

The Intersection of Technology and Environmental Science: A Study of Satellite Sensing

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Abstract

As coastal communities continue to deal with the many threats that climate change brings, satellite sensing is becoming an increasingly vital tool for assessing and managing risk. By using this technology, environmental scientists, lawmakers, and city planners can make better choices that will make coastal cities safer and stronger in the long run. Using satellite data in city planning and disaster preparedness has made a big difference in lessening the effects of extreme weather, environmental damage, and rising sea levels. Satellite data has made this possible. Not only are resilience and adaptability options, they are also necessities. Satellite sensing makes it possible to achieve both of these goals successfully. There has been a revolution in how we keep an eye on sea levels thanks to satellite sensors. This technology gives us important information that helps us understand how climate change affects sea levels around the planet. As technology gets better, satellite observations will become more and more important for helping vulnerable people all around the world and supporting climate resilience measures. The use of cutting-edge sensing technologies, teamwork, and easier access to data are all helping to start a new age in environmental monitoring. All of these things are important for the future of our planet.

Keywords: Satellite sensing, climate change, coastal areas, environmental study, sea level

INTRODUCTION

Scientists and governments are both paying close attention to sea level rise as climate change becomes more of a danger. Rising sea levels are a threat to the lives of people, ecosystems, and economies all across the world. Even though traditional ground-based measuring methods are useful, they can be hard to use and limited in what they can measure. Satellite sensing, on the other hand, provides a complete, quick, and accurate way to keep an eye on changes in sea level all across the world. This article talks about the technology that makes satellite-based sea level monitoring possible, why it's important, and what it means for our understanding of climate change and future policy efforts.

Radar altimetry is a common method for satellite sensing of sea level. It estimates how long it takes for a RADAR signal to travel from the satellite to the sea surface and back. Scientists can figure out the height of the ocean surface quite well by measuring this time. This lets them cover the whole world all the time [1–8]. Recent advancements in satellite technology have facilitated the initiation of several projects aimed at measuring sea level, including NASA's Jason series, the European Space Agency's (ESA) Sentinel-6, and the GRACE (Gravity Recovery and Climate Experiment) missions. These satellites not only keep an eye on changes in sea level, but they also collect information on ocean temperature, salinity, and the movement of ice sheets. This gives us a complete picture of the marine ecosystems on our planet.

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Importance of Sea Level Monitoring as shown in Figure 1.

1. *Understanding Climate Change:* Monitoring sea level allows scientists to gauge the effects of climate change, estimate future trends, and understand local variability.
2. *Risk Assessment for Communities:* Coastal cities and communities are particularly vulnerable to sea level rise. By providing accurate predictions on changes, satellite data helps authorities plan for and mitigate potential risks. This includes infrastructure assessment, disaster preparedness, and the development of long-term adaptation strategies.
3. *Ecosystem Preservation:* Coastal ecosystems, such as mangroves, wetlands, and coral reefs, are essential for biodiversity and act as buffers against storm surges. Monitoring sea level helps in managing and protecting these vital ecosystems, ensuring their resilience to changing conditions.
4. *Support for Policy Implementation:* Reliable satellite data serves as a critical resource for policymakers. It enables informed decision-making regarding environmental regulations, coastal development, and climate adaptation strategies, fostering sustainable practices that benefit both people and the planet.

While satellite sensing provides unparalleled benefits for sea level monitoring, it is not without its challenges. Data accuracy can be influenced by factors like ocean currents, atmospheric conditions, and terrestrial changes (e.g., land subsidence). Scientists are continuously working to improve algorithms that account for these variables to enhance overall data accuracy.

Furthermore, integration of satellite data with ground-based measurements remains crucial for validation and calibration. Collaborative efforts between international space agencies, academic institutions, and governmental organizations are vital for creating a comprehensive monitoring framework [9–14].

Looking forward, advancements in technology, such as the launch of next-generation satellites equipped with more sophisticated sensors and improved imaging capabilities, promise even greater precision in sea level monitoring. Enhanced machine learning algorithms and data analytics can further optimize data interpretation, enabling real-time assessments of sea level changes. Figure 1 shows the sea level study.

Satellite sensing is revolutionizing our approach to monitoring sea level rise, providing critical insights into the impacts of climate change. As we continue to explore and refine this technology, we gain a clearer understanding of the challenges ahead and the strategies needed to protect our coastal communities and ecosystems. The urgency to act is apparent, and satellite data stands at the forefront of the fight against climate change, offering both hope and guidance as we navigate our uncertain future.

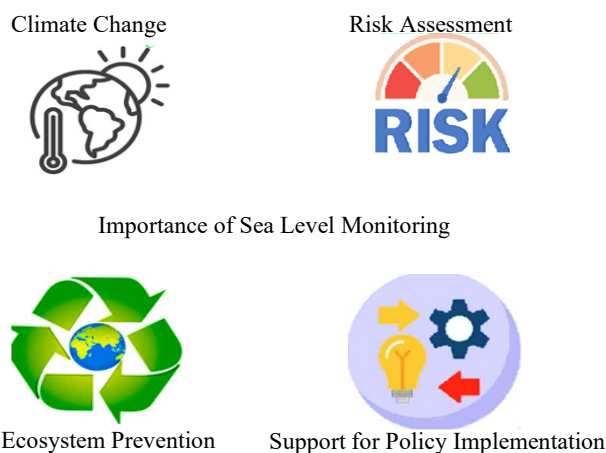


Figure 1. Sea Level monitoring Importance.

TRANSFORMING URBAN MANAGEMENT AND SUSTAINABILITY

Coastal cities are growing, but they are also facing a lot of problems, such as climate change, rising sea levels, urbanization, and environmental degradation. These problems require new ways to manage resources well and make sure that cities can keep going. Satellite sensing technology is the most promising way to solve these problems. As shown in Figure 2, coastal towns may get important information for urban planning, environmental monitoring, disaster management, and climate resilience by combining the capabilities of remote sensing satellites.

Satellite sensing is the use of satellite-based technology to collect information about the surface of the Earth using several types of sensors, such as optical, infrared, and radar. These sensors can take pictures and collect data in different spectral bands. This gives us information on how land is used, how much vegetation there is, the quality of the water, and the infrastructure of cities. Satellite sensing data is very useful for scientists, decision-makers, and urban planners who are in charge of coastal cities [15–20].

Key Applications of Satellite Sensing in Coastal Urban Areas

1. *Monitoring Land Use and Urbanization:* Changes in land use in coastal cities often occur rapidly. Satellite imagery helps track urban sprawl, identify informal settlements, and monitor land cover changes. This data is crucial for developing effective urban planning strategies that balance growth with environmental sustainability.
2. *Assessing Environmental Health:* Coastal areas are sensitive ecosystems that are often affected by pollution, habitat loss, and climate-related changes. Satellite sensors can monitor water quality, detect algal blooms, and assess coastal erosion. This information helps in managing natural resources and protecting biodiversity.

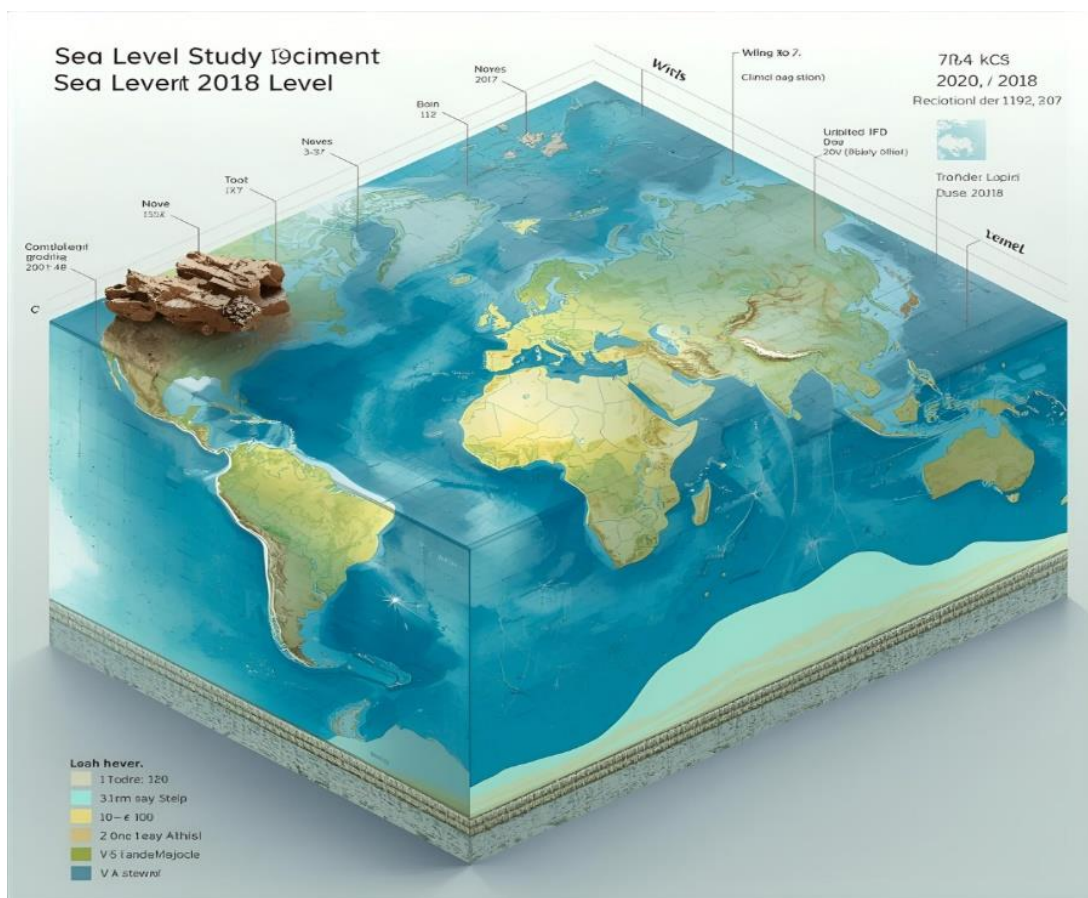


Figure 2. Sea Level study.

3. *Disaster Management and Response*: Coastal cities are vulnerable to natural disasters such as hurricanes, floods, and tsunamis. Satellite sensing provides real-time data that can enhance disaster preparedness and response. High-resolution imagery allows for damage assessment, facilitating expedited recovery efforts and informing evacuation plans.
4. *Climate Change Adaptation*: Long-term climate data obtained from satellite observations enables cities to model and predict the impacts of climate change on coastal environments. This information is vital for developing adaptive strategies, such as infrastructure designs that can withstand storm surges and rising sea levels.
5. *Infrastructure Monitoring*: Coastal cities often have critical infrastructure like roads, bridges, and services that are at risk due to changing environmental conditions. Satellite-based monitoring can provide insights into the structural integrity of these facilities and detect early signs of deterioration.

The use of satellite sensing in coastal cities offers numerous benefits:

- *Cost-Effectiveness*: Collecting data through satellite imagery is often more economical than traditional ground-based methods, especially over large areas.
- *Timeliness and Frequency*: Satellites can capture data frequently and in near real-time, providing up-to-date information that is crucial for ongoing urban management efforts.
- *Comprehensive Coverage*: Satellite sensors can cover large geographic areas, making it possible to conduct regional assessments and support integrated coastal zone management.
- *Enhanced Decision-Making*: The ability to visualise and analyse spatial data allows city planners and politicians to make knowledgeable decisions grounded on empirical evidence.

While satellite sensing presents significant advantages, it is not without challenges. Data interpretation can be complex, requiring expertise in remote sensing and geographical information systems (GIS). Additionally, the integration of satellite data with local datasets can be challenging, particularly when aligning different temporal and spatial resolutions. There's also the issue of data privacy and security, particularly concerning urban surveillance [21, 22].

As technology endures to evolve, the potential applications of satellite sensing in coastal cities are expected to expand. Integrating artificial intelligence (AI) and machine learning (ML) with satellite data can enhance predictive modeling and automate monitoring processes. Collaborative efforts between governmental agencies, academia, and private sector partners will be essential in developing comprehensive frameworks that utilize satellite sensing effectively.

In conclusion, satellite sensing stands at the forefront of innovative solutions for managing the complex challenges faced by coastal cities. By leveraging this technology, urban planners and policymakers can foster resilience, enhance sustainability, and protect the delicate balance of coastal ecosystems, ensuring these vibrant urban areas thrive for generations to come. As we look to the future, embracing satellite sensing may well be the key to unlocking a sustainable path forward for coastal urban development.

SATELLITE SENSING TECHNOLOGIES

Satellite sensing methods have revolutionized our capability to monitor sea levels with unprecedented accuracy and spatial coverage. The following technologies have significantly contributed to our sympathetic of sea level dynamics:

Altimetry

Satellite altimetry is the most prominent method for measuring sea surface height. Satellites equipped with radar altimeters send signals to the ocean surface and measures time taken for signals to arrival. By calculating the distance traveled, scientists can determine changes in sea surface height with remarkable precision.

Examples of missions utilizing radar altimetry include:

- *TOPEX/Poseidon*: Launched in 1992, this mission provided critical early data on global sea level rise.
- *Jason-1, Jason-2, and Jason-3*: Successor missions that have continued monitoring effort, with ongoing contributions to understanding ocean circulation and climate variations.
- *Sentinel-6 Michael Freilich*: Launched in 2020, this mission provides high-resolution sea level data and aims to extend the time series of sea level observations.

Gravity Measurements

Satellite gravity missions, like Gravity Recovery and Climate Experiment (GRACE) and GRACE-FO, offer unique insights into mass changes in Earth's system. Changes in the distribution of water—both on land and in the ocean—affect the Earth's gravity field. By monitoring these changes, scientists can infer information about ice melt in Polar Regions and water storage variations, which are vital for understanding sea level rise.

Remote Sensing

Remote sensing technologies, including optical and microwave sensors, are increasingly utilized to study the influences of sea level increase on coastal habitats and urban areas. These sensors provide critical data for mapping coastal erosion, monitoring land use changes, and assessing the impact of sea level increase on infrastructure.

Integrated Models

Advancements in computational models that integrate satellite observations and other data sources enhance our understanding of sea level rise. By combining satellite data with in-situ measurements and climate models, researchers can better predict future sea level changes and assess the potential impacts on coastal systems.

The field of satellite sensing for sea level monitoring continues to evolve, with several exciting developments on the horizon:

1. *Next-Generation Satellites*: Upcoming missions, like European Space Agency's Copernicus program and NASA's Surface Water and Ocean Topography (SWOT), promise enhanced capabilities for high-resolution sea level measurements.
2. *Increased Collaboration*: International collaborations between space agencies, research institutions, and governments will further advance sea level monitoring efforts and foster data sharing.
3. *Enhanced Data Accessibility*: Open-access data policies will facilitate the use of satellite-derived sea level data for scientific research, policymaking, and public awareness.
4. *Engagement with Local Communities*: Integrating satellite data with local knowledge and community input will lead to more effective adaptation strategies tailored to specific coastal contexts.

SATELLITE SENSING FOR RISK ASSESSMENT IN COASTAL CITIES

Coastal cities are often at the forefront of climate change impacts, facing threats from rising sea levels, increased storm intensity, and erosion. As urban populations swell and infrastructure strains under environmental pressures, the need for effective risk assessment and management is more critical than ever. Satellite sensing technology, with its capability to offer realtime data on various environmental parameters, is emerging as a valuable tool in risk assessment for these vulnerable urban centers.

Satellite sensing includes the usage of satellite-mounted sensors to gather information about Earth's surface and atmosphere. These sensors capture a range of electromagnetic radiation, from visible light to infrared, enabling the monitoring of various phenomena, including land use, vegetation cover,

temperature variations, and water quality. The data obtained can be analyzed to assess environmental conditions, identify trends, and predict future hazards.

Coastal cities, often characterized by their economic activities and cultural significance, are uniquely susceptible to a variety of risks:

1. *Sea Level Rise*: Global warming is causing ice caps to melt and seawater to expand, leading to rising sea levels. Coastal cities must continuously assess which areas are at risk of flooding and erosion.
2. *Storm Surges*: Hurricanes and tropical storms can unleash devastating storm surges, overwhelming infrastructure and leading to significant economic losses.
3. *Erosion*: Coastal erosion threatens vital infrastructure and habitats, necessitating ongoing monitoring to inform mitigation strategies.
4. *Urban Heat Islands*: Towns often experience higher temperatures than nearby areas due to human activities and infrastructure. This phenomenon exacerbates heatwaves and can endanger public health.
5. *Water Quality Degradation*: Coastal urban areas face challenges related to pollution and runoff, impacting marine environments and public health.

THE ROLE OF SATELLITE SENSING IN RISK ASSESSMENT

Satellite sensing plays a vital role in addressing these risks by providing a comprehensive and holistic view of coastal environments. Figure 3 shows the risk assessment using satellite imaging.



Figure 3. Risk assessment using satellite imaging.

Here are some ways satellite technology enhances risk assessment:

Real-Time Monitoring

With the capability to provide continuous data collection, satellite sensors can monitor changes in land and water features in real time. This is crucial for tracking storm systems, flood extents, and water quality changes, allowing city planners and emergency responders to act promptly.

Data-Driven Decision Making

Planners can use this information to understand vulnerability hotspots and prioritize investments in infrastructure, such as seawalls or green spaces that can mitigate flooding and heat.

Mapping Vulnerability

Advanced satellite imaging techniques, like Synthetic Aperture Radar (SAR) can map coastal areas to identify vulnerable regions. This information is invaluable for disaster preparedness, allowing cities to develop tailored evacuation plans and resource allocation strategies.

Ecosystem Monitoring

Satellites can monitor coastal ecosystems, like mangroves & coral reefs, that provides natural fences against storms streams and corrosion. By understanding the health of these ecosystems, municipalities can implement conservation measures, enhancing their resilience against environmental stresses.

Climate Adaptation Strategies

With the wealth of data available from satellite sensing, cities can model and simulate various climate adaptation strategies. This capability helps decision-makers evaluate the effectiveness of proposed interventions, such as enhancing green infrastructure or instituting zoning changes.

Case Studies in Action

Several coastal cities around the world have already harnessed satellite sensing for risk assessment:

- *Miami, Florida:* Miami utilizes satellite data to monitor sea level rise and storm surge impacts, informing an adaptive plan that includes raising road elevations and enhancing drainage infrastructure.
- *New Orleans, Louisiana:* Following the devastation of Hurricane Katrina, New Orleans has invested in satellite technology to assess flood risk and improve its levee systems, significantly enhancing the city's resilience to future events.
- *Venice, Italy:* The city is using satellite data for its MOSE project, a system of barriers to protect against flooding, enabling effective monitoring and management of the city's historical resources.

CONCLUSION

Coastal communities are still dealing with the many dangers that climate change brings, and satellite sensing is becoming an important tool for assessing and managing those risks. By using this technology, city planners, lawmakers, and environmental scientists can make better choices that will make coastal communities safer and stronger. Using satellite data in urban planning and disaster preparedness is a big step forward in changing the effects of rising sea levels, severe weather, and environmental damage. Adaptation and resilience are not just choices; they are required, and satellite sensing gives us the tools we need to make them happen. Satellite sensing has changed how we keep an eye on sea levels. It gives us important information that helps us understand climate change and how it affects sea levels around the world. As technology continues to improve, satellite observations will become more important for helping populations throughout the world that are vulnerable and for supporting climate resilience initiatives. A new era in environmental monitoring is beginning thanks to the use of novel sensing methods, teamwork, and better access to data. This is important for protecting the future of our planet.

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