satellites could play a significant role in sustainable energy delivery, addressing both energy security and environmental concerns. By providing a continuous and reliable energy supply, solar satellites are poised to become a crucial component of future energy solutions.

# Title: Space Quantum Gravimetry

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**Abstract :** Our article is based on the presentation of quantum gravimetry which is an emerging technique that uses quantum principles to measure variations in the gravitational field with high precision. Quantum gravimetry devices, especially those using cold atoms, can detect variations in gravity caused by masses or underground structures. We explore ; in the following, this concept both in space and on Earth.

First, note that quantum gravimetry on Earth is used for geophysical exploration that detects gravitational anomalies related to the composition and underground structures such as cavities, groundwater reservoirs and mining resources). Also for volcanic and seismic monitoring where we follow the evolution of the mass inside volcanoes to prevent eruptions or monitor tectonic movements. Hydrological studies that map changes in water tables and detect hidden water reservoirs, use quantum gravimetry. Finally, it can be of great help in the field of construction and engineering, it allows to control the stability of soils before large constructions such as bridges or tunnels.

However, the sensitivity of quantum sensors makes it possible to accurately measure very small variations in Earth's gravity, even due to seasonal phenomena such as water movements in oceans or glaciers.

For quantum gravimetry in space, it has promising applications for space exploration and scientific research such as firstly the mapping of planetary gravitational fields which studies gravitational variations on the Moon, Mars, and other celestial bodies and which can be mapped with increased precision, revealing their internal structure. Secondly comes the detection of gravitational waves using quantum sensors. We can still hope to detect gravitational perturbations caused by cosmic events such as the merger of black holes. Finally gravimetry can help explore exoplanets by characterizing their mass as well as their internal distribution.

Quantum sensors in space can provide more stable measurements, being out of the influence of environmental perturbations such as terrestrial vibrations.

At the end of this article we present the principles of quantum gravimetry, which is based on techniques such as atomic interferometry, where cold atoms (often rubidium or cesium atoms) are cooled and used as "matter waves" in gravitational fields. These waves behave similarly to light waves in an interferometer, allowing gravitational variations to be detected with extreme precision.

In summary, quantum gravimetry is a revolutionary technique with applications both on Earth and in space, enabling major advances in geophysics, environmental monitoring, and cosmic exploration.

## Low-cost thermal vacuum testing setup for CubeSats

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**Keywords:** CubeSat, Environmental Testing, Thermal vacuum testing.

This study is conducted within the framework of the FACT project, which is coordinated by the Center for Research on Microelectronics and Nanotechnology (CRMN) of Sousse and includes other academic and industrial partners. The FACT project aims to: (1) provide necessary training to academics, researchers, and students from Tunisian universities doing research on space technology, and (2) acquire and install required equipment for CubeSat integration and testing.

Among the equipment acquired during the FACT project is the environmental testing platform. In fact, environmental testing of CubeSats is crucial to ensure that they can survive the extreme space conditions during their missions. One of the most performed environmental tests that CubeSats are subjected to is the thermal vacuum testing where space environment is simulated in laboratory. During this test, the CubeSat is put in a high vacuum chamber where the internal temperature is changed between two extreme values in a cyclic manner. During the test, the CubeSat is switched on and is set to record internal housekeeping data. Analyzing this data allows to check that all the CubeSat subsystems remain working during the test and are not subjected to malfunctions.

In this context, the aim of the present study was to design and implement a low-cost thermal vacuum system that simulates space conditions at low-earth orbits (LEO). In fact, commercialized thermal vacuum systems are expensive compared to the project's budget. Furthermore, they require high maintenance and operational costs. The developed system is composed of three main parts: a vacuum chamber allowing testing CubeSats of up to 3 units in size, a pumping module incorporating the primary and the turbomolecular pumps in addition to the pump control electronics, and a chiller allowing temperature cycling by means of a tubed cold plate. The temperature control and measurement modules were made in-house.

Testing of the thermal vacuum platform designed and implemented during this work showed that it can reach high-vacuum with a pressure around  $10^{-6}$  mbar and a temperature ranging from -25C to more than 100C with a temperature variation profile set programmatically based on the required test. The results achieved with this platform are within the requirements of CubeSat environmental testing in LEO at third the price of the commercialized systems.

## Attitude Determination of a CubeSat Based on Multi-sensor Data Fusion

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**Keywords:** CubeSat, ADCS, Attitude determination, Data fusion.

The attitude of a satellite describes how this object is oriented in space. Since stability and precise pointing of the payloads and antennas are essential for the satellite's mission to succeed, controlling this attitude is crucial.

Controlling the attitude of the CubeSat requires precise knowledge of its orientation with respect to a frame of reference. The subsystem that performs this function is the Attitude Determination and Control System (ADCS).

Within the framework of the FACT project, which is led by the Center for Research on Microelectronics and Nanotechnology (CRMN) of Sousse and includes additional academic and industrial partners, the investigation and development of a full ADCS system for a CubeSat is being conducted. The FACT program intends to provide space technology training to academics and students from Tunisian universities.

The aim of the present study is to estimate the attitude of a CubeSat using MEMS sensors and data fusion algorithm. Its main objective is to find the most accurate and reliable approach for determining the CubeSat's attitude.

Different attitude estimation methods have been studied and some estimation algorithms were implemented and tested to determine the most reliable one.

As a first stage, a simulation phase has been conducted, using Python language, to study strengths and weakness of each algorithm. Then the chosen method, which is based on the Extended Kalman Filter, was tested on a real CubeSat prototype.

The study approach and the preliminary test results are presented in this paper.

## Miniaturized UHF Sierpinski Gasket microstrip patch antenna for CubeSat Communication

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**Keywords:** Sierpinski Gasket microstrip patch antenna, UHF communication, CubeSat, Long-range (LoRa), Internet of things (IoT)

The term Internet of things (IoT) is used to describe the connection of different objects to networks. These systems need a technology that uses less energy and has an extensive range. Long Range (LoRa) and LPWANs (Low Power Wide Area Networks) are becoming essential alternatives in the rapidly expanding IoT industry. LoRa requires the use of satellite networks in order to achieve global IoT coverage. The deployment of picosatellites such as CubeSats can provide a wide coverage area with a long communication range. Similar to traditional satellites, they are viable and robust yet cost less, use less power, and allow for quick development.

LoRa pose inherent challenges in Microstrip Patch Antennas, emphasizing critical aspects that necessitate attention, including the need for miniaturization and integration, advancements in substrate materials and fabrication techniques, and the imperative for reconfigurable and adaptive antennas.

In this work, the design of UHF Sierpinski gasket, also known as the Sierpinski triangle Fractal Antennas for LEO CubeSat communication operating at a 920 MHz frequency is presented. For the chosen operating frequency, the Sierpinski Carpet Fractal enables a  $\lambda/3$  reduction in antenna size. The structure of the suggested antenna is thin and compact in size. The S11 magnitude of the proposed design is -16.06 dB. Additionally, the simulation results demonstrate that the suggested Sierpinski Carpet Fractal antenna with a size of  $74*74*1.635$  mm<sup>3</sup> will have a maximum gain of 1.77 dB and an omnidirectional emission pattern.

## **The Atom: A Solution For The Fight Against Climate Change**

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**Keywords:** atom, nuclear energy, climate change

The atom is the smallest part of a simple body. It has a large nucleus capable of breaking in two when hit by a projectile. Nuclear energy is the binding energy of the constituents of the nucleus of atoms. Not only must it be safe, but it must also be used only for peaceful purposes. Unlike other forms of energy, nuclear energy was first used to make weapons. It was only later that non-destructive applications of this type of energy, such as civil nuclear power, came into being. This article highlights the non-destructive applications of the atom, focusing on aspects of climate change mitigation. A brief history of the atom has been given before presenting some of the initiatives already in place that use and promote nuclear energy to achieve climate goals. Some of the challenges in this area were presented before providing recommendations.

## **TUN'Sat1**

The Tunis Science City (CST) has the great privilege of regularly hosting conferences, workshops and interactive exhibitions, allowing the public to discover the latest advances in space exploration. The center also offers screenings of documentary films at the planetarium, guided tours of the Universe pavilion, conferences during astronomical evenings, training on cubic satellites, as well as summer schools dedicated to Space.

These initiatives aim to raise awareness and interest the general public in space exploration, while highlighting the scientific, technological and environmental issues of this human adventure.

Our participation will include two parts:

1. **\*\* CST activities in the field of Space and Astronomy\*\***: A brief presentation of the various activities of the Tunis Science City.
2. **\*\* TUN'Sat1\*\***: "TUN'Sat1" is the inaugural non-commercial educational satellite, designed to engage younger demographics with advanced and applied science and technology in the field of astronomy and space. This sector presents a unique opportunity to address a multitude of interrelated challenges, including scientific, technical, economic, and ethical considerations. TUN'Sat1 provides a platform for hands-on experience with design tools, enabling users to apply their knowledge to mission analysis and satellite operations.

## Space as a Global Commons to Attain the UN Agenda 2030: An African Perspective

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**Keywords:** Space Governance, Global Commons, Cooperation, SDGs, Africa

Africa faces distinct challenges in achieving the Sustainable Development Goals (SDGs) outlined in the UN 2030 Agenda, including poverty, climate change, and infrastructural gaps. The Space 2030 Agenda, recognized in UN resolution 76/3, underscores the critical role of space in sustainable development. Africa, with its growing space capabilities, can harness space technology to address these challenges, stressing the importance of equitable access to outer space as a Global Commons. Moreover, such a dream has been fuelled by the recent inclusion of the African Union in the G20, as it strengthens Africa's ability to advocate for its interests in global space governance, as well as in international financial stability, climate change mitigation, and sustainable development.

Thus, the author of this paper emphasizes on the strategic opportunity to integrate space governance into the broader G20 agenda, advocating for space as an essential element in discussions on sustainable development. Furthermore, it also proposes a governance model inspired by *Environmental Principles and Policies*, that could foster international partnerships and support for Africa's space ecosystem through knowledge sharing, technology transfer, and resource pooling between established spacefaring nations and Africa's emerging space entities. For a implementation viewpoint of the above model, the paper employs a comparative analysis of existing international collaborations and governance frameworks to identify best practices to achieve success of the afore-mentioned model.

Therefore, by aligning space activities with Africa's development goals, this framework would address the continent's specific challenges while contributing to global SDGs, and on how, space, as a Global Commons, can be leveraged for sustainable development, ensuring that the benefits of space are equitably shared across Africa as the continent ventures further into the cosmos.

## **SmartSDGTunisia: An AI and Remote Sensing Framework for Advancing Sustainable Development Goals in Tunisia**

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**Keywords:** Remote sensing,SDG, Tunisia, Data analysis, Machine learning

The SmartSDGTunisia framework uses AI and machine learning to advance the United Nations Sustainable Development Goals (SDGs) in Tunisia, specifically targeting SDGs 1 (No Poverty), 2 (Zero Hunger), 6 (Clean Water and Sanitation), 11 (Sustainable Cities and Communities), 13 (Climate Action), and 15 (Life on Land). The primary objective of SmartSDGTunisia is to generate and monitor key SDG indicators, providing both current assessments and predictive insights. By leveraging AI, the framework supports proactive decision-making crucial for sustainable development, addressing Tunisia's environmental and socio-economic challenges with actionable insights. The framework consists of three core components: data collection, data processing, and SDG-focused applications. Data collection sources information from various channels, including remote sensing technologies and socio-economic databases. During data processing, the information undergoes cleaning, normalization, and integration, with machine learning algorithms identifying patterns and generating insights. Long Short Term Memory (LSTM) was used to predict indices such as Normalized Difference Vegetation Index (NDVI) and the Standardized Precipitation Index (SPI). The developed applications are tailored to each SDG, offering valuable insights for policymakers, researchers, and stakeholders. In this paper, we primarily focus on SDG-15 and SDG-13. Therefore, we have started by collecting NDVI data from MYD13A2 for 16-days with 1-km spatial resolution between 2001 and 2019. The LSTM model is applied to predict NDVI and SPI values for December 2025. The model achieved a strong predictive performance, with RMSE values of 0.099 for NDVI and 0.78 for SPI, and accuracies of 0.87 and 0.79, respectively. These predictions are crucial for understanding environmental changes and supporting sustainable practices.

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# **Bridging Digital Divides: Addressing Regulatory Gaps in Satellite Internet Integration for Sustainable Development in Tunisia**

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**Keywords:** Satellite Internet Connectivity, Space Law, Starlink, Space Governance, Sustainable Development Goals (SDGs)

The deployment of satellite internet technologies, such as SpaceX's Starlink and Amazon's Kuiper projects, presents a transformative opportunity to address significant connectivity gaps across various sectors. These satellite systems are poised to enhance digital access in remote and underserved regions, potentially revolutionizing education, healthcare, economic development, and communication. By extending high-speed internet to areas lacking traditional infrastructure, satellite internet has the potential to significantly contribute to achieving several United Nations Sustainable Development Goals (SDGs).

This paper explores the implications of a recent pilot project involving Starlink in Tunisia, conducted from October to December across three cities: Tunis, Ariana, and Gabes. The experiment could be a key to potentially increasing connectivity and fostering user growth in these regions. However, the project also revealed substantial regulatory gaps that could impede the broader implementation of satellite internet services.

The paper employs a qualitative analysis approach, including a case study analysis of the Starlink pilot project, a comparative legal analysis of Tunisia's regulatory framework versus international best practices, and a policy analysis to evaluate the current policies related to satellite internet. Based on these analyses, the paper proposes a detailed legal framework to address the identified gaps, recommending clear licensing procedures, enhanced regulatory oversight, and robust data protection measures. By addressing these regulatory deficiencies, Tunisia can better support the integration of satellite internet technologies, which may facilitate an anticipated increase in internet users and advance the nation's broader development objectives