The Role of Remote Sensing in Surveillance and Assessment of Climate Change

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Abstract: Climate change has currently evolved into a serious concern across the globe. Mainly focusing on climate change and its effects on humanity in different aspects, this paper delves into the history and development of Remote Sensing and analyzes the pivotal roles it plays in monitoring and assessing climate change by scrutinizing previous studies and evaluating the effectiveness of the technology in three climatic phenomena - sea level rise, glacial retreat and forest fires. The research results indicate that Remote Sensing can be accurate and efficient in these climatic phenomena. However, the technology has limitations, such as limited spectral range and coarse spatial resolution. To solve the problem, Remote Sensing can be coupled with other technologies, such as Geographic Information System (GIS), to obtain remarkable efficiency and accuracy when combating climate change. In the future, it can be leveraged across various sectors in efforts against climate change. In addition, this paper emphasizes the necessity for ongoing enhancements in Remote Sensing technologies, particularly in improving spectral range and spatial resolution. It also underlines the critical role of international cooperation and data sharing in leveraging Remote Sensing for more comprehensive and precise climate monitoring and mitigation efforts.

1 INTRODUCTION

With an increasing rate of industrialization and urbanization, climate change has become a significant concern to all. Climate change is defined as a chronic alteration in weather patterns across the globe. While numerous traditional methods, such as weather stations, weather balloons, radars, ships and buoys, have been undertaken across various sectors to investigate its causes, track its progression, and minimize its impacts, there is still a critical need for a more comprehensive and effective tool in the effort.

In recent years, Remote Sensing has developed rapidly and stood out as a convenient and powerful tool for conducting geographical surveillance and assessment due to the large area it can cover and its capacity to provide insightful details on certain geographical features. For example, it can help satellites quickly identify infrared rays or ultraviolet in a particular region, which human eyes cannot identify. Calculating the NDVI (Normalized Difference Vegetation Index) can also assist in analyzing the status of vegetations in certain areas. Nevertheless, there remains a noticeable lack of studies and analyses on the effectiveness of Remote Sensing technologies in climatic issues. This paper intends to contribute to closing this gap by carrying out insightful analyses of the role of Remote Sensing in detecting the effects and potential threats associated with various climatic phenomena in aspects including sea level rise, glacial retreat, and forest fires. It is expected that through harnessing images and data collected through Remote Sensing, as well as GIS (Geographical Information System) and other geographic technologies, the paper will help to gain a more comprehensive understanding and more detailed information regarding the existing and potential impacts of climate change from diverse perspectives alongside showcasing how the geographical technologies can be employed for the betterment of the humanity. Furthermore, the paper intends to contribute to the global bid to combat climate change and mitigate related natural disasters.

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2 MAIN ASPECTS OF CLIMATE CHANGE

In the last few decades, climate change has been primarily characterized by a rise in global temperature and an increase in natural disasters worldwide.

The rise in global temperature, commonly known as "global warming," is a key driver of climatic changes, with a notable impact on oceans leading to rising sea levels. This phenomenon thus serves as a crucial indicator of the extent and pace of global warming (Eniolorunda et al., 2014). In retrospect, the retreat of glaciers in polar regions is a major contributor to rising sea levels, underscoring the undeniable signs of climate change. For this reason, local authorities must monitor glacier losses and ice thickness reduction to manage climate-related challenges effectively (Peduzzi et al., 2010).

Among a series of natural disasters that have occurred over the decades, forest fires stand out as a prominent concern due to their increasing frequency over the years. Flannigan et al. (2006) state in their research that the link between fire and climate change has essential implications for the management of forests and the protection of communities. They also claim that weather and climate conditions, influenced by human-induced climate change, are vital in fueling these devastating fires (Flannigan et al., 2014). Understanding these dynamics is a major key to efficient mitigation strategies and preparedness measures.

In light of the considerations above, this paper focuses on sea level rise, glacial retreat, and forest fires as main aspects of climate change analysis, aiming to provide a comprehensive and insightful perspective about the threats of climate change posed to mankind and the vital role played by Remote Sensing in monitoring and assessing these environmental shifts.

3 DEFINITION AND DEVELOPMENT OF REMOTE SENSING

Remote Sensing is the technology that scans the Earth with the help of satellites or high-flying aircraft to obtain related information. Unlike on-site observations, it is essentially distinguished by acquiring geographical images without direct contact with the ground.

The evolution of Remote Sensing technology has been intertwined with the advancement of flight. Since the advent of photography, individuals have affixed micro cameras to birds to capture panoramic views of their surroundings. In 1858, a French balloonist, G. Tournachon, captured an aerial photo of Paris from his hot balloon, marking the formal inception of modern Remote Sensing (Cracknell et al., 2018). Advancements surged in the 20th century as aerial photography from aircraft, created for armed forces during World War I, shifted to civilian uses after the war.

The term Remote Sensing started in the mid-20th century, reflecting American geographer Evelyn Pruitt's realization that traditional terms like "aerial photography" were insufficient to describe the emerging data streams fueled by technological advancements. Remote Sensing is widely deployed across multiple fields, with over 950 in-orbit satellites traveling around Earth, providing detailed planetary information.

Broadly stated, Remote Sensing can be categorized into two main types based on their principles - Passive Remote Sensing and Active Remote Sensing. Passive sensors collect radiation from their circumstances, with sunlight being a major source. Infrared and film photography are common instances of passive Remote Sensing. In contrast, Active Remote Sensing emits energy to survey the surrounding environment. A sensor then analyzes the radiation reflected from the target area. LiDAR and RADAR are examples of Active Remote Sensing techniques.

Presently, Remote sensing enjoys a reputation as a potent assistant in capturing data about the Earth (Borre et al., 2011). Several noticeable advantages have been recognized that contribute to its efficiency. One invaluable merit is its capability to collect data of impenetrable areas - from deep oceans to dense forests and remote deserts. Remote Sensing enables detailed data acquisition, making it a valuable tool for research on climate and ecosystems. Moreover, Remote Sensing offers a cost-effective and efficient alternative to ground-based data collection processes, considerably minimizing disturbances in areas under analysis while ensuring swift processing and retrieval of crucial information.

4 APPLICATION OF REMOTE SENSING IN SEA LEVEL RISE

Historically, people have set up weather stations along coastlines and set off weather balloons over oceans to monitor sea conditions. The trend of using remote sensing technology for research is becoming obvious in recent years.

Kavak et al. (2011) found a significant association between sea surface temperature and levels of chlorophyll (contributing to the variation of watercolor) during the same period. They concluded that Remote Sensing technology could considerably promote studies on global ocean characteristics and their potential impacts on the planet. This underscores the vital role of Remote Sensing in monitoring and handling sea level rise and its related effects (Peduzzi et al., 2014).

On the other hand, Yang et al. (2013) have pointed out that the global average sea level rise, as measured by Remote Sensing since the 1990s, exceeds the estimates derived from twentieth-century tide-gauge data. This suggests that achieving absolute precision in analyzing the extent of sea level rise remains a considerable challenge. An extended duration, therefore, is in demand to identify the year-to-year and decade-to-decade changeability. Fortunately, an effort that leverages multi-satellite altimetry data to produce week-by-week sea level data for part of the Earth (polar regions excluded) has recently provided a valuable solution to the problem. With the help of Remote Sensing technology, Yang et al. (2013) accurately measured the variation in sea levels between 1993 and 2012 (Figure 1), which not only reveals significant changes over the years but also demonstrates the differences between data collected using differing methods (Yang et al., 2013). It can be inferred that with the emergence of newly developed Remote Sensing methods, the precision and accuracy of Remote Sensing in analyzing sea conditions has been continuously improving.

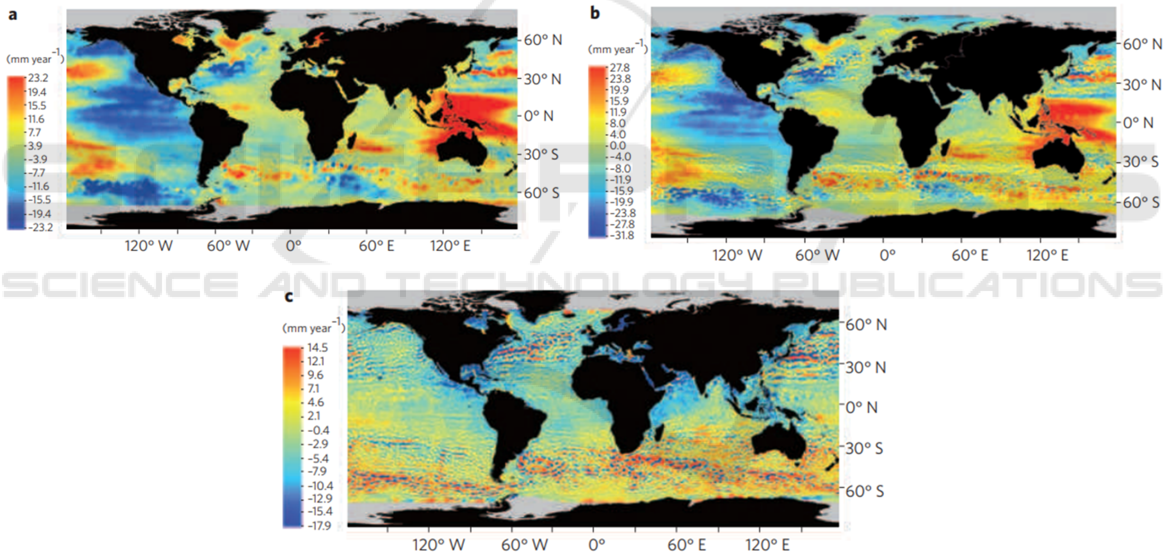

Figure 1: Sea-level changing trends from 2008 to 2012, measured by different Remote Sensing methods (Yang et al., 2013)

5 APPLICATION OF REMOTE SENSING IN GLACIAL RETREAT

Traditionally, scientists have set up surveillance stations in polar regions to detect glacial activities. While this method is cost-effective and straightforward, it lacks efficiency in tracking overall glacial changes in expansive areas.

At present, multiple Remote Sensing technologies, the most representative including Satellite Pour l' Observation de la Terre (SPOT) and Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER), have been deployed to monitor glacial retreat, characterized by extraordinary accuracy, despite minor errors, in analyzing and predicting glacial changes (Yang et al., 2013).

Peduzzi et al. (2010) leveraged Remote Sensing in combination with DEM (Digital Elevation Model) to analyze the changes in Nevado Coropuna, a glacier located in Peru, over the years. Their research collected data on glacier areas from 1955 to 2008 (Table 1), supporting the evidence of significant global glacier decline occurring at a relatively consistent rate over the decades.

Table 1: Evolution of Ice Cover from Nevado Coropuna, Peru from 1955 to 2008 (Peduzzi et al., 2010).

Date	Surface Area of Glacier (km^2)	Loss of Ice Areas (km^2/year)	Ice Cover Percentage (1955 as reference)
1955	122.7		100%
November 6, 1980	80.14	1.7	65.3%
June 12, 1996	65.5	0.9	53.4%
May 7, 2003	57.3	1.2	46.7%
September 25, 2008	48.1	1.8	39.2%

Moreover, the research suggests that data obtained through Remote Sensing technologies exhibited exceptional reliability even before corrections. Through further refinement of the data, the study successfully mitigated errors from Remote Sensing analysis (Table 2), lowering the standard deviation to 14.4 meters (lower than that acquired in a study by Racoviteanu et al., 2007). This underscores the considerable capability of Remote Sensing in determining the magnitude and pace of glacial retreat across time.

Table 2: Comparison Between Pre-correction and Post-correction Remote Sensing DEM Analysis (Peduzzi et al., 2010)

	Pre-correction		Post-correction 1		Post-correction 2	
	Difference	Standard Deviation	Difference	Standard Deviation	Difference	Standard Deviation
DEM 97-55	-0.24m	18.6	-0.24m	16.1	0.00	18.6
DEM 00-55	0.04	18.2	0.00m	13.2	0.00	13.2
DEM 02-55	71.01m	42.1	2.71m	27.9	3.28	14.4

6 APPLICATION OF REMOTE SENSING IN FOREST FIRES

When addressing natural disasters such as forest fires, traditional methods typically involve deploying manpower into forested areas and installing fire alarms in high-risk zones. However, these conventional approaches put lives at stake and fall short in facilitating rapid responses to sudden fire outbreaks.

In light of these challenges, Remote Sensing emerges as a highly effective alternative to traditional methods. In a seasonal perspective, Ahmad et al. (2018) leveraged Remote Sensing imagery provided by the Forest Survey of India (FSI) and found that most forest fires (approximately 79%) occurred during April and May, with April recording the highest frequency of fires. Their study illustrates the fire occurrence patterns in a typical forest fire area in India, shedding light on broader trends worldwide (Table 3).

Table 3: Monthly Forest Fires in An Area in India (Ahmad et al., 2018).

Month	January	February	March	April	May	June
Frequencies	14	80	553	3369	2545	956
Percentage	0.19%	1.06%	7.36%	44.81%	33.86%	12.72%

In addition, Flannigan et al. (2006) opine that coupling simulation models and classification models with Remote Sensing can be instrumental to the analysis of forest fires. In a recent investigation, Sunar et al. (2001) combined Remote Sensing with the Neural Network Supervised Classification Model to analyze a forest fire in a region in Turkey. Their study suggested that Remote Sensing gives rise to decisions of greater objectivity, higher definitiveness, and lower biasedness to be made from a meteorological viewpoint. It also can analyze vegetation quantity in finer detail compared to ground-based measurements. As depicted in Figure 2, the classifications visually represent areas with distinct characteristics using varied colors. It can be further inferred that there will be substantial potential for future advancements if Remote Sensing technologies are fully integrated with a diverse array of models and algorithms.

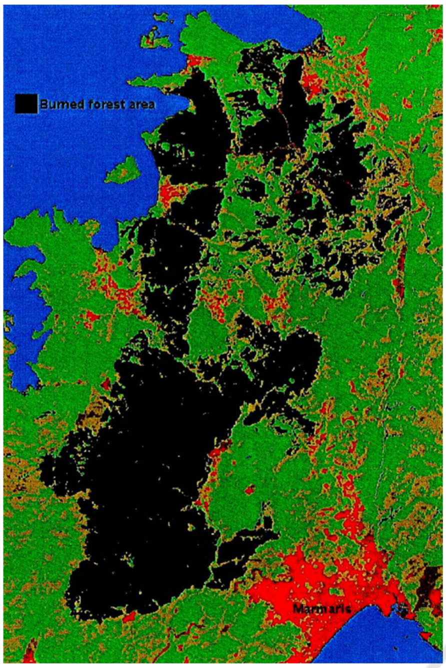

Figure 2: Classification Result of IRS-1C Image, Supervised by Neural Network (Sunar et al., 2001).

7 DISCUSSION

In general, papers written over the decades not only implicated the rapid development and high effectiveness of Remote Sensing but also highlighted the pivotal roles it plays in fighting against climate change. Through comparison and analysis of these papers, Remote Sensing, when appropriately utilized, can be effective and accurate in monitoring climatic phenomena. Likewise, GIS, ASTER, SPOT, GCM and other technologies can also be exceptionally useful for modeling the future trends of such phenomena. Remote Sensing can be further enhanced by these auxiliary technologies to acquire data handling of higher efficiency, modeling with greater accuracy, and estimates with increased precision (Park et al., 1991). These findings underscore the pivotal role that Remote Sensing can play in the surveillance, evaluation, and mitigation of climate change and its associated impacts. A more extensive literature review reveals that climate change is prominently implicated in the three analyzed aspects - sea level rise, glacial retreat, and forest fires, necessitating heightened awareness across all sectors of society regarding its potential consequences. Collaborative efforts are imperative to combat climate change effectively.

However, despite the considerable advantages of Remote Sensing technology, they also have certain limitations. For example, Moran et al. (1997) investigated "Precision Crop Management (PCM)" utilizing Remote Sensing and highlighted challenges related to such properties of sensors as restricted range of spectrums, low resolution, extended detection intervals, and inadequate coverage repetition, which could impede its performance. Thus, Remote Sensing technology alone may not suffice in addressing climate-related challenges and should be complemented by other technologies to maximize its efficacy. Continuous enhancements are required to refine the precision of Remote Sensing techniques in the future.

While this paper specifically focuses on the roles of Remote Sensing in three main aspects of climate change, it acknowledges that other climate-related phenomena demand investigation. Future studies should explore topics such as flooding, vegetation changes, greenhouse gas increases, marine life variations, and the application of Remote Sensing in these realms to gain a more comprehensive understanding of climate change dynamics and the potential of Remote Sensing.

8 CONCLUSION

Intended to address the insufficiency of papers investigating the role of Remote Sensing in handling threats posed by climate change, this paper has undertaken a comprehensive evaluation of key climate change aspects and traced the evolutionary trajectory of this pivotal technology. Central to its analysis is a detailed exploration of the functions and utilitarian values of Remote Sensing, particularly when integrated with diverse methodologies for monitoring and assessing sea level rise, glacial retreat, and forest fires - three critical aspects in comprehending the impacts of climate change.

From multiple perspectives, previous papers have utilized Remote Sensing and other technologies and adopted various perspectives of analysis to assess the effectiveness and accuracy of Remote Sensing. This paper primarily makes a comprehensive comparison and analysis and highlights two key points regarding these studies conducted over the decades. For one thing, Remote Sensing demonstrates significant accuracy in analysis, further strengthened through correction models and complementary technologies, including supervised classification, GIS, AVHRR, and ASTER. For another, the application of Remote Sensing proves promising for aiding humanity in combatting climate change. It is therefore, evident that Remote Sensing and relevant technologies have a bright prospect. With future efforts, Remote Sensing has the potential to achieve higher resolution, increased precision, and enhanced accuracy in information retrieval. Undeniably, it will play a central role in helping humans navigate climatic crises.

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