Introduction

Monitoring Change

“Change doth unknit the tranquil strength of men.”

Matthew Arnold, *A Question*

“To some will come a time when change itself is beauty, if not heaven.”

Edward Arlington Robinson, *Llewellyn and the Tree*

Change is a loaded word. It stirs the imagination of the poet. Yet somewhere between the insecurity of disruption and the excitement of new opportunities there is a more pragmatic notion, to

contemplate continually all things coming to pass by change, and accustom yourself to think that Universal Nature loves nothing so much as to change what is and to create new things in their likeness. For everything that is, is in a way the seed of what will come out of it…

Marcus Aurelius, *Meditations* book iv section 36

As this Roman Emperor acknowledged, part of nature is to change and our future is derived from those things changing. It is wise to acknowledge that change occurs, responding to that change in a way which can improve our future. Monitoring changes in the landscape and our environment can help reduce the effects of detrimental changes and guide policy or programs working to eliminate further degradation. Consider these examples. The National Wetlands Inventory’s one primary objective of producing comprehensive, statistically valid estimates of the Nation’s wetlands acreage is done to monitor changes in these critical areas and guide policy (Dahl *et al.*, 1991; Tiner, 1984). The National Oceanic and Atmospheric Administration Coastal Change Analysis Program
(NOAA C-CAP) has been established to provide land cover change data based on the idea that these data are essential to the implementation of a “No Net Loss” wetland policy (Dobson et al., 1995, p. 2). The National Forest Management Act (NFMA) of 1976 implicitly requires change analysis by mandating that forest management plans “shall be revised from time to time when … conditions in a unit have significantly changed” (NFMA, 1976, section 6.f.5). These are only a few of the national and international programs set up to monitor regional and/or global change. For each of these examples the idea is to monitor change, then react in a way to promote sustainable development to preserve the environment or minimize further environmental degradation.

Perhaps the most important initial concern for regional or global environmental monitoring is obtaining reliable measurements of change. Utilizing the unique perspective from space, satellite imagery can provide relatively accurate and timely data for monitoring large areas. Two current national programs which are relying on satellite imagery to provide foundational data for large-area change detection are the NOAA Coastal Change Analysis Program and the National Aeronautical and Space Administration (NASA) Mission to Planet Earth (MTPE). The research contained in this dissertation is connected to both of these programs. The satellite imagery and the corresponding ground area covered in this research are a subset of the imagery and area covered by the C-CAP study “Land Cover Inventory and Change Detection of Coastal North Carolina using Landsat Thematic Mapper Data” (Khorram, et al., 1994), being conducted at the Computer Graphics Center (CGC) concurrently with the research presented here. The explorations and findings presented in the following research are meant to compliment the CGC C-CAP project. They are also meant to support the general vision of NOAA to couple societal and economic decisions with solid environmental research (Baker, 1995). The second program with which this thesis is connected, NASA’s MTPE, is through the Earth System Science Graduate Student Fellowship (formerly named the Global Change Fellowship). As the following research has been funded by this program, it has been focused in the direction given by MTPE which is to observe, monitor and assess large scale environmental processes (NASA -
“What is MTPE”, 1996). Both of these programs are interested in change detection. Both call upon satellite data to provide foundational data. The research presented in this report should help future work in these and other programs which rely on satellite data, or, in general, image processing, to determine change.

**Current Change Detection Methods**

A popular change detection technique for large areas is to use the spectral information from two satellite images acquired at different dates. This method considers individual pixels in an image and compares them to their corresponding pixels from the other image. For each pixel, if the *difference* between the reflectance values from the two images is *big enough*, the area represented by that pixel is considered to have changed. Change detection methods vary in how they determine if the “difference” is “big enough”. First there is the question of what is meant by “difference”. Is it changes in infrared reflectance? Is it changes is some vegetation index? In general, the “difference” is some function of the reflectance values. For example, the difference might be a simple subtraction of the infrared reflectance for a pixel at one time from the infrared reflectance for the corresponding pixel at another time. The next question is how big is “big enough”. This is the issue of choosing a threshold. If the difference is beyond the threshold then the area represented by the pixel is believed to have experienced a change in land cover sometime between the two images’ acquisition. A binary change images is created by labeling those pixels whose functional values are beyond the threshold as changed and those pixels whose functional values are less than the threshold to be unchanged. Choung (1992) and Fung and LeDrew (1988) have investigated the determination of optimal threshold levels. Both studies reveal an intuitive balance of errors for various threshold levels. For example, with image differencing the lower the threshold, the more non-changed pixels were classified as changed (commission errors); the higher the threshold, the better the chance of changed pixels classified as non-changed (omission errors).
In all studies that create a binary change image, the value at which the threshold is set is somewhat arbitrary. With respect to image differencing, Jensen states that “most analysts prefer to experiment empirically...thus the amount of change...is often subjective and must be based on familiarity with the study area” (1996, p.269). With respect to the application of a binary change mask, the final outcome is dependent on the quality of the mask (Jensen, 1996, p.270) and the quality of the mask will depend on the appropriate threshold level for the mask (Jensen et al., 1993). In order to avoid the subjectivity and arbitrary nature of setting a threshold, we have worked to develop a procedure that can be used as a more analytical method for investigating the effect of the location of the threshold level on the change detection accuracy.

**Proposed Method**

In this dissertation we explore the use of generalized linear models (GLMs) as a way to enhance satellite based change detection. Generalized Linear Models are a broad class of regression-type models. The use of GLMs has continued to gain attention since they were introduced by Nelder and Wedderburn in 1972 (Agresti, 1990). Unlike standard linear regression, GLMs can be used to model binary or discrete response variables. In this dissertation, the main idea is that GLMs can be used to regress the binary response of "change/no-change" on the reflectance values from satellite imagery. The binary response is determined from the interpretation of air photos. The radiance values are extracted from the satellite images.

The object of this dissertation is to defend the thesis that GLMs can be used to enhance satellite-based change detection. This will be done by describing how GLMs fit into the existing change detection algorithms and then conducting an example change detection utilizing GLMs. There are three ways to utilize the models. First GLMs can help select the most significant set of explanatory variables to use in the change detection. Next, the output from the GLMs can be used to produce what we will refer to as "accuracy assessment curves". These curves show the relationship between the threshold value used...
to classify change areas and the accuracy of this classification. The third use is through incorporating the modeling with the image data to produce continuous "probability of change" (POC) images in which the pixel values range from zero to one. These values represent the probability that the area represented by that pixel has changed. Through these three components, GLMs enhance satellite based land cover change detection by guiding a more quantitative procedure and producing a more informative change detection product.

The dissertation is arranged as follows. The next chapter, Chapter 2, describes the materials used in our example. This includes a description of the image and reference data as well as a brief description of the two land areas. Chapter 3 describes the "pre-processing" of the image data. In this chapter, the two sections "Essential results of geometric correction" and "Essential results of radiometric correction" may suffice for a reader whose primary interest in on the use of GLMs for change detection. In Chapter 4 we digress somewhat with background on satellite based land cover change detection. The final section in that chapter describes the "application of statistical models" to change detection. This sets the stage for the theoretical foundation of the dissertation contained in Chapter 5. In this chapter, change detection is put into the context of GLMs. Chapter 6 starts the example change detection. This chapter describes the sampling technique used to collect the data for the model as well as the modeling results. In Chapter 7 we compare the models resulting from Chapter 6 with a change detection derived from a standard algorithm. It is in this chapter where we introduce "accuracy assessment curves" as a way to compare models. Chapter 8, utilizes the GLMs to produce "probability of change" (POC) and "variability" images. This chapter describes how these images can be used with other spatial information to guide land management. Chapter 9 concludes the dissertation with a summary, a step-by-step guide on how to use GLMs for satellite based change detection, and areas for further research.