

Satellite Sensing in Climate Change: A Study

Kazi Kutubuddin S.L.^{1,*}, G.M. Kosgiker¹

Abstract

Satellite sensing has become an indispensable tool in the study of climate change, providing critical data that enhances our understanding of atmospheric, terrestrial, and oceanic processes. By employing advanced remote sensing technology, satellites facilitate the collection of extensive datasets on key climate indicators, such as temperature variations, greenhouse gas concentrations, and changes in land cover. This aerial perspective allows researchers to monitor large-scale environmental changes with unparalleled precision and consistency, enabling the identification of trends and patterns that might otherwise remain undetected. Moreover, satellite observations enable real-time monitoring of climate phenomena, such as hurricanes, droughts, and wildfires, offer valuable insights into their development and impact. The data generated from these observations are instrumental in validating climate models, which are essential for predicting future climate scenarios. By participating satellite data into climate research, scientists can improve accuracy of the predictions, assisting policymakers and stakeholders in making well-versed decisions for climate mitigation and adaptation strategies.

Keywords: Satellite, satellite sensing, climate change, sensors, monitoring environment

INTRODUCTION

Climate change is the most pressing challenge facing humanity today, and sensors play a pivotal role in studying its myriad effects on the environment. By deploying a network of advanced sensors throughout various ecosystems, researchers can collect real-time data on atmospheric conditions, soil moisture, temperature fluctuations, and even wildlife movements. These sensors help scientists monitor how climate change is impacting different biomes and inform mitigation strategies. For instance, sensors equipped with satellite technology can track changes in forest cover due to rising temperatures and shifting precipitation patterns, while ground-based sensors can provide detailed insights into how these changes affect local biodiversity [1–3].

Moreover, sensors are integral to understanding the feedback mechanisms associated with climate change. They can detect changes in greenhouse gas emissions from specific sources, such as urban areas or industrial sites, and allow for more accurate modeling of future emissions scenarios. For policymakers looking to create successful climate action strategies, this data is essential. In addition, integrating sensor data with machine learning algorithms can enhance our predictive capabilities, enabling scientists to anticipate potential climate impacts more accurately. The continual advancement

of sensor technology also means we can gather increasingly precise information, such as microclimate variations, which can have significant implications for agriculture, water management, and ecosystem health.

Collaboration between different disciplines is also key to maximizing the potential of sensor technologies in climate change studies. Environmental scientists, data analysts, and engineers must work together to design robust sensor networks and interpret the data they

*Author for Correspondence

Kazi Kutubuddin S.L.
E-mail: drkkazi@gmail.com

¹Professor, Department of Electronics and Telecommunication Engineering, Brahmdevdada Mane Institute of Technology, Solapur, Maharashtra, India

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generate. Novel applications are encouraged by this interdisciplinary approach, such as the deployment of drones with sensors to monitor vast and difficult-to-reach areas. By harnessing these technological advancements, we can improve our understanding of climate dynamics and enhance our capacity to develop adaptive strategies that protect both the planet and its inhabitants. In summary, the integration of sensors into climate change research not only fuels scientific inquiry but also equips us with the tools needed to combat this global crisis more effectively [4–7].

As the world grapples with the consequences of climate change, researchers are turning to innovative technologies to better understand our planet's complex systems. Among these technologies, sensors have emerged as a pivotal tool in climate change studies, allowing for real-time data collection and analysis that can inform mitigation strategies, policy decisions, and public awareness. This article explores how sensors are being utilized in climate research and the impact they are having on our understanding of environmental changes.

One of the biggest problems of our day is climate change, which has an impact on human existence, weather patterns, ecosystems, and sea levels. Traditional methods of data collection, such as periodic ground-based surveys and satellite imagery, while valuable, often lack the granularity and immediacy required to effectively monitor the rapid changes occurring in our environment. In this context, sensors—devices capable of detecting and measuring environmental variables—are revolutionizing the way researchers gather data.

Types of sensors and their applications:

1. *Atmospheric Sensors:* These devices measure air quality, greenhouse gas concentrations, and meteorological variables. Equipped with high-precision technology, they are deployed in various locations, from urban environments to remote wilderness areas, providing critical data to evaluate the effectiveness of air quality policies and track emissions.
2. *Soil Sensors:* Soil health is a crucial component in climate resilience, and sensors help monitor soil moisture, temperature, and nutrient levels. This information is vital for understanding agricultural productivity, assessing ecosystem health, and implementing effective land management practices.
3. *Ocean Sensors:* Monitoring ocean temperatures, salinity, and acidity is essential for understanding climate change's impact on marine ecosystems. Ocean buoys and underwater drones equipped with sensors enable researchers to study changes in ocean chemistry and biodiversity, helping to predict future ecological shifts.
4. *Ice and Snow Sensors:* As polar ice caps and glaciers recede, understanding the rate and causes of this melting is critical. Sensors installed on ice sheets and in snowy regions measure temperature fluctuations, snowpack depth, and melt rates, contributing valuable data to models predicting future sea level rise.

REAL-TIME MONITORING AND DATA INTEGRATION

The most important advantage of sensor technology is its ability to provide real-time data. Researchers can monitor changes as they occur thanks to this real-time data, which makes it easier to react quickly to new environmental risks. Networks of sensors, for example, can give early warnings of extreme weather events, allowing communities and governments to efficiently prepare and respond.

Moreover, sensor data can be integrated with advanced analytics and machine learning algorithms, enhancing predictive capabilities. By combining datasets from various types of sensors, researchers can create a comprehensive picture of climate dynamics, leading to more accurate models of future scenarios and the effectiveness of proposed interventions [8–12].

CITIZEN SCIENCE AND COMMUNITY ENGAGEMENT

The rise of affordable sensor technology has also empowered citizen scientists and local communities to contribute to climate research. Individuals can deploy sensors in their backyards to monitor local

environmental conditions, contributing valuable data to larger datasets. This grassroots approach not only increases data collection but also raises awareness about climate issues, inspiring collective action for sustainability.

Despite the potential of sensors in climate change research, challenges remain. Issues such as data quality, sensor calibration, and maintenance can impact the reliability of measurements. Additionally, the vast amounts of data generated necessitate robust data management systems and sophisticated analytical tools to derive meaningful insights.

Scientists are investigating how to combine sensor data with artificial intelligence (AI) and machine learning, which may improve the capacity to forecast climate consequences and patterns. Sensors are becoming more affordable as technology develops, opening the door for their broad use.

Sensors are becoming more and more important in climate research as climate change threatens to threaten our world. By providing real-time, high-resolution data, sensors are transforming our understanding of environmental changes and equipping policymakers, scientists, and communities with the information they need to combat this global challenge. In the fight against climate change, technology is not just a tool; it is an ally—one that can help us navigate the complexities of our changing world.

In an era where technological advancements proliferate daily, satellite sensing has emerged as a seminal tool for gathering vital information about our planet. This remarkable field combines cutting-edge technology, data analysis, and environmental science to provide vital insights into global phenomena ranging from climate change to urban development [13–17].

Fundamentally, satellite sensing is the process of gathering information about the Earth's surface and atmosphere using equipment installed on satellites. This data is gathered through a variety of electromagnetic spectrum wavelengths—visible light, infrared, and microwave—that provide unique insights into different features of the Earth.

There are primarily two types of satellite remote sensing: passive and active. Natural energy that bounces back or generated from the Earth, usually sunlight, is detected by passive sensors. Examples include optical and infrared sensors found on satellites like Landsat and MODIS (Moderate Resolution Imaging Spectroradiometer). Conversely, active sensors can determine the reflected signals because they release their own energy, typically in the form of laser or RADAR pulses. A key example is the synthetic aperture radar (SAR), utilized by satellites such as Sentinel-1.

The technological advancements in satellite sensing have been nothing short of revolutionary. Modern satellites are equipped with high-resolution cameras, multi-spectral sensors, and advanced algorithms that enable them to capture data with unparalleled accuracy. The deployment of small satellites, or CubeSats, has further democratized access to satellite data, allowing smaller organizations and even individual researchers to conduct their studies.

Additionally, the emergence of AI and machine learning in data analysis has transformed how satellite data is interpreted. These technologies enhance the ability to process vast amounts of data quickly, leading to more timely and informed decision-making.

THE TRANSFORMATIVE POWER OF SATELLITE SENSING APPLICATIONS

In an era where data drives decision-making and innovation, satellite sensing technology has emerged as a powerful tool across various sectors. By capturing high-resolution images and environmental data from space, satellites provide insights that are pivotal for progress in agriculture, disaster management, urban planning, and more. This article explores the diverse applications of satellite sensing and its transformative impact on society.

Satellite sensing, sometimes referred to as remote sensing, is the process of employing satellites to gather information about the Earth's surface. These satellites use a variety of sensors to gather information in recognizable, infrared, and microwave frequencies. The common types of satellite sensors include optical sensors, which detect visible light, and radar sensors, which can penetrate clouds and work in all weather conditions [18–23].

Key applications of satellite sensing are as follows.

Agriculture

Agricultural practices have been revolutionized by satellite sensing technology. Satellite imaging can be used by farmers to observe growth trends, evaluate soil conditions, and keep an eye on crop health. They can optimize yields and reduce environmental impact by using precision agriculture techniques to make data-driven decisions about pesticide use, fertilization, and irrigation. This capability is especially crucial in the face of climate change, where crop resilience is increasingly important.

Environmental Monitoring

In order to monitor and conserve the environment, satellite sensing is essential. Water quality, ecological health, and deforestation are all tracked using satellite data. For instance, NASA's MODIS satellite provides essential data on land cover changes, forest fires, and greenhouse gas emissions. Policymakers and environmentalists can use this information to create plans that effectively preserve species and restore habitat.

Urban Planning and Development

As the global population continues to urbanize, effective city planning is paramount. Planners in cities may see land use changes, construction of infrastructure, and urban sprawl from above with satellite sensing. By analyzing satellite data, planners can assess traffic patterns, evaluate the impact of new developments, and make informed decisions about zoning and public transport systems. Cities that use this data-driven strategy are more livable and affordable.

Disaster Management

In times of natural disasters, timely information can save lives. Satellite sensing provides crucial data for disaster preparedness, response, and recovery. During events such as hurricanes, earthquakes, and floods, satellites can assess damage, track the movement of hazardous materials, and monitor the overall situation in affected areas. Organizations like FEMA (Federal Emergency Management Agency) and international disaster relief agencies rely on real-time satellite imagery to coordinate their responses effectively.

Climate Change Research

In the battle against global warming, satellites are now essential. They offer a unique perspective on global warming and its impacts, providing data on temperature changes, ice melting, sea level rise, and extreme weather events. This information is critical for scientists studying climate patterns and for governments formulating strategies to mitigate the effects of climate change.

Infrastructure Monitoring

The integrity of critical infrastructure—such as bridges, roads, and pipelines—can be monitored using satellite data. By employing synthetic aperture radar (SAR) technology, engineers can detect subsidence, movement, and structural changes over time. Disasters can be avoided, and the security and dependability of vital services can be guaranteed with this proactive surveillance.

Satellite sensing technology has a wide range of uses that are radically changing our understanding of and relationship with the planet. The precision and availability of satellite data will only increase as technology develops, opening the door for more breakthroughs in a variety of industries. From

enhancing food security to facilitating disaster response, satellite sensing is not just a technical tool; it is a catalyst for positive change, empowering societies to build a more sustainable and resilient future. As we continue to harness the capabilities of satellite sensing, we move closer to addressing some of the pressing challenges of our time [24–26].

SATELLITE SENSING IN CLIMATE CHANGE: MONITORING OUR PLANET FROM ABOVE

In an era where climate change poses significant challenges to humanity, the importance of robust monitoring systems cannot be overstated. Satellite sensing technology has emerged as a powerful tool for understanding the dynamics of our changing climate. By gathering and analyzing vast amounts of data from space, satellites play an essential role in climate science, enabling scientists and policymakers to better anticipate, mitigate, and adapt to the impacts of climate change.

Satellite sensing plays a pivotal role in the study and understanding of climate change, providing crucial data that enhances our knowledge of Earth's changing environment. By utilizing advanced remote sensing technologies, satellites can monitor various climate indicators across large geographic areas, such as temperature, sea level rise, ice sheet melting, and vegetation changes. For instance, instruments aboard satellites like NASA's MODIS enable scientists to observe land surface temperatures and track seasonal variations in vegetation health, offering insights into how ecosystems respond to climate fluctuations.

The ability of satellites to collect data over vast and often inaccessible regions makes them invaluable for climate research. Continuous observations from satellites allow for the detection of long-term trends and anomalies, facilitating global climate models that predict future scenarios. For instance, satellite altimetry aids in measuring variations in ocean height, which is essential for comprehending how thermal expansion and glacier melt are causing sea levels to increase. Moreover, remote sensing can also assess greenhouse gas concentrations in the atmosphere, offering a clearer picture of anthropogenic contributions to climate change.

Satellite sensing is crucial for prompt and efficient decision-making because climate change presents many complicated difficulties. Governments, organizations, and researchers rely on satellite data for developing climate adaptation strategies, disaster response plans, and policy frameworks aimed at mitigating the impact of climate change. Understanding the dynamics of our planet's climate requires a comprehensive approach, which is highlighted by the integration of satellite data with ground-based measurements and climate model predictions. In harnessing the power of satellite sensing, we can better equip ourselves to address the pressing environmental issues that arise from a changing climate.

Satellite sensing is the process of gathering information about the surface of the planet, atmosphere, and oceans via remote sensing technology. By leveraging advanced sensors and imaging technologies, satellites can capture a multitude of environmental variables, such as temperature, humidity, land use, vegetation cover, and sea level rise, among others. This data provides critical insights into climate patterns, events, and trends.

Data Collection and Monitoring

The Earth's surface is regularly monitored by satellites such as the Worldview satellites, the European Space Agency's Copernicus program, and NASA's Landsat series. High-resolution photos taken by these satellites show deforestation, glacier retreat, and changes in land cover. By aggregating this data over time, scientists can analyze how these factors contribute to climate variability.

Atmospheric and Ocean Measurements

Instruments aboard satellites can measure greenhouse gas concentrations, aerosol levels, and sea surface temperatures. For instance, NASA's OCO-2 (Orbiting Carbon Observatory 2) satellite actively

measures carbon dioxide levels in the atmosphere, thereby helping researchers understand its sources and sinks. Similarly, sea surface temperature data collected by satellites like Aqua and Jason-3 provide crucial insights into oceanic changes that drive weather patterns and affect climate.

Disaster Response and Risk Management

Satellite data has been instrumental during climate-related disasters, such as hurricanes, wildfires, and floods. For instance, a combination of high-resolution imagery and radar data allows emergency responders to assess damage, coordinate relief efforts, and create evacuation plans promptly. Satellites also play a role in long-term risk assessments by identifying vulnerable ecosystems and communities.

Satellite sensing not only enables the monitoring of current climate conditions but also enhances the predictive capabilities of climate models. By providing continuous and comprehensive data, satellites feed into climate models that help scientists understand future climate scenarios. This understanding is vital for informing global and regional policy decisions and identifying necessary mitigation and adaptation strategies.

Feedback Mechanisms

Satellite data helps scientists understand critical feedback mechanisms in the climate system. For example, the melting of polar ice caps and glaciers alters the Earth's albedo, leading to increased solar absorption and, consequently, further warming. By monitoring these changes, scientists can refine their models to forecast potential tipping points.

Long-term Data Sets

The long-term data collected by satellites is invaluable for understanding climate change trends. Scientists are able to differentiate between anthropogenic impacts and natural variability via decades of continuous monitoring. This capability is essential for attributing specific weather patterns and climate trends to climate change.

Despite the advancements in satellite sensing technologies, challenges remain. Data accessibility, integration, and interpretation can pose obstacles for researchers and policymakers. Furthermore, in order to properly analyse the massive volume of data produced, advanced algorithms and machine learning approaches are needed. Governments, academic institutions, and commercial enterprises must work together to address these issues. International frameworks, such as the Global Earth Observation System of Systems (GEOSS), aim to enhance data sharing and improve the accessibility of satellite data for all nations.

The future of satellite sensing in climate change is promising. With the advent of new technologies, such as CubeSats and other microsatellite systems, we can expect to see more frequent and higher-resolution data collection. This will improve policymaking and deepen our understanding of climate change.

Our method of tracking and comprehending climate change is being completely transformed by satellite sensing technologies. By providing critical data on various environmental parameters, satellites help scientists unravel the complexities behind climate patterns, support disaster response efforts, and enhance future climate projections. As we confront the realities of a changing climate, the insights gained from satellite data will be essential for developing effective strategies to protect our planet and ensure a sustainable future for generations to come.

THE ROLE OF SATELLITE SENSING IN CLIMATE CHANGE STUDIES

As the world grapples with the tangible effects of climate change, the need for precise data collection and monitoring has never been more critical. Satellite sensing has emerged as a pivotal tool in understanding the nuances of our changing climate, helping researchers, policymakers, and the global

community at large make informed decisions. The advancements in satellite technology have revolutionized our capacity to observe and analyze Earth's systems on a global scale, providing invaluable insights into climate dynamics and environmental shifts.

Satellite sensing refers to the collection of data from satellites orbiting the Earth. These satellites are equipped with sophisticated sensors that capture various types of data across different wavelengths of the electromagnetic spectrum. This data encompasses a wide array of environmental parameters, including land cover, sea surface temperatures, atmospheric conditions, and greenhouse gas concentrations.

Monitoring Environmental Changes

The significant contributions of satellite sensing to climate change studies is the ability to monitor changes in land use and land cover. Satellite imagery allows scientists to observe deforestation, urbanization, and agricultural expansion from a macro perspective. By analyzing these changes over time, researchers can quantify the impact of human activities on natural landscapes and identify regions where climate mitigation efforts are urgently needed.

Furthermore, satellite sensors carry out continuous monitoring of glaciers and ice sheets, crucial indicators of climate change. For instance, satellites like NASA's ICESat and the European Space Agency's CryoSat have provided critical insights into the melting rates of polar ice and the implications for sea level rise. These observations are essential for understanding the speed and scale of climate change effects, which are often driven by rising global temperatures.

Climatic Data Collection and Integration

Climate is determined by long-term patterns, and satellite data allows for the collection of large-scale meteorological data that spans decades. Satellites monitor atmospheric conditions, including temperature, humidity, and wind patterns, which are essential for climate models. These models rely on historical data captured by satellites to predict future climate scenarios and assess the potential impacts of climate change on ecosystems and human societies.

Furthermore, satellite data is essential for determining each region's carbon footprint. Satellites like NASA's OCO-2 track carbon dioxide concentrations in the atmosphere, enabling scientists to pinpoint sources and sinks of greenhouse gases. This information is vital for developing policies aimed at mitigating emissions and achieving climate targets set in international agreements like the Paris Accord.

Enhancing Disaster Response

Satellite technology is not only integral in monitoring climate change but also crucial for disaster response. During extreme weather events—such as hurricanes, floods, and wildfires—satellite data provides real-time information about conditions on the ground, helping first responders and governments to efficiently allocate resources and coordinate relief efforts. For instance, the European Space Agency's Copernicus Emergency Management Service uses satellite imagery to assess damage and support recovery efforts in disaster-stricken areas.

Despite the remarkable advantages of satellite sensing, several challenges remain. Data accuracy, resolution, and retrieval costs can vary significantly between satellite systems, impacting the reliability of the information collected. Furthermore, as climate change is a worldwide problem that cuts beyond national boundaries, there is a need for increased cooperation and data exchange across nations.

Looking to the future, advancements in technology, such as the deployment of new satellite constellations and the integration of artificial intelligence and machine learning for data analysis, promise to enhance our ability to monitor climate change effectively. Initiatives like the Copernicus Program and NASA's Earth Observing System aim to provide open access to vast, high-quality datasets that can empower researchers worldwide.

SATELLITE SENSING FOR CLIMATE DATA COLLATION: A GAME CHANGER FOR ENVIRONMENTAL MONITORING

Accurate and timely climate data is more important than ever in an era where ecosystems and human cultures are both facing existential threats from climate change. Satellite sensing technology offers a robust solution for collating climate data, enabling scientists, policymakers, and communities to better understand environmental changes and make informed decisions. This article delves into the role of satellite sensing in climate data collation, its applications, and the future it promises for our planet.

Many industries, including public health, agriculture, urban planning, and disaster management, depend on climate data. Accurate data helps researchers track climate variations, predict extreme weather events, model future climate scenarios, and formulate mitigation and adaptation strategies. Traditional ground-based data collection methods, while valuable, often lack the spatial coverage and frequency needed to capture the nuances of global climate trends. Satellite sensing is useful in this situation.

Satellite sensors collect information on the Earth's surface and atmosphere using a variety of technologies, such as optical, infrared, and radar systems. These sensors are mounted on various types of satellites, which orbit the Earth at varying altitudes and inclinations. These sensors gather data, which is then processed by sophisticated algorithms and sent to researchers, governments, and organizations around the world.

Key Types of Satellite Sensors:

1. *Optical Sensors:* These sensors capture images in visible and infrared light, enabling the monitoring of land use, vegetation cover, and urban expansion.
2. *Thermal Sensors:* These instruments measure the thermal radiation emitted by the Earth, facilitating temperature mapping and thermal anomaly detection.
3. *Radar Sensors:* Radar satellites can penetrate cloud cover and darkness, providing valuable information on terrain deformation, moisture content, and vegetation structure.

Applications of Satellite Sensing in Climate Data Collation:

1. *Temperature Monitoring:* Satellites continuously monitor surface temperatures, providing high-resolution data on global temperature variations. This data is essential for identifying climate change trends like warmer seas and changed weather patterns.
2. *Vegetation Analysis:* Remote sensing allows for the tracking of vegetation health and coverage over time. Satellite data can assess deforestation rates, agricultural productivity, and the impact of climate phenomena like drought and floods.
3. *Sea Level Rise Measurement:* Satellites equipped with radar altimeters monitor changes in sea level with unrivaled precision. Scientists can better comprehend how climate change affects coastal ecosystems and communities thanks to this data.
4. *Atmospheric Composition:* Satellites can measure greenhouse gas concentrations, aerosol distributions, and ozone levels in the atmosphere. These measurements are vital for understanding air quality and its effects on health and climate.
5. *Disaster Response:* By delivering real-time data during natural disasters like hurricanes, floods, and wildfires, satellite photography helps with disaster management. This information helps coordinate emergency responses and assess damage.

Despite its numerous advantages, satellite sensing for climate data collation faces challenges, including data processing complexities, costs of satellite launches, and the need for international collaboration in data sharing. Furthermore, ensuring data privacy and ethical considerations in using collected information is critical.

Looking ahead, advancements in satellite technology—such as small satellites, AI, and machine learning—hold the potential to revolutionize climate data collation. These innovations could lead to

more precise, efficient, and cost-effective methods of gathering and analyzing climate data, empowering stakeholders at all levels to tackle climate change effectively.

CONCLUSION

The role of satellite sensing in climate change studies is invaluable. By offering comprehensive, real-time data on environmental changes, satellite technology is at the forefront of our understanding of climate dynamics. As the impacts of climate change continue to manifest across the globe, the insights garnered from satellite observations will be critical in shaping effective responses, guiding policy decisions, and fostering international collaboration in the pursuit of a sustainable future. As we look ahead, enhancing satellite capabilities and ensuring equitable access to data will be essential in addressing the pressing challenges posed by climate change. In the continuous battle against climate change, satellite sensing technology is essential. By providing high-quality, timely, and comprehensive climate data, satellites enable a more profound understanding of our planet's dynamics and inform critical decisions that can shape a sustainable future. As technologies advance and collaboration grows, the potential for satellite sensing to contribute to climate action will only increase, heralding a new era in environmental monitoring and management.

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