

The Role of Remote Sensing and Economic Development: Glaciological Applications with Landsat 4-5 Imagery

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Abstract

Comprehensive use of remote sensing imagery has provided and enabled researches and policy makers alike the ability to study the dynamics of arctic sea-ice relative to global climatic change. Based on Landsat 4-5 imagery, this paper provides a study and analysis of sea-ice variations as located within the polar Northwest Passage as an indicator of global climatic changes. Particularly important is its impact on issues relative to national sovereignty, security and, economic development of countries bordering the arctic region and the world at large.

Keywords: Albedo, Climate Change, Economic Development, Multi-temporal Remote Sensing, Sea-ice Formation and Security threat.

1 Introduction

The polar regions of the world plays an important balance between solar radiation received, atmospheric and oceanic circulation and also, the amount of energy (albedo) reflected back into the atmosphere. Balance between solar radiation received and that scattered and reflected back results in the existence of earth's cryosphere. The remoteness and harsh conditions of the two Polar Regions' make it difficult for direct observation by the human eye and/or other sensors. As such data and imagery obtained by remote sensing satellites and its applicable innovative techniques have provided those interested in the study of the cryosphere a scientific tool box Bindschadler [1]. The World Meteorological Organisation (WMO) has predicted the continuous increase and raise of greenhouse gases mostly made of carbon dioxide and methane in the atmosphere. It predicated an increase of 1.5° C and 4.5° C above the decadal temperature by 2030 Piwowar and LeDrew [2]. Although small ice mass cannot directly affect global climate, large snow and sea-ice are able to directly affect and thus, impact climate as it influences atmospheric and ocean circulation pattern and more significantly, global sea level Bindschadler, Dowdeswell, Hall and Winther 2001 [3]. To buttress this assertion, some researchers adopting a holistic approach to an investigation and analysis of climate

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change, argue that there is a strange interrelation between sea ice and climate as the atmosphere, oceans and ice cover are all components of a single thermodynamic system Maykut and Untersteiner 1971 [4]. Henceforth, a change in one component is more likely to have a direct effect of the whole system. Concomitantly, variables within the cryosphere impact and thus, effect national sovereignty, security and economic development particularly of countries bordering the arctic region. In this paper, the author utilizes Landsat 4-5 imagery to study and analyse sea-ice variations as located within the polar Northwest Passage as an indicator of global climatic changes. Multi-temporal remote sensing (Landsat 4-5) imagery (winter and summer: 1993 and 2003) are employed within ENVI software as it extract temporal signals in spatially coherent manner of sea-ice linkages in the arctic. Apart from the introduction, the paper is divided into seven sections. Section two provides a write up on sea-ice formation; section three equally provide a brief write on sea-ice and the radiation budget. Section four dwells on sea-ice thickness, seasonality and extent; section five analyse the material and methodology used. Section six is about land 4-5 imagery acquisition plan and section seven is about the results and analysis undertaken. In balance of the study then, a brief summation of the properties of the arctic sea ice cover which are directly linked to climate change and economic development is undertaken in section eight __conclusion.

2 Sea-ice Formation

Relatively, fresh water freezes at 0° C, salt water on the other freezes at lower temperatures; seawater then does not free before reaching -1.9° C. As part of the process of brine rejection, salt is excluded from seawater making it denser enabling fresh ice to float. Floating ice serves as a barrier between the ocean and the atmosphere that prevents the transfer of heat and gasses across. The high albedo (reflectivity) and the lack of heat exchange makes sea-ice one important control variable on global climate regimes Marsden and Mysak 1991 [5]/ Ruddimann 2001 [6].

3 Sea-ice and the Radiation Budget

Since darker surfaces tend to have lower albedos as they absorb many wavelengths emitting from the sun, lighter surfaces on the other hand reflect most of its wavelengths. This results in snow and sea-ice surfaces having high albedos compared to snow-less and uncovered surfaces. Snow and/or ice albedo at the high latitude can reach 60 percent; oceans at the same latitude reach near 10 percent. The positive feedback of sea-ice increases albedo effect with an increase in the size and extent. Thus, whenever sea-ice melts the opposite is the norm Hartmann 1994 [7].

4 Sea-ice Thickness, Seasonality and Extent

The relative thickness of sea-ice to a degree reflects the average winter temperature and that of mid-summer solar radiation. Therefore, a reduction in the average thickness of sea-ice in the arctic region may be indicative of global warming and hence, climate

change. In terms of areal extent, the arctic sea-ice has average seasonal cycle reading between a minimum of $8.5 \times 10^6 \text{ km}^2$ in the summer (September) to a winter maximum of $15 \times 10^6 \text{ km}^2$ in March _ see Figures 1 A and B respectively Gloersen and Campbell 1988 [8]/ Parkinson and Cavalieri, 1989 cited in Piwowar and LeDrew 1995 [2]. During winter months, new ice rapidly forms on sea surfaces as a result of heat loss; in the summer months, the development of dark open water surfaces within sea-ice cover absorb more solar radiation than the reflective ice cover thus, enhancing the processes of melting (Carsey, 1992; Cavalieri, 1994 cited in Bindshadler 2001 [1]. Remote sensing technology is needed and required as no other approach allows for the study and measurements to be made at the required spatial and temporal resolutions. In addition to seasonality, the large extent of arctic sea-ice calls for and requires such advanced technology. A major limitation in the application of remote sensing technology in monitoring the northern cryosphere is the inability to access data and imagery during the long polar night of winter (with the exception of bands located at thermal infrared wavelengths). Also, arctic cloudiness averages 70 to 80 percent from June to August thus, impacting the ability to access clear imagery of the northern cryosphere. Moreover, surface discrimination is to less extent inhibited by saturated bright ice and snow returns (Comsio and Sullivan 1986 [9]. However, Landsat imagery more or less serves as an effective proxy for field observations allowing for the validation of ice-classification algorithms and discrimination of sea-ice and other surface features.

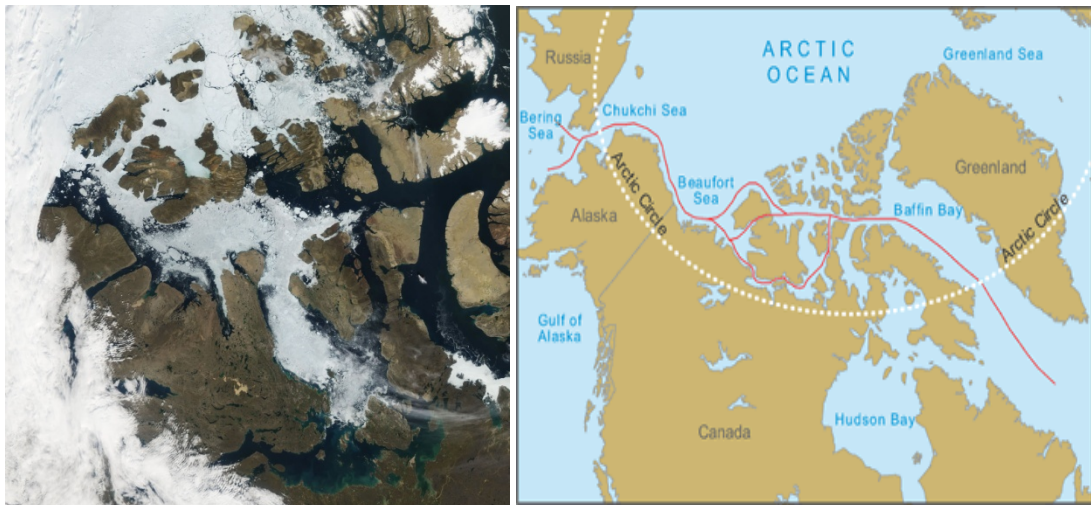


Figure 1A: Satellite Image of the Northwest Passage, Figure 1B: Map of the Arctic Sea
Source: The Canadian Archipelago [10], Geology.com/Map Resources [11].

5 Materials and Methodology

For the purposes of multi-decadal investigation and analysis of the cryosphere, an advantage was taken of the enormous potential of satellite and associated techniques in imagery calibrations. To a measure, this is to overcome such noted limitations the relatively short time window that enables snow and sea-ice offer the maximum amount of information; the vast extent of sea-ice cover in the arctic; the pervasiveness of cloud cover; the prolonged periods of arctic day and night; and more importantly, the automated

difficulty in discriminating between land, water, snow and sea-ice. The methodology employed in this study is explained below.

6 Landsat 4-5 Acquisition Plan

To take advantage of the potential of satellite imagery in this study, a systematic collection strategy is required and followed. Land, water and sea-ice (between 59.84668N and 87.51665W) imagery were obtained from the Earth Resources Observation and Science Center (EROS)/ Glovis Global Visualisation Viewer hosted by the United States Geological Survey. Since at high polar latitudes large proportion of the Earth's surface is ice covered and, to enhance the robustness of the study, both winter and summer (1993/2003) imagery of the study area was acquired. To increase visibility and hence, reduce cloud cover late summer imagery is preferred because sun elevations are low highlighting subtle surface relief. The winter (1993- February-18) __ see Figure 2 A and summer (1993- September-03) __ see Figure 2 B scenes contained within Landsat 4-5 below were acquired.

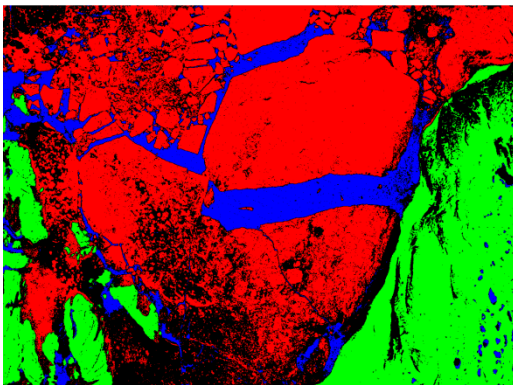


Figure 2A: Satellite Image: Winter

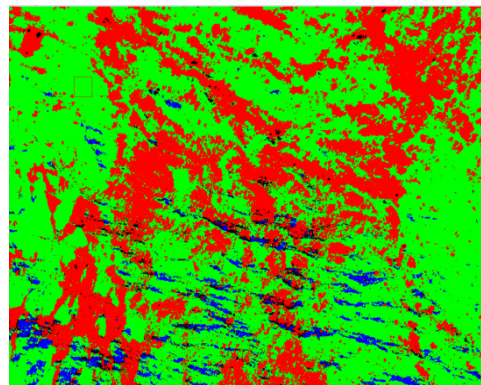


Figure 2B: Satellite Image: Summer

Source: United States Geological Survey [12], United States Geological Survey [12].

In order to compare and contrast land, water and sea-ice extent within the study area relative to climate change, Landsat 4-5 scenes for winter (2003-March-03) _ see Figure 3 A and summer (2003 –September-06) were equally acquired and processed using ENVI 4.7.

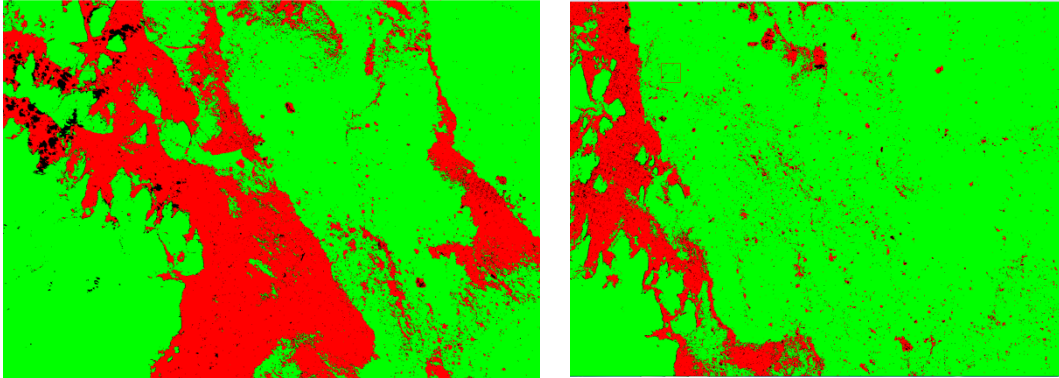


Figure 2A: Satellite Image: Winter Figure 2 B: Satellite Image: Summer
 Source: United States Geological Survey [12], United States Geological Survey [12].

Since the land cover (land, water and sea-ice) in this study was not obtained in situ, a supervised classification technique was undertaken. This was accomplished after having extracted the Meta GeoTIFF imagery and digitised the area of study as part of obtaining multiple polygons for the training data in ENVI using the Region of Interest Tool: Sea-ice [Red]; Water [Green]; and Land [Blue]. Associated with this process was changing the grey scale band into Red, Green and Blue colour bands of 4, 3 and 2 respectively. Due to heavy cloud cover, automatic classification of the imagery could not be effected. Rather, after spatially subsetting the images, a parallelepiped supervised classification was undertaken. The results acquired and processed imagery are ready for analysis based on their associated statistical computations __ confusion matrix.

7 Results and Analysis

The use of Landsat 4-5 imagery in this brief study has contributed to research of the cryosphere. Thus, it is applied as a proxy ground-truth for the determination of particularly sea-ice concentration within the Northwest Passage relative to climate change. Visualisation and examination of the four imagery above brings to light the interrelationship between Sea-ice shrinkage and climate change. The area coverage of Sea-ice [Red] in 1993 (both winter and summer) in contrast to 2003 scenes shows a discriminated decrease in the Sea-ice extent by 2003. This assertion is buttressed below by the line graphs _ Figure 3 (A and B) and their associated Kappa Coefficient (κ). The equation for κ is:

$$\kappa = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)} \tag{1}$$

Where $\Pr(a)$ is the relative observed agreement among raters, and $\Pr(e)$ is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly saying each category. If the raters are in complete agreement then $\kappa = 1$. If there is no agreement among the raters other than what would be expected by chance (as defined by $\Pr(e)$), $\kappa = 0$ [13].

The Kappa Coefficient assesment is analysed according to yardstick provided by Landis and Koch 1977 [14].

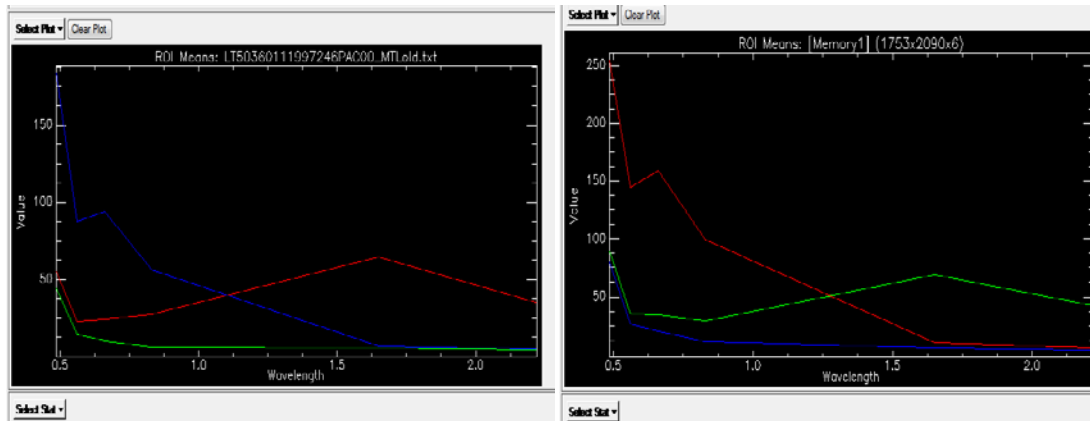


Figure 3A: Sea-ice cover: Summer (1993) Figure 3B: Sea-ice cover: Summer (2003)
Source: Authors compilation (2013), Authors compilation (2013).

Confusion Matrix: [Memory1] (1719x2056x1)
Confusion Matrix: [Memory1] (1953x2289x1)
Overall Accuracy = (3534264/3534264) 100.0000%
Overall Accuracy = (4470417/4470417) 100.0000%
Kappa Coefficient = 1.0000
Kappa Coefficient = 1.0000

From the above line graphs, one could deduce that sea-ice cover (Red Line) in late summer of 1993 __ see Figure 3 A, was higher relative to water coverage (Green Line). In contrast, in the summer of 2003__ see Figure 3 B, the extent of sea-ice had reduced in size relative to water coverage within the study area. The Kappa Coefficient is almost perfect (1.0) in terms of accuracy. The reduction in sea-ice thickness and coverage means a reduction in its surface albedo (reflectivity). This increases the interrelationship as a variable on global climater regimes. Increases in the water coverage area at such high latitude has an albedo of 10 percent compared to sea-ice and/or snow cover that record a high figure of 60 percent respectively. Water bodies absorb more solar radiation than the reflective sea-ice cover, thus enhancing the processes of melting and climate change. The increased coverage of water relatively, opens up the Northwest Passage in the arctic for commerical shipping and exploration of sea-bed minerals. However, a negative concomittant effect is the heighthen security threat resulting from nations competing for the up-coming shipping lanes and minerals within the arctic region.

8 Conclusion

In this paper, the importance and critical role remote sensing techniques play in monitoring land cover change__ cryoshpere has been brought to the fore. An analysis of Landsat 4-5 imagery processed via ENVI software parkage, indicated changes to sea-ice extent, that is, spatial and temporal resolution by remote sensing techniques to make these

variables potential global climatic indicators. Furthermore, examination of these imagery in addition to the large temporal variability exhibit seasonalities. Apart from mineral desposits, the potential of the Northwest Passage are significant in the face of climate change. However, for the first time in human recorded history, the probability of modern nation states going to war over sovereignty and issues of economic resources are quite high.

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