

**REMOTE SENSING APPLICATIONS FOR
PHYSICAL AND ECOLOGICAL STATE OF
TURKISH COASTAL WATERS**

83777

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İZMİR

REMOTE SENSING APPLICATIONS FOR PHYSICAL AND ECOLOGICAL STATE OF TURKISH COASTAL WATERS

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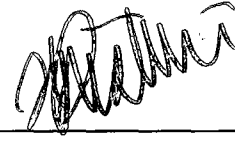
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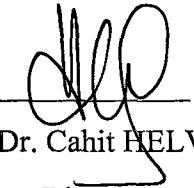
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*to my family
who suffered most*

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A. Hüsnü ERONAT

ABSTRACT

Many projects, modeling and monitoring programs, scientific studies and symposia have been developed concerning the physical and ecological state of the Turkish coasts and coastal waters. Pollution, for instance, and erosion in the Turkish coastal waters have been occurring over a long period of time. However, none of these studies has considered these problems holistically; therefore, only limited, short term solutions have been prepared and/or implemented.

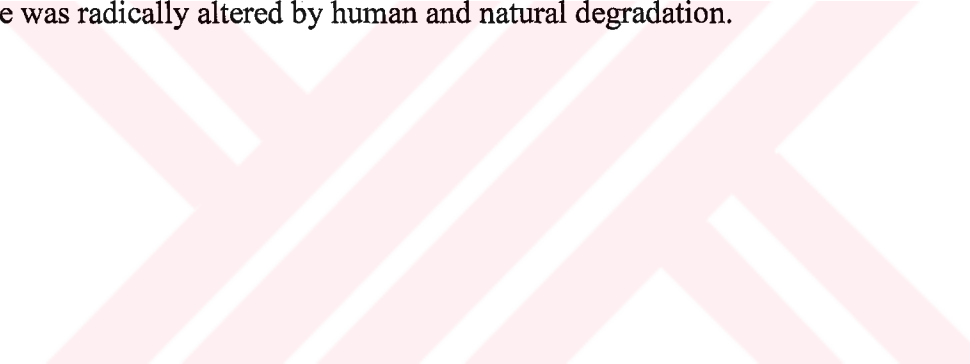
Polar-orbiting satellites like NOAA-9, NOAA-10 and NOAA-14 can cover thousands of square kilometer areas with an overpass frequency of 12 hours. When three satellites are orbiting with 3 daytime and 3 nighttime overpasses it is possible to monitor Sea Surface Temperature (SST) and turbidity when the sky is unclouded. Other satellites such as Landsat 5, have very good spatial capabilities (30 meter), but lack favorable temporal capabilities. The Landsat Thematic Mapper (TM) of Landsat-5 covers a 180 x 180 km area with an overpass frequency of 16 days. This high resolution capability is particularly useful in coastal change studies.

The purpose of this study was to examine the occurrences of pollution and erosion as they are affecting the Turkish coastal waters. This was accomplished by an analysis of the infrared, near-infrared and visible images collected on various dates, as received by the Institute of Marine Sciences and Technology's High Resolution Picture Transmission (HRPT) earth station, SMART Station. Two

Landsat TM (Thematic Mapper) images that were commercially obtained, were also used.

The infrared images that were obtained by the SMART Station were then used to reveal the SST, and also to map small and mesoscale ocean features using their SST signatures. These atmospherically corrected visible images proved that ocean color is a powerful tool for monitoring water quality parameters such as algal and plankton densities that contain a large amount of implicit information about the state of a coastal marine environment. These images can contribute a lot to the understanding of the physical and ecological processes in the sea.

Additionally, analysis of commercially attained Landsat TM images at two different times clearly demonstrated that the physical appearance configuration of the shoreline was radically altered by human and natural degradation.



ÖZET

Uzaktan Algılama, cisimlere direkt temas etmeden onların öncelikle fiziksel ve buna bağımlı olarak da diğer özellikleri hakkında bilgi edinme bilimidir.

Uzaktan algılama sistemi bir aşama dizisidir ve bu da; enerji kaynağından yeryüzü oluşumlarının yansıttığı enerjinin algılanmasına, algılayıcı sistemlerden görüntü işleme/düzeltilme uygulamalarına; sonuç olarak kullanıcı ve yorumlayıcıya kadar uzanan birçok farklı evreyi kapsar.

Uzaktan algılama işlemleri sırasında yansıyan enerji dalgalarının gücünü düşüren hata kaynaklarının varlığı nedeniyle, her uydu verisi bazı düzeltmelere tabi tutulmak zorundadır. Bu düzeltmeler coğrafi, radyometrik, geometrik ve atmosferik olarak sınıflandırılabilir. Su buharı, yanardağ gazları, CO₂, bulutlar, elektronik gürültü ve uydunun görme açısı hata kaynaklarının başında gelir. Atmosferik etkiler, algılayıcıda ve sayısal veri dönüştürme sistemlerinde gürültü olarak görülür. Günümüz bilgisayar teknolojisi ve programlamacılıkta ulaşılan düzey, uydu verilerinin bu tip hata kaynaklarından arındırılmasına imkan tanımaktadır. Geliştirilen algoritmalar, bu veriler üzerindeki algılayıcı sistemlerden kaynaklanan radyometrik ve atmosferde bulunan moleküllerden kaynaklanan atmosferik hataları filtreleyerek yok etmektedir. Dünyanın şeklinden kaynaklanan görüntü geometrisi bozuklukları coğrafi düzeltmeler yapılarak

giderilerek veri coğrafi koordinat sistemine dönüştürülür. Sonuç olarak termal veri sıcaklık değerlerine, görünür kanal verisi ise renk dağılımına göre sınıflanarak, örneğin askıda yük değerleri olarak gözlemlenir veya alg ve plankton gibi su kalitesi parametrelerini etkileyen biyolojik varlıkları tespit ederek kullanıcılara sunulur.

Uzaktan algılamanın günümüzde kullanımı her alanda hızla artmaktadır. Özellikle deniz bilimlerinde uydu verilerinin kullanımı son on yılda büyük bir hızla artmıştır. SeaWiFs, ERS-1, Landsat-5 ve AVHRR gibi yeryüzünü tarayan algılayıcı sistemlerin ve bu sistemleri taşıyan uyduların son yıllardaki teknolojik gelişimi ile birlikte uydu yer istasyonların ve uydu verilerinin analizi günümüz hızlı bilgisayarları sayesinde kolaylaşıp maliyetleri düşmüştür. Böylelikle daha fazla bilim adamının daha çok uydu verisine ulaşması imkanı ortaya çıkmıştır. Veri alım yöntemlerinde çok önemli değişiklikler olmamakla birlikte bunları işleyen programların ve programlarda kullanılan algoritmaların gelişmesi, uydu verilerinin önemini arttırmıştır. Bütün dünyada geniş uygulama alanları bulabilen uzaktan algılama yöntemleri, yurdumuzda da teknolojik gelişmelere paralel olarak deniz bilimlerinde yoğun olarak kullanılmaya başlanmıştır. Bunun yanı sıra, uzaktan algılama diğer bilim dallarında da uygulama alanları bulabilmektedir.

Türkiye'nin Fransa ile yaptığı telekomünikasyon uydu antlaşmasıyla elde edilecek mali kaynak ve teknolojik transferin de gerçekleşmesi sonucunda, Türk yapımı araştırma uydularının da uzaydaki yerlerini almaları mümkün olacaktır. Böylelikle Türkiye'deki bilim çevrelerinin ihtiyaç duyduğu veri akışı sağlanacak ve kullanıcı sayısı ile alanı artmış olacaktır.

Türkiye denizlerinin ve kıyılarının fiziksel ve ekolojik durumu hakkında birçok proje, modelleme ve izleme çalışması, bilimsel çalışma ve sempozyumlar yapılmıştır. Örneğin, Türkiye kıyılarında uzun zamandır deniz kirlenmesi ve erozyon vardır. Ne yazık ki, bu konularda yapılan çalışmalar olayı bir bütün

olarak kabul etmemekte yalnızca dar kapsamlı ve kısa süreli çözümler üretilmektedir.

Kutup yörüngeli NOAA serisi uydular, kısa aralıklı geçiş süreleriyle binlerce kilometrekarelik alanı görüntüler. Üç uydu, 3 adet gece geçişi ve 3 adet gündüz geçişi ile bulutsuz ortamda, yüzey suyu sıcaklığını ve türbiditeyi izleyebilmektedir. Landsat 5 gibi uyduların çözümleme kapasiteleri oldukça yüksek (30m) olmakla birlikte geçiş süreleri aralıktır. Landsat-5 Thematic Mapper (TM) algılayıcısı 180x180 km lik bir alanı, 16 günde bir defa görüntüler.

Belirli bir bölgedeki zamana bağlı değişimleri izlemek için farklı tarihlerdeki Landsat görüntüler üzerinde atmosferik ve geometrik düzeltmeler uygulanarak güneş ve uydu açısının zamansal farklılığı yok edilmekte, böylelikle yeryüzündeki zamana bağlı gerçek değişiklikler ortaya çıkartılabilmektedir. Bu uydunun yüksek çözümleme kapasitesi özellikle kıyı değişimi çalışmalarında iyi sonuç vermektedir.

Türkiye kıyılarını etkileyen erozyon ve kirlenmenin kaynaklarını inceleyen bu çalışmanın ilk bölümünde, Altınova sahillerini uzun yıllardır etkisi altına alan kıyı tahribatını inceleyebilmek için Landsat uydusunun bu yüksek çözünürlük özellikleri kullanılmıştır. Halk arasında “Altınova’yı deniz eritiyor”, “Altınova’da deniz sahili yedi”, “Doğanın intikamı” gibi yorumlara yol açan kıyı erozyonu farklı tarihli uydu verileri kullanılarak bilimsel açıdan incelenmeye çalışılmıştır. İki değişik tarihli Landsat TM görüntüsü, geçmişten bugüne, Altınova kıyı çizgisinin fiziksel görünümünün insan ve doğa tarafından geri döndürülemez bir şekilde bozulduğunu açıkça göstermiştir. Eksik bir planlanlama ile, doğada yapacağı onarılmaz tahribatı düşünmeden inşa edilen Madra Barajı ve yoğun ikinci konut yapılaşması, kısa bir süre içinde doğal bir felaketin kaynakları olarak karşımıza çıkmıştır.

Madra Barajı'nın inşasıyla birlikte, Madra Çayı'ndan gelen su miktarının düşmesinin yanı sıra, bu çay tarafından kıyıya taşınan sediment girdisinde de önemli bir azalma meydana gelmiştir. Böylelikle çay kıyısı besleyemez duruma gelmiştir. Çay yatağında ve sahilde mevcut kumun hem Madra Barajı hem de ikinci konut inşaatları sırasında sorumsuzca talan edilmesi, çok ince dengelerle birbirine bağlı olan doğal süreçler alt üst edilmiş; böylelikle denizin karaya doğru ilerlemesi karşısında hiç bir engel kalmamıştır. Sahildeki kum talanı sırasında bitkilerin kum çalan araçlar tarafından tahrip edilmesi erozyonun etkilerinin daha da büyümesine neden olmuştur.

1989 ile 1996 tarihlerindeki Landsat TM görüntülerinin karşılaştırılması ve buna 1963 ve 1978 tarihli haritalardan çıkartılan bilgilerin eklenmesi sonucunda; 1,530,000 m² sahil arazisine denk gelen 3,000,000 m³ plaj kumunun deniz tarafından taşındığı belirlenmiştir. Elde mevcut bulunan 34 yılı kapsayan veriler üzerinde görüntü işleme ve Coğrafi Bilgi Sistemleri tekniklerinin kullanılmıştır. Bu çalışmalar sonucunda, bazı yerlerde denizin karaya doğru 200 ila 250 metre arasında ilerlediği ama genelde kuzey kıyılarında 4000 metre uzunluğunda 50 metre genişliğinde arazinin deniz tarafından yok edildiği ortaya çıkmıştır. Ayrıca, eldeki verilerin karşılaştırılması, erozyonun %50 sinin Madra Barajı'nın inşası ile başlayan son yedi yılda meydana geldiğini göstermiştir.

Bu çalışmanın ikinci kısmını oluşturan ve Türkiye kıyılarını etkileyen kirlenmenin kaynaklarının incelendiği bölümde, Deniz Bilimleri ve Teknolojisi Enstitüsü (D.B.T.E.) Uydu Yer İstasyonu (SMART Station) tarafından alınan görünür, yakın kızıl ötesi ve kızılötesi görüntüler kullanılmıştır.

D.B.T.E uydu yer istasyonu tarafından alınan kızılötesi görüntüler kullanılarak İzmir Körfezi genelinde, deniz yüzeyi sıcaklığı haritalanması ve termal karakteristikler kullanılarak da küçük ve orta ölçekli oşinografik oluşumların haritalanması gerçekleştirilmeye çalışılmıştır. Atmosferik düzeltmesi yapılmış görünür kanal verilerinden hareket edilerek, deniz yüzeyi renk

farklılıklarının, denizdeki alg ve plankton varlıklarının tespiti gibi su kalitesi parametrelerinin incelenmesi ile uzaktan algılamanın deniz ortamındaki fiziksel ve ekolojik oluşumların anlaşılmasında yararlı bir araç olduğu görülmüştür.

Üç yıllık bir süreyi kapsayan ve İzmir Körfezi'nin deniz yüzeyi sıcaklığını gösteren haritalar kullanılarak Körfez için yüzey sıcaklığı aylık ortalama değerleri hesaplanmıştır.

AVHRR verileri kullanılarak yapılan çalışmalar sırasında Karadeniz kökenli suyun, Ege Denizi suyunu etkilemesinde öte, belirli atmosferik ve oşinografik şartların oluşması halinde Ege Denizi'ni boydan boya geçip İzmir Körfezi suyunu da etkileyebileceği gözlenmiştir.

Ayrıca İzmir Körfezi yüzey sıcaklığı değerlerinin tespiti sırasında gözlemlenen ve R/V K.Piri Reis tarafından elde edilen CTD ölçümleri ile desteklenen normal mevsimsel maksimumun 2-3°C üstündeki sıcaklık değerleri, İzmir Körfezine tabandan gelen sıcak su kaynağının varlığını göstermektedir.

Uydu verileri ile yapılan çalışmalar göstermiştir ki; deniz bilimciler, daha önce elde edilen uydu verilerinden edindikleri deneyim temelinde gemi izleme ve örnekleme programı planlayabilirler, araştırma gemisinin seferi sırasında elde edecekleri görüntülerden gözlemledikleri değişen veya normal dışı oşinografik olaylara gemiyi anında yönlendirebilirler ve sefer sırasında elde edilecek *in situ* veriler ile uydu verilerini kalibre edebilirler. Böylelikle araştırma gemisinin gerçek verileri elde edemediği yerlerde bu kalibre edilmiş değerleri kullanarak gerçek verilere yakın veriler elde edebilirler.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Many projects, modeling and monitoring programs, scientific studies have been developed and symposia conducted concerning the physical and ecological state of the Turkish coasts and coastal waters. Pollution, for instance, and erosion in the Turkish coastal waters have been occurring over a long period of time. However, none of these studies have considered these problems holistically; therefore, only limited, short-term solutions have been prepared and/or implemented.

Studying oceanic processes from research vessels is very hard because of temporal and spatial considerations. In a marine environment, most processes occur in a short time, much faster than research vessels can cover a large area or map them. Thus, use of remote sensing and image processing methods in today's world is rapidly increasing in every field of earth sciences. The use of visible, infrared, thermal and microwave images in the marine sciences has increased dramatically over the last 20 years. The technical advancement of image sensors and immediate processing of obtained images by advanced computers and software has made remotely-sensed images a less expensive and more accessible monitoring tool than traditional field data gathering methods for many scientists in various disciplines. Systematically collected remotely-sensed data of the entire Turkish coasts will improve scientific understanding of physical and biological processes in these areas.

Polar-orbiting satellites like NOAA-9, NOAA-10 and NOAA-14 can cover thousands of square kilometer areas with an overpass frequency of 12 hours. When three satellites are orbiting with 3 daytime and 3 nighttime overpasses it is possible to monitor Sea Surface Temperature (SST) and turbidity when the sky is unclouded. Other satellites such as Landsat-5, have very good spatial capabilities (30 meter), but lack favorable temporal capabilities. The Thematic Mapper (TM) of Landsat-5 covers a 180x180 km area with an overpass frequency of 16 days. This high resolution capability is particularly useful in coastal zone management studies.

The purpose of this study was to examine the sources of pollution and erosion as they are effecting the Turkish coastal waters. This was accomplished by the analysis of the infrared, near-infrared and visible images collected on various dates, as received by the Institute of Marine Sciences and Technology's High Resolution Picture Transmission (HRPT) earth station, SMART Station. Two Landsat TM (Thematic Mapper) images that were commercially obtained, were also used.

The infrared images that were obtained by the SMART Station were used to reveal the SST, and also to map small and mesoscale oceanic features using their SST signatures. These atmospherically corrected visible images proved that ocean color is a powerful tool for monitoring water quality parameters such as algal and plankton blooms and understanding physical and ecological processes in the marine environment.

Additionally, analysis of commercially attained Landsat TM images at two different times clearly demonstrated that the physical configuration of the shoreline was radically altered by human and natural degradation.

CHAPTER TWO

CONCEPTS OF SATELLITE REMOTE SENSING

Remote Sensing is the noncontact recording of information from the electromagnetic spectrum by means of mechanical, photographic, numeric, or visual sensors located on mobile platforms (Fussell, Rundquist & Harrington, Jr, 1986, p1507).

A satellite remote sensing system consists of three parts: a source of electromagnetic radiation, an object which modifies the radiation in a certain way, and a device which measures the reflected energy.

2.1. Source of Energy

The sun is the primary electromagnetic radiation source of a passive remote sensing system. Remote sensing systems detect radiation from different sections of the electromagnetic spectrum (Figure 2.1). The total energy and spectral composition of radiation are strongly dependent on the temperature of the object. The human eye can detect light only in the visible portion of the electromagnetic spectrum.

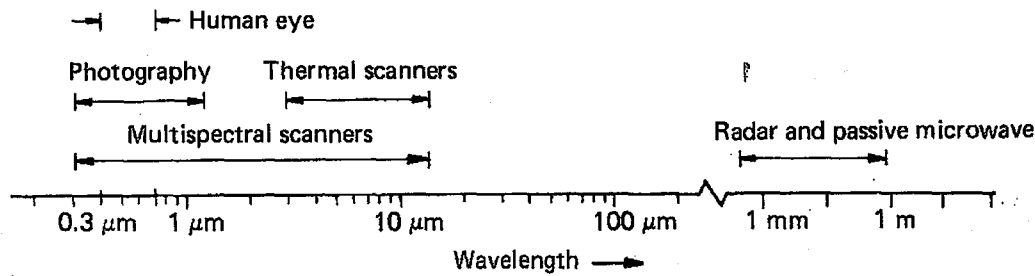


Figure 2.1. Electromagnetic spectrum.

2.2. Atmospheric Interactions

Radiation sensed by the sensors passes through the atmosphere (path length). Atmospheric effects vary according to the travelled path, magnitude of the radiation, atmospheric conditions and the wavelengths. Atmospheric effects are caused by the mechanism of scattering and absorption (Figure 2.2).

Processes of Atmospheric Radiation

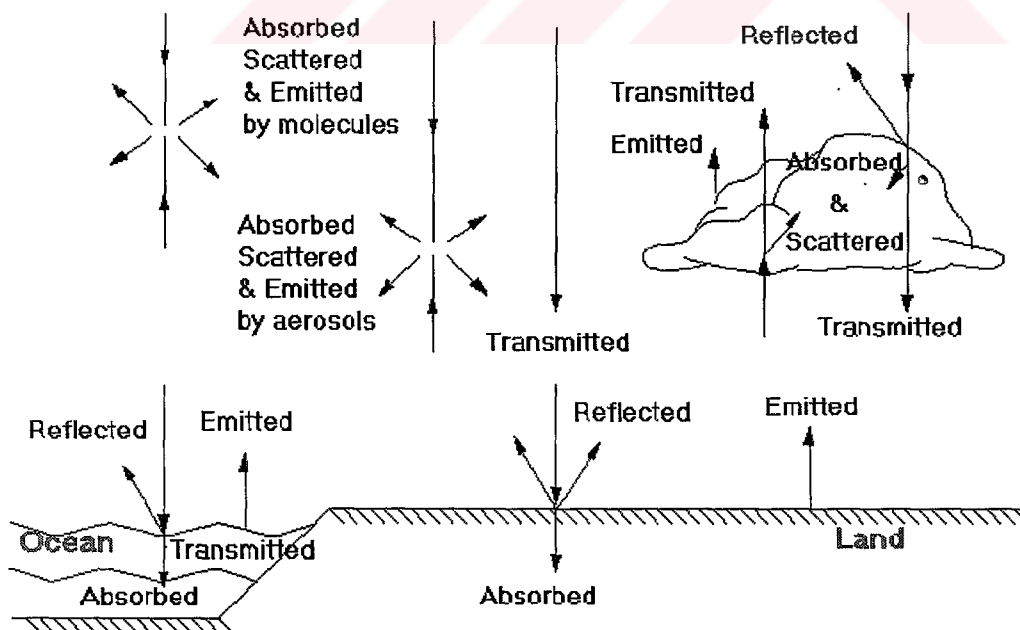


Figure 2.2. Processes of Atmospheric Radiation

2.2.1. Scattering

Atmospheric scattering may be defined as the diffusion of radiation by particles in the atmosphere. Scattering may be classified in three ways:

- *Rayleigh scatter* is common when radiation interacts with atmospheric molecules and tiny particles that are much smaller in diameter than the wavelength of the interacting radiation. The effect of Rayleigh scatter is inversely proportional to the fourth power of the wavelength (Lillesand and Kiefer, 1979, p.10). Scattering effect may decrease with increasing wavelength. Haze in an image is the result of Rayleigh scatter.
- *Mia Scatter* exists when atmospheric particle diameters essentially equal the energy wavelengths being sensed. Water vapor and dust are major causes of Mia scatter (Lillesand and Kiefer, 1979, p.10).
- A more bothersome phenomenon is *nonselective scatter*, which occurs when the diameters of the particles causing scatter are much larger than the energy wavelengths sensed. Water droplets, for example, cause such scatter (Lillesand and Kiefer, 1979, p.10).

2.2.2. Absorption

Absorption is the effective loss of electromagnetic energy to water vapor, ozone and carbon dioxide. These gases tend to absorb electromagnetic energy in specific wavelength bands; they strongly influence “where we look” spectrally with any given remote sensing system. The wavelength ranges in which the atmosphere is particularly transmissive of energy are referred to as *atmospheric windows* (Lillesand and Kiefer, 1979, p.11) (Figure 2.3).

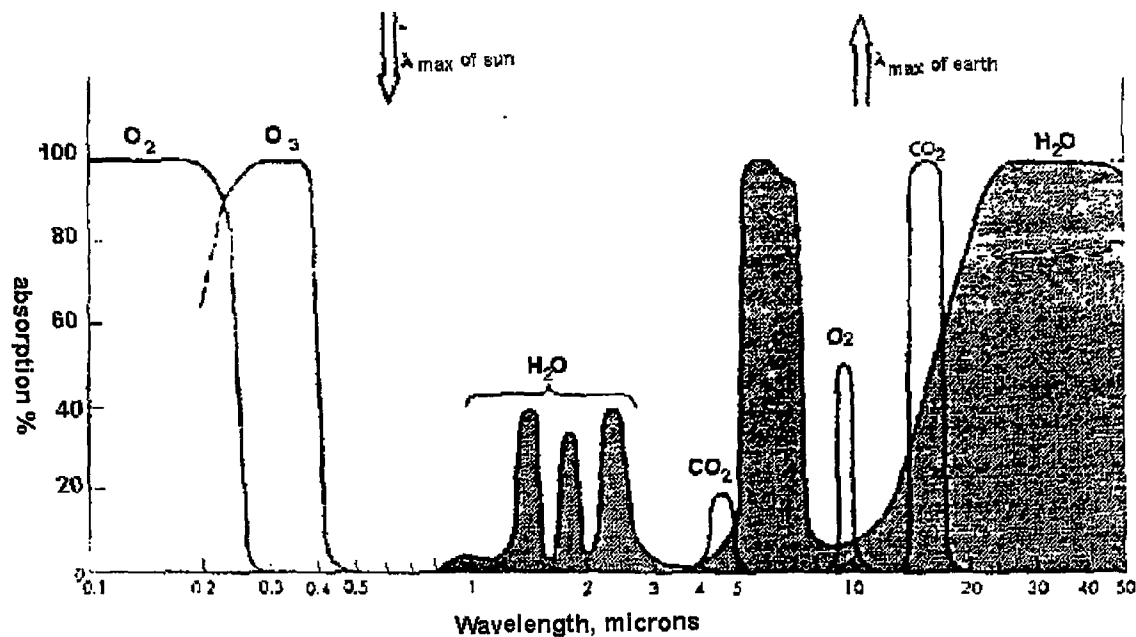


Figure 2.3. Absorptivity of water vapor and other atmospheric gases (UNESCO/IOC, Manual and Guides 24, 1992, p.93)

2.3. Earth Surface Interactions

Electromagnetic energy incident on the water or on any given earth feature is partly *reflected*, partly *absorbed* and partly *transmitted* according to the characteristics of the object and this also varies for different wavelengths (Figure 2.4.). These differences permit us to distinguish different features on an images. Transmission of the energy is mostly very small therefore it may be neglected.

2.3.1. Reflection

Reflection occurs when incoming radiation is redirected by a non-transparent surface. If the surface is rough, incoming radiation is scattered nearly equally in all directions (Verbyla, 1995, p.46). This kind of a surface is called a *Lambertian* surface or perfectly diffuse reflector (exp. uniform lawn). The surface which reflected incoming radiation at a angle equal to the angle of incidence is called *specular* reflector (exp. mirror).

The sensors in remote sensing are in most cases not perfectly aligned with the energy source, so the reflection signal received comes from the diffused energy due

to the surface roughness of the object. Surface roughness depends on the height variations of the object compared to the incident energy wavelength. Thus, the reflectance of an object depends strongly on its roughness compared to the incident wavelength (UNEP/IOC, Technical Report Series, No.67, 1992, p.8).

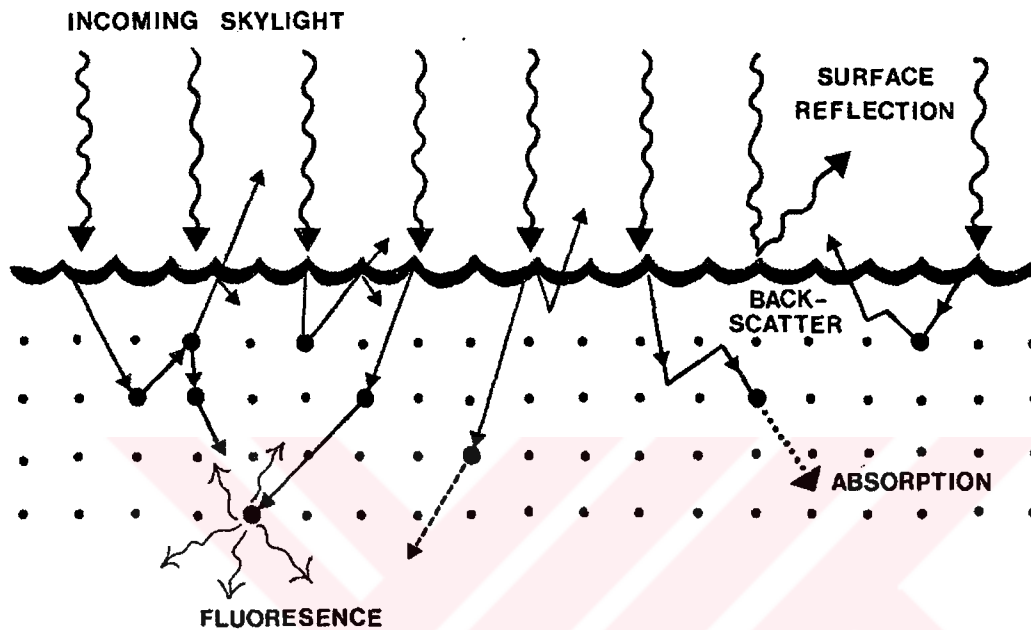


Figure 2.4. Absorption and scattering by sea-water (UNESCO/IOC, Manual and Guides 24, 1992, p.94)

The reflectance characteristics of earth surface features can be quantified by measuring the portion of incident energy that is reflected. This process is measured as a function of wavelength and is called spectral reflectance, R_λ . It is the reflectance ratio for a given range of wavelengths and is mathematically defined as

$$R_\lambda = \frac{E_R(\lambda)}{E_I(\lambda)} = \frac{\text{Energy of wavelength } \lambda \text{ reflected from the object}}{\text{Energy of wavelength } \lambda \text{ incident upon the object}} \times 100$$

where R_λ is expressed as a percentage. Albedo refers to the reflectance ratio for total incoming solar radiation (wavelengths between 0.3 to 4.0 μm).

A graph of the spectral reflectance of an object as a function of wavelength is termed a spectral curve. The configuration of spectral reflectance curves gives us insight into the spectral characteristics of an object and has a strong influence on the choice of wavelength region(s) in which remote sensing data can be acquired for particular applications (Lillesand & Kiefer, 1979, p14). Figure 2.5 shows typical spectral reflectance curves for vegetation, soil and water.

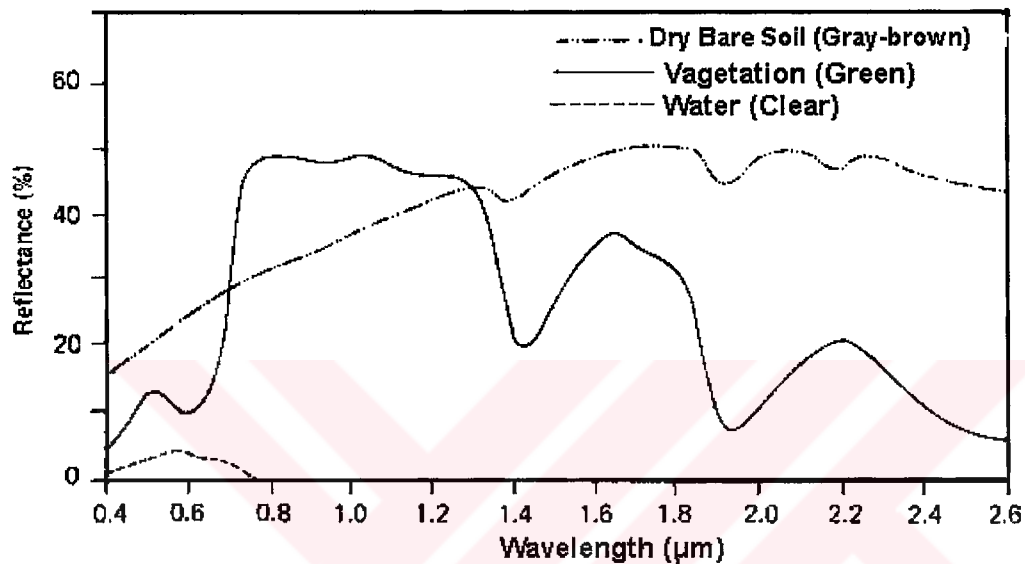


Figure 2.5 Typical spectral reflectance curves for vegetation, soil and water. (Lillesand and Kiefer, 1979, p18)

2.3.2. Absorption

The proportion of incident energy absorbed is subsequently radiated and is qualified by the spectral emissivity of the object. Emissivity may be defined as the emitting ability of materials and has values between 0 and 1 and varies with the wavelength.

2.4. Satellite Driven Sea Surface Temperature (SST)

For purpose of identifying and mapping of the sea surface temperature following corrections have to made an infrared images:

- Cloud detected and eliminated,
- Geometric rectificated,
- Calibration of data (determination of brightness temperature),
- Conversion of satellite received radiance in to water leaving radiance,
- Conversion of water leaving radiance into SST (APP A).

There are many sources of error at the SST determination. The most important error source of the SST data is the atmosphere.

2.4.1 Atmospheric Correction of Sea Surface Temperature

The following information concerning the atmospheric correction of SST was gathered as a result of intensive searching of various WEB sites.

Correctness of the satellite driven SST observations depends on the error introduced by the atmosphere. Clouds, water vapor and aerosols are the main sources of error. Dense and widespread clouds were obvious and easy to detect by the visible channels. However, thin clouds such as cirrus and very low stratus clouds are of major concern. They will lower the sea surface temperature measured by the satellite, but will not so much that the temperatures are obviously wrong. Cirrus clouds are really cold. Therefore, only a few small clouds can contribute large errors. Because they are thin, they are nearly invisible and channel 1 spectral response is unable to detect cirrus clouds.

There are two steps to removing the influence of the atmosphere:

1. Detect and eliminate pixels containing clouds.
2. Once the cloud-free pixels are identified, the remaining pixels are corrected for the residual influences of water vapor.

Cloud Detection Methods

3. Maximum Temperature - all observations of a small surface area over a relatively short period of time are compared, and the highest temperature is retained as the best estimate of temperature in that area.

This method is based on:

- Ocean surface features are more persistent than clouds.
- Clouds are colder than the surface.

This method works poorly for persistent, thin clouds.

4. Two Wavelength IR - compare temperature from 3.7 mm and 10.5 mm. If the temperatures are the same, then we can assume the measured signal came from:

- the sea surface, or,
- uniform clouds, which will probably be detected in a visual image of the area of interest.

If the temperatures at the two wavelengths are different, then there are scattered, undetected clouds in the scene.

5. IR Variability - temperatures of clouds tend to be much more variable in space than temperature of the sea surface. Therefore, all areas having a small deviation from a mean brightness temperature close to that expected of the sea in the region are accepted as good values.

6. Two Wavelength VIS-IR - uses reflected sunlight to detect clouds, on the assumption that the sea is much darker in visible wavelengths than clouds (because clouds are a better reflector of visible light than the sea surface!).

Once cloud-free pixels have been identified, the IR radiance of the remaining pixels must be corrected for the influence of water vapor in the atmosphere in order to obtain accurate values for SST.

Water Vapor Corrections –

7. Single-Wavelength Corrections - Many instruments use only a single IR wavelength, usually 10.5 μm . Therefore, there is no independent information for estimating the influence of water vapor available from the spacecraft. In this case, climatological estimates of water vapor or regional radiosonde observations must be used.

Two-Wavelength Corrections - Because radiation at 10.5 μm is much more sensitive to water vapor than radiation at 3.7 μm , the 10.5 μm measurements can be used to correct the 3.7 μm measurements. The difference in temperature at the two wavelengths is used to estimate the correction for the influence of water vapor.



CHAPTER THREE

SATELLITE, GROUND STATION AND IMAGE PROCESSING SYSTEMS

Marine scientists all over the world, have been using many different types of satellite data to conduct research for quite an extended period of time. Whatever the main purpose for their launch every satellite has application possibilities for oceanographic research. The best example of this is the Landsat series of satellites which were designed chiefly for land applications but are extensively used for oceanographic purposes. Oceanographers started to use satellite data in the late 1960's. Since the launch of the Seasat, TIROS-N/AVHRR (Television Infrared Observation Satellite/Advanced Very High Resolution Radiometer) in 1978. Followed by the launch of the CZCS (Coastal Zone Color Scanner) satellites and their successor SeaWiFS, these satellites have been major tools utilized for oceanographic investigations.

3. 1 Characteristics of the LANDSAT Satellites

Previously, the Landsat series of satellites were named Earth Resource Technology Satellites (ERTS). For more than 20 years, the LANDSAT series of satellites have been recording pictures of the Earth's surface, dramatically changing our perspective of the way in which we visualize our planet. As they are extremely helpful in oceanography through their use in producing detailed maps of shores and areas not larger than 20 thousand square kilometers, it was a shame to rename these satellites as Landsat.

The first generation of the Landsat series of satellites was launched beginning in July 1972. Landsat satellites 1 through 3 carried return beam vidicon (RBV) cameras and the MSS sensor. Landsats 1 through 3 operated in a near-polar orbit at an altitude of 920 km with an 18-day repeat coverage cycle. These satellites circled the Earth every 103 minutes, completing 14 orbits a day. Over these eighteen days, 251 overlapping orbits were required to provide nearly complete coverage of the Earth's surface with 185km wide image swaths. The amount of swath overlap or side lap varies from 14 percent at the Equator to a maximum of approximately 85 percent at 81 degrees north or south latitude. The RBV cameras did not achieve the popularity of the MSS sensor. The MSS sensor scanned the Earth's surface from west to east as the satellite moved in its descending (north-to-south) orbit over the sunlit side of the Earth. Six detectors for each spectral band provided six scan lines on each active scan. The combination of scanning geometry, satellite orbit, and Earth rotation produced the global coverage necessary for studying any change in the land surface. The resolution of the MSS sensor was approximately 80 m with radiometric coverage in four spectral bands from the visible green to the near-infrared (IR) wavelengths. Only the MSS sensor on Landsat 3 had a fifth band in the thermal-IR wavelength

Landsats 4 and 5 marked the beginning of the second generation of remote sensing satellites, which are characterized by two innovations, one spectral and the other spatial. The first innovation refers to the increased capability for data acquisition in the infra-red mode and the second refers to the improved resolution of 30 m. These satellites carry both MSS and thematic mapper (TM) sensors; however, routine collection of MSS data was terminated in late 1992. The MSS sensors aboard Landsats 4 and 5 are identical to the ones that were carried on Landsats 1,2 and 3. The MSS and TM sensors primarily detect the reflected radiation from Earth's surface in the visible and near-infrared (IR) wavelengths, however, the TM sensor provides more in-depth radiometric information than the MSS sensor. The wavelength range for the TM sensor is from 0.45 μm to 0.52 μm (blue), through the mid-IR, into the thermal-IR portion of the electromagnetic spectrum. Sixteen detectors for the visible and mid-IR wavelength bands in the TM sensor provide 16

scan lines on each active scan. There are four detectors for the thermal-IR band which provide four scan lines on each active scan. The TM sensor has a spatial resolution of 30 m for the visible, near-IR, and mid-IR wavelengths and a spatial resolution of 120 m for the thermal-IR band. These satellites orbit at an altitude of 705 km and provide a 16-day, 233-orbit cycle with a swath overlap that varies from 7 percent at the Equator to nearly 84 percent at 81 north or south latitude. These satellites were also designed and are being operated to collect data over a 185 km swath.

All of the Landsats have been in sun-synchronous orbits with equatorial crossing times ranging from 8:30 a.m. for Landsat 1, 9 a.m. for Landsat 2, and up to 9:45 a.m. for Landsat 5.

Table 3.1 Launch and duration dates for the Landsat series satellites.

Satellite	Launched	Decommissioned	Sensors
Landsat 1	July 23, 1972	January 6, 1978	MSS and RBV
Landsat 2	January 22, 1975	February 25, 1982	MSS and RBV
Landsat 3	March 5, 1978	March 31, 1983	MSS and RBV
Landsat 4	July 16, 1982	*	TM and MSS
Landsat 5	March 1, 1984	*	TM and MSS

* in standby mode used for range and command as of December 14, 1993.

3.1.1 Sensor Characteristics

A Landsat 4 and 5 TM scene has an instantaneous field of view (IFOV) of 30 x 30 square meters in bands 1 through 5 and band 7. Band 6 has an IFOV of 120 x 120 square meters on the ground.

Table 3.2 Channel characteristics of the Landsat-MSS

Landsats 1-3	Wavelength(micrometers)	Resolution(meters)
Band 4	0.5 - 0.6 (visible)	80
Band 5	0.6 - 0.7 (visible)	80
Band 6	0.7 - 0.8(near-IR)	80
Band 7	0.8 - 1.1 (near-IR)	80
Band 8	10.4 - 12.6 (thermal-IR)	120

Table 3.3 Channel characteristics of the Landsat-TM

Landsats45	Wavelength(micrometers)	Resolution(meters)
Band 1	0.45-0.52 (visible)	30
Band 2	0.52-0.60 (visible)	30
Band 3	0.63-0.69 (visible)	30
Band 4	0.76-0.90 (near-IR)	30
Band 5	1.55-1.75 (mid-IR)	30
Band 6	10.40-12.50 (thermal IR)	120
Band 7	2.08-2.35 (mid-IR)	30

3. 2 Characteristics of the TIROS-N/AVHRR Satellites

The main advantage for the use of certain satellite data such as the TIROS-N/AVHRR over others is because it is very simple and inexpensive to obtain. Also, all other satellite data is sent by satellite and received by central ground stations. Then the data is corrected, modified and processed which increases its expense to the final users.

However, it is not necessary to invest a large amount of capital or build complicated ground stations which need high technology to obtain the TIROS-N/AVHRR data. A small dish antenna and complementary system are adequate enough to receive AVHRR data.

Even if it has lower resolution than other satellite data, because of the continuous data flow (AVHRR already has two successors in various stages of design and development), ease in obtaining data, daily data repetition, and near-real time direct-readout of the data, necessary corrections may be made by the user. Suitable spectral bands for practical applications make AVHRR data the most widely utilized satellite image data throughout the world.

Table 3.4 Launch and duration dates for the TIROS-N series satellites

Satellite	Launch Date	Date Range
TIROS-N	October 13, 1978	October 19, 1978-January 30, 1980
NOAA-6	June 27, 1979	June 27, 1979-March 5, 1983, July 3, 1984-November 16, 1986
NOAA-B	May 29, 1980	Failed to achieve orbit
NOAA-7	June 23, 1981	August 19, 1981-June 7, 1986
NOAA-8	March 28, 1983	June 20, 1983-June 12, 1984, July 1, 1985-October 31, 1985
NOAA-9	December 12, 1984	February 25, 1985-November 7, 1988
NOAA-10	September 17, 1986	November 17, 1986-present
NOAA-11	September 24, 1988	November 8, 1988-April 11, 1995
NOAA-12*	May 14, 1991	May 14, 1991-present
NOAA-13	August 9, 1993	August 9, 1993-August 21, 1993
NOAA-14	December 30, 1994	April 11, 1995-present
NOAA-15	May 13, 1998	July 7, 1998-present

* According to NOAA Memorandum NOAA 98-74, NOAA-15 replaces NOAA-12 at 10/26/1998.

AVHRR data may be obtained in four classes, namely:

1. High Resolution Picture Transmission (HRPT) data are 1 km resolution data received by real-time ground stations such as the IMST Smart Station:

2. Global Area Coverage (GAC) is sampled on-board the satellite to represent a 4.4 km pixel, allowing daily global coverage that is systematically stored and played back to NOAA ground stations at Wallops Island, Virginia, and Fairbanks, Alaska, in the USA and a station operated at Lanion, France, by the Centre National d'Etudes Spatiales (CNES),
3. Local Area Coverage (LAC) is 1 km data recorded on-board the satellite for later replay back to the NOAA ground stations; and
4. Automatic Picture Transmission (APT) is an analog derivative of HRPT data which is transmitted at a lower resolution and high power for low-cost VHF ground stations (Hastings and Emery, 1991).

3.2.1 Sensor Characteristics

Polar orbiting satellites of the NOAA TIROS-N series carry an instrument package called the Advanced Very High Resolution Radiometer (AVHRR). This is a four or five channel multi-spectral scanner (MSS) (Figure 3.1).

The AVHRR sensor records the energy detected in each of the spectral channels as 10-bit integer values (range of values 0 - 10²³). This 10-bit data value is called the raw count data value (RCDV). The energy detected in channels 1 and 2 (the reflective visible and near IR channels) is a function of:

1. the sunlight scattered by the atmosphere back to the sensor before reaching the earth's surface;
2. the reflective properties of an object on the earth's surface that is struck by sunlight; and
3. the scattering of the reflected sunlight by the atmosphere while traversing the atmosphere to be captured by the satellite sensor.

For the thermal channels the energy detected by the satellite is a function of:

1. the blackbody temperature of an object
2. the emittance properties of the surface (water is assumed to have an emissivity of 1.0); and
3. the scattering and absorption of this emitted radiation as it traverses the atmosphere to the sensor.

The number of spectral channels or bands is dependent on which satellite is being considered. The channels are located in the reflective and emitted thermal portions of the spectrum. The NOAA-N series AVHRR spectral bands are as follows:

Table 3.5.Channel characteristics of the AVHRR.

Channel #	Description	Band Width for NOAA-6,8,10	Band Width for NOAA-7,9,11,12,14
Channel 1	visible band	.58-.68 μm	.58-.68 μm
Channel 2	near infrared (IR) band	.725-1.10 μm	.725-1.10 μm
Channel 3	thermal infrared band	3.55- 3.93 μm	3.55- 3.93 μm
Channel 4	thermal band	10.5-11.5 μm	10.3-11.3 μm
Channel 5	thermal band	Repeated	11.5-12.5 μm

The reflection of the sunlight off land, clouds, and the foliage of vegetative matter generates the data present in the imagery of channels 1 and 2. The reflection and scattering of the sunlight for channels 1 and 2 may be coarsely grouped as two and three dimension processes. The reflection of sunlight off land and the foliage of vegetative matter is a two dimensional process. For oceans (clouds) the reflection of sunlight off the sea (cloud) surface and the penetration and scattering of sunlight within the water column (cloud) determine the raw count data values, thus rendering

a three dimensional process. Scattering by water particles and any other material (living, dead, or inorganic) suspended within the water column is recorded by the AVHRR instrument in channels 1 and 2. Thus, the three dimensional distribution of suspended material within the water column will determine the RCDV for the water pixels. The depth within the water column from which sunlight is scattered back towards the sensor is dependent on the wavelength of light and the vertical distribution of the scatterers.

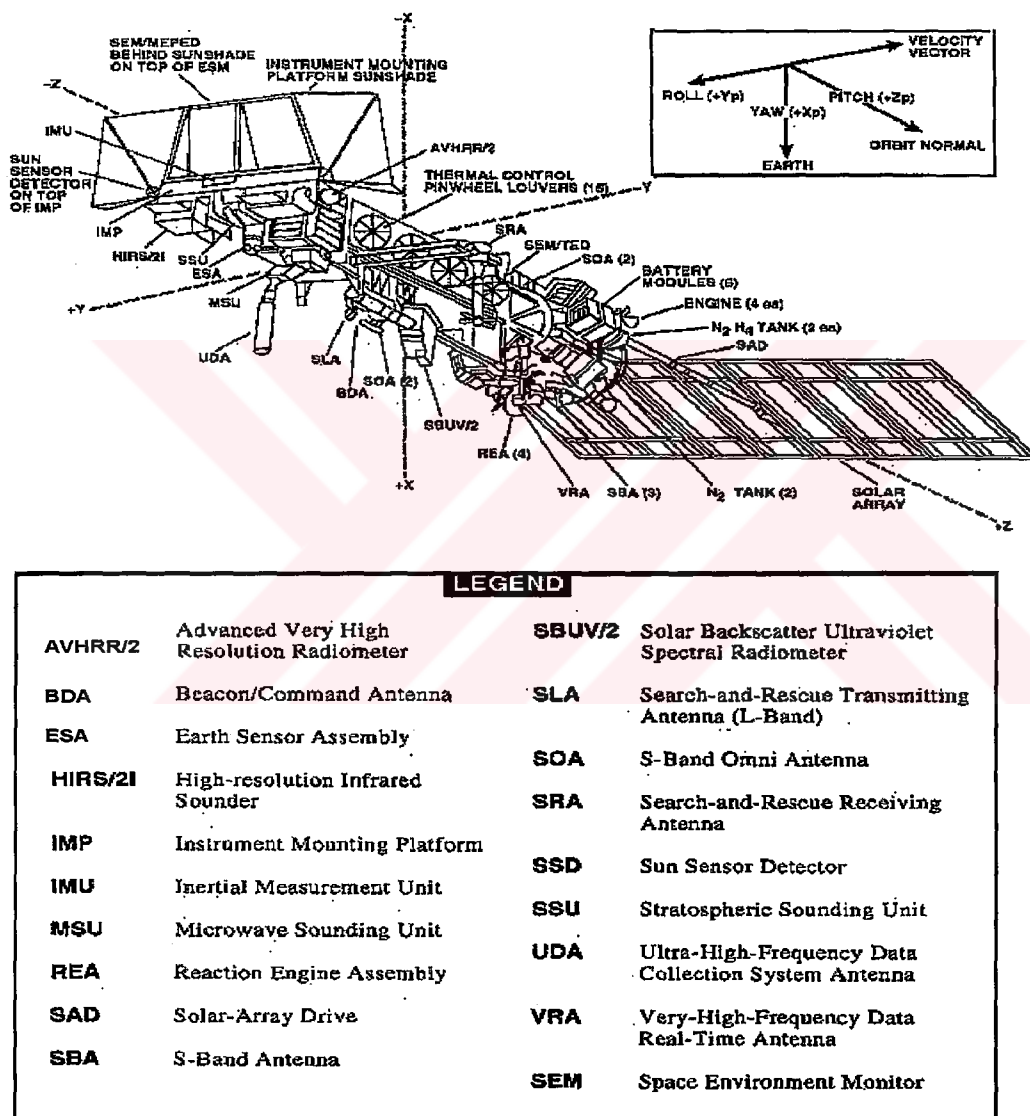


Figure 3.1 Characteristics of the NOAA series of polar orbiting satellites.

Channel 1 (the visible channel) has a water penetration depth on the order of mere meters to ten's of meters. If the amount of scattering is immense, the amount of reflected sunlight detected is large while the penetration depth is small. In open ocean waters the penetration depth is large due to the small number of scatterers. The scattering of sunlight from the sea floor in shallow areas must also be considered as for clear oceanic waters near coral islands the return signal may be primarily due to light being reflected off the coral bottom due to the lack of suspended scatterers.

Channel 2 (the near-IR wavelength channel) has a smaller water penetration depth than the channel 1 visible channel. Water molecules absorb the near-IR energy of sunlight, reducing the amount of sunlight reflected back to the satellite. The absorption in the near-IR channel is such that the water RCDV for channel 2 is generally smaller than channel 1, i.e., channel 2 imagery is darker for water features than the same features in channel 1 (the reverse is true for healthy vegetative matter.). The channel 2 RCDV is larger (brighter) than the values in channel 1, (i.e., channel 2 imagery is brighter for healthy vegetative matter than channel 1). The amount of sunlight that is reflected back in this near-IR band depends upon the amount of scattering produced in the surface layers (decimeters to one or two meters) of the water column. A high return signal for channel 2 indicates highly turbid waters at the sea surface. Clear oceanic waters have a small channel 2 return signal due to the limited number of scatterers in the upper meters of the water column.

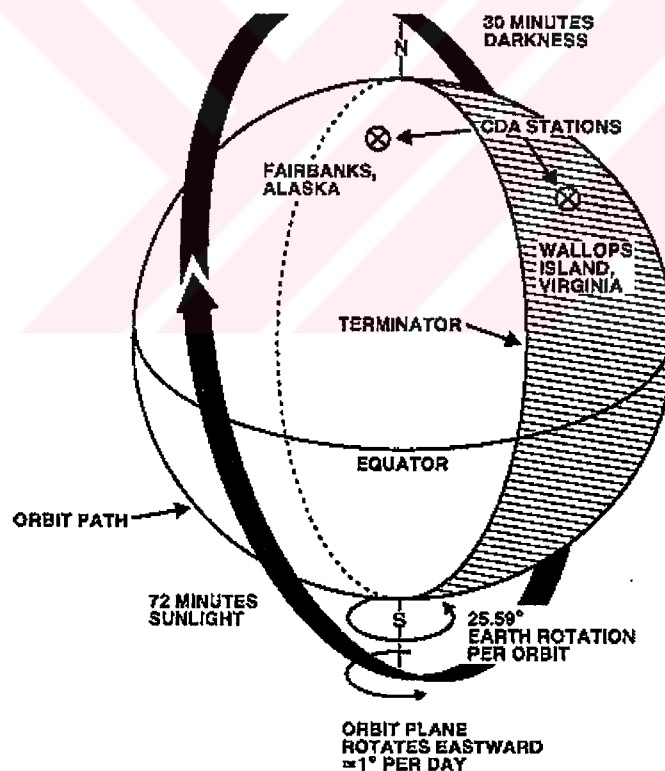
Data from two or three of the thermal channels may be combined through regression equations developed by the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) to generate estimates of sea surface temperatures. These estimated temperatures are called Multi-Channel Sea Surface Temperatures (MCSST). An accuracy of approximately $\pm 1^{\circ}\text{C}$ may be obtained from the MCSST algorithms .

The Field Of View (FOV) of the AVHRR sensor is 110.8 degrees, i.e., it scans through an angle of ± 55.4 degrees from nadir (the point on the earth's surface directly below the satellite). The Instantaneous Field of View (IFOV) of all the

sensor channels is approximately 1.4 milliradians, i.e., the sensor collects data over an incremental angle of 1.4 milliradians. At the nominal satellite altitude of 833 km. the nadir ground resolution is approximately 1.1 km.

The analog signal from the sensors is digitized at a rate equivalent to 0.95 milliradians, which results in a nadir round resolution pixel (picture element) size of approximately 0.8 km. The resulting scan line of data contains 2048 equal-angle pixels. For each pixel the digitized analog signal results in a digital 10-bit raw data count value for all channels which are recorded and stored on magnetic tape.

Orbital characteristics of the NOAA-N series satellites are shown below.



ORBITAL CHARACTERISTICS	
Apogee	870 km (470 nmi)
Perigee	870 km (470 nmi)
Minutes per orbit	102.12

Figure 3.2 Orbital characteristics of the NOAA-N series satellites.

3.3. SMART Station

The SMART Station (Figure 3.4) has the ability to capture images from east of the Caspian Sea to east of the Atlantic Ocean and from the North Sea to south of the Red Sea. For practical reasons the Institute only stores images from the Institute's main areas of interest, namely the Black Sea, Aegean Sea and Eastern Mediterranean Sea.

The Institute's earth station receives two images per day, one during the daytime and one at nighttime. The day images are used for determining Suspended Sediments, Pollution, Plankton Distribution, Currents and Gyres, which effect reflectance. The day images also may be used for Normalized Difference Vegetation Index (NDVI). The night images are used for determining the Sea Surface Temperature (SST).

The SMART Station acquires and processes real time HRPT data from the NOAA series of polar-orbiting environmental satellites (currently NOAA 10, NOAA 12 and NOAA 14). In the near future, SeaWiFS data will be aquired after receiving and attaching an ORBIMAGE Sea Star Ground Processor (SGP) unit to the present system to decode the data.

SMARTTrack is the user interface for the SMART Station. SMARTTrack performs all necessary functions, including:

- Configuration and control of the SMART Antenna;
- Control of the HRPT radio electronics;
- Orbital modeling for on-screen satellite tracking and scheduling data acquisition;
- Maintenance of accurate time using a GPS antenna;
- Capturing HRPT data from the NOAA series of environmental satellites and SeaWiFS data from the Sea Star satellite;

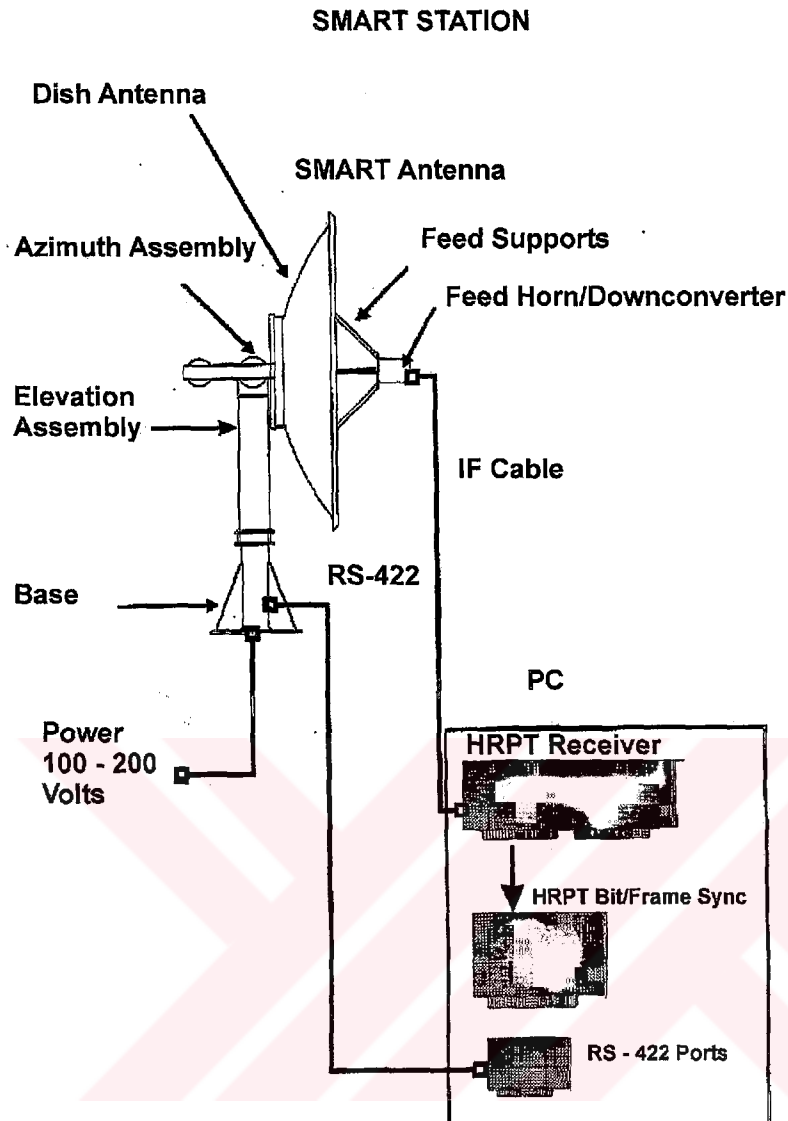


Figure 3.3 SMART Station Components.

- Acquiring orbital elements by connecting with SMARTech using SMART Link;
- Calibrating AVHRR and SeaWiFS data;
- Calculating earth location points for AVHRR and SeaWiFS data;
- Determining sun and satellite zenith angles for AVHRR and SeaWiFS data;
- and
- Exporting AVHRR and SeaWiFS data to ERDAS or NOAA Level 1B for processing.

SMARTTrack functions through a Graphical User Interface (GUI). This interface uses windows, pull-down menus and point-and-click execution via a mouse (Figure 3.5, APP.B).

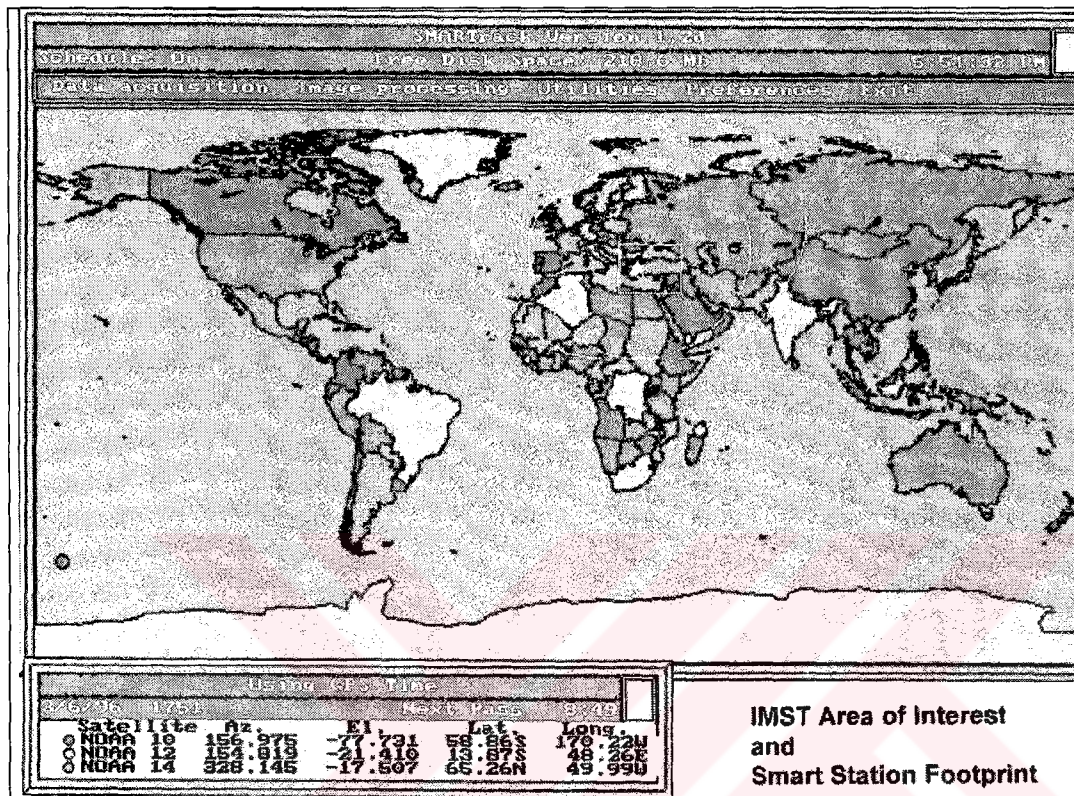


Figure 3.4 The MAP window, which appears on the screen when SMARTTrack is started.

3.4 The KODAK DC50 Camera

The KODAK DIGITAL SCIENCE DCSO zoom camera gives pictures of outstanding quality for computer display and printouts. Since it is fully automatic, taking pictures is simple. It is fully featured, both for taking pictures and using them in conjunction with any computer. The DC50 zoom camera allows great versatility both in taking and using pictures for computer display and output. Through the use of this camera in no time at all the use of bright, colorful pictures in presentations, reports, databases, and web pages will be simple. The following features make the DC50 the best digital camera in its class:

- Square-pixel image sensor designed and optimized by Kodak to give outstanding picture quality,
- Image-processing algorithms that give higher quality pictures,
- Full compatibility with PCMCIA-ATA Type I and II removable cards for fast and convenient handling of image files, and
- 3x zoom lens with close-focusing mode so that the picture may be framed for best composition.

With its 3x zoom lens, close-up mode, and built-in flash, the ability to take the pictures necessary in a variety of situations is fulfilled. The fully compatible PCMCIA-ATA (Type I and II) permits easy storage and quick transfer of the pictures to a computer (APP.C).

3.5 GERMIN GPS90

For aviation use, the GPS 90 became the most widely used handheld GPS by offering pilots powerful navigation features and in the smallest GPS package available. The GPS 90 is the preferred choice of pilots around the world because of its crisp, back lit LCD display, an easy-to-use operating system and up to 20 hours of use on just four AA batteries.

The GPS 90 features a full Jeppesen database complete with runway diagrams, airport frequencies, airport services and altitude sensitive, sectorized Class B and C airspace alerts, all of this data appears on a 2.2 x 1.5 display that offers superior readability even in direct sunlight. It is easily accessible through a few simple keystrokes. The GPS 90s moving map display keeps track of every move of the airplane, along with the presence of nearby airports, navy yards and way points. With continuous track, bearing, distance and ground speed data on screen, the moving map can be used to navigate straight to the destination.

However, the power of the GPS 90 does not stop there. The navigation page provides steering guidance to the destination, complete with VNAV, ETE and cross-track data. Additionally there is a full complement of standard accessories such as a universal yoke mount, power cable and antenna mount. There is also a handheld version of the GPS. GARMIN GPS 90 is the most popular camera for all these reasons among pilots (APP.D).

3.6 The Future of Marine Remote Sensing

In August 1997, with the launch of SeaWiFS (Sea-Viewing Wide Field-of-view Sensor), a new era was initiated in ocean color from space. In February 1998, a new series of operational environmental satellites, namely, the NOAA-K, NOAA-K, L, and M were launched which will be the successors to the current NOAA-operated, polar orbiting satellites. The next generation in the Landsat series of satellites will continue with the launch of Landsat 7 in the future.

These new satellites are carrying and will carry a series of instruments which have been modified and improved from those presently in orbit on board the currently operational satellites (APP. E).

CHAPTER FOUR

REMOTE SENSING STUDIES FOR COASTAL EROSION: ALTINOVA-MADRA CREEK REGION

4.1 Introduction

The Altınova Coastal Region is located in Dikili Bay, south of Edremit Bay and east of Midilli Island between $39^{\circ} 10.3' \text{ N } 26^{\circ} 45.5' \text{ E}$ and $39^{\circ} 20.3' \text{ N } 26^{\circ} 40.5' \text{ E}$. Altınova is one of the most favorite touristic districts around the town of Ayvalık. Altınova and the adjoining municipalities depend considerably upon their coastlines for their economic and social well-being. Madra Creek is the main sediment source for these coastlines. Madra Creek was born and takes its name from Madra Mountain (Madra-Kozak Massif) which is located between Bergama and the Edremit Plains in the northwest section of the Aegean region (Figure 4.1). Madra Creek, known as Kozak Creek in the upper parts, flows over a narrow pass to the southwestern hills, then reaches the Aegean Sea by passing through the southern part of Altınova. In 1991, the narrow pass was closed and the Madra Dam was constructed as part of the Government Water Works Altınova Project, which was planned for the irrigation and drainage of 7872 ha of agricultural land (DSİ, 1998).

Long, sandy beaches and a low wave and tidal energy regime characterize the Altınova portion of the coastline. Despite the low average energy of the Altınova shores, they are highly dynamic, changeable and subject to erosion. The problem of coastal erosion along the Madra Creek and Salta region of the coastline of Altınova

has significantly intensified in recent years. The vibrant beauty of the Altınova coastline is attracting a growing population of homeowners and vacationers; however, the transient character of this coastline makes it hazardous for both people and for buildings and structures. The enlargement of developed land is creating a land disturbance that has increased erosion and sedimentation through hydrologic alteration, which has increased runoff. Ignorance and continued disregard for the geological processes that constantly reshape the Altınova coastline are tragically intensifying collisions between man and nature.

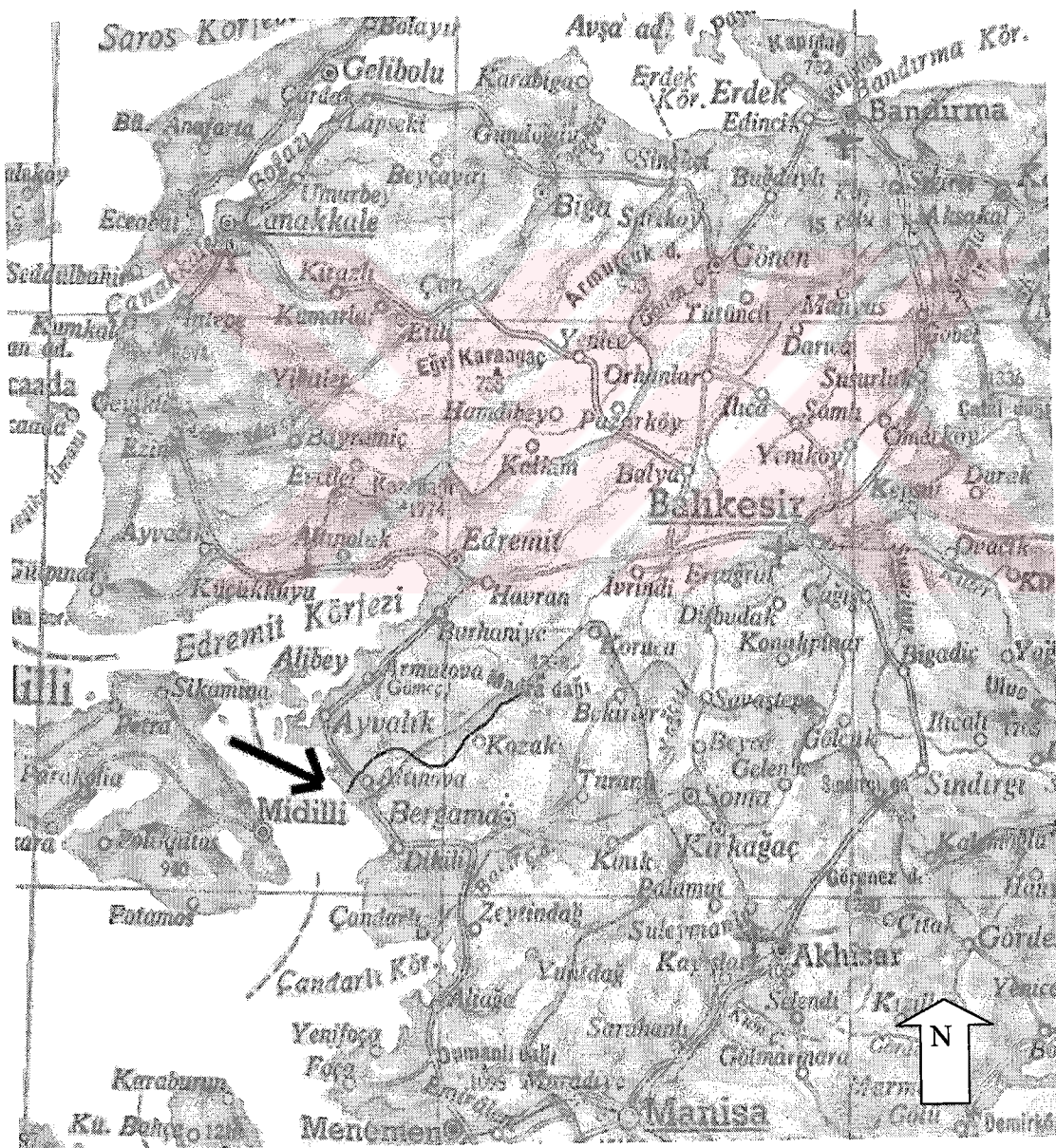


Figure 4.1: Location of the Madra Creek

The erosion of the shoreline is the most visible result of a complex system of sediment transportation and redistribution along the coast and in the coastal region. This system is driven by a variety of processes from a wide range of environments which, over the last 15 years, has resulted in a net loss of 3 million cubic meters of sand from the mouth of the Madra Creek and the beach areas. It has also invoked the movement of sediment up to 6 kilometers across the entire continental shelf north of Madra Creek in the Altınova region.

Diverse and complex *natural processes, local characteristics* of the coast and *human activities* are directly and indirectly modifying and disrupting the Altınova coast and the natural processes that affect this coastal change.

Natural Processes

Natural processes constitute the main cause of erosion in coastal lands all over the world, as they do in the Altınova shores. In general, causes of this type of erosion may include as: waves, tides and storm systems; sea-level changes; and the abundance or lack of coastal vegetation.

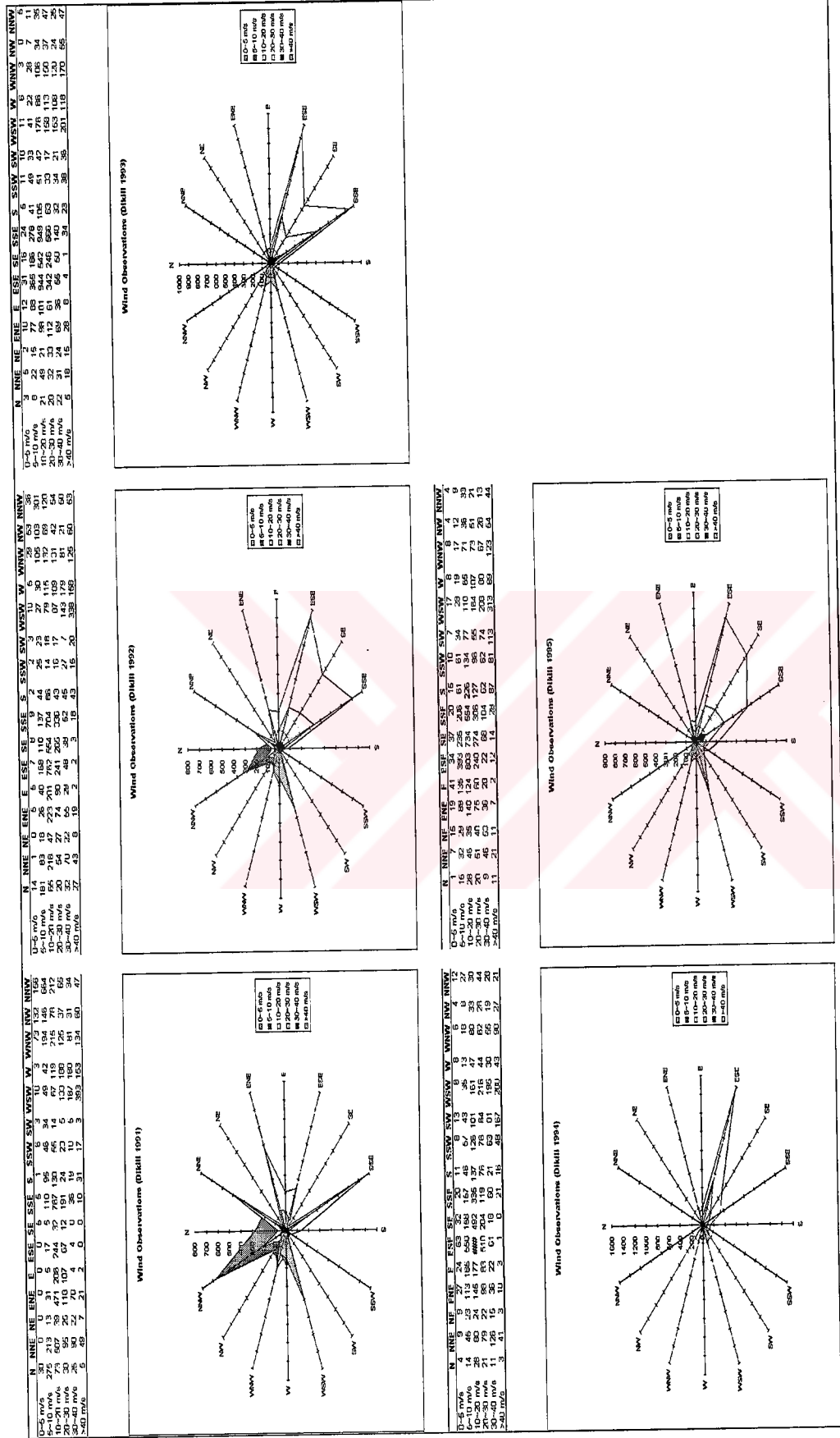
The shores and sediments in Altınova are constantly in motion. Breaking waves move sand along the coast, thus eroding sand from the mouth of Madra Creek and depositing it at the adjacent beaches of the İskele-Çamlık region (İskele Island) which is located 6 kilometers north.

Tidal cycles convey sand onto the beaches and then carry an increased amount back out into the surf. Though there is insufficient conclusive information concerning the tidal regime of this region, it is assumed that the tidal ebb and flood have a minimal effect on the Altınova coastlines because tides and tidal waves are not one of the major causes of erosion at the Turkish coasts (Aksu & Piper, 1983). This phenomenon is due largely to the very restricted amplitudes of tidal cycles along these coasts.

Storm systems along the Altınova coastlines contain moderately high winds (Figure 4.2a,b,c,d,e) which create wave height up to 2.5 meters (ANON. 1997c) and cause storm surges that raise water levels above normal, thus carrying the sand seaward. It may be observed from wind data that the dominant wind directions are sequentially ESE, SSE and SE; however, strong winds which effect the Altınova coast, blow from a WSW and WNW direction on very rare occasions.

According to Kayan (1997), the most suitable way of determining the effects of sea level changes, coastal development and environmental impact on low coasts is by studying core samplings of alluvions that accumulate on those coasts. Western Anatolian coasts are best suited for these types of studies. Shores are formed under the influences of various horizontal and vertical forces. First, elongated bays were formed because of the transgression following the last great ice age at the river mouths, which are located in the structural basins of the Western Anatolian coasts (including Madra Creek (Altınova)). Then, 6,000 years ago, after the sea level reached its recent height, the river mouth bays were rapidly filled up with alluvions and became delta plains. According to Kayan's work, roughly a 2-meter sea-level drop occurred in these coasts between 5,000-3,500 years ago (Figure 4.3) leveling back off to sea level today. Consequently, it is possible to find archeological ruins under the sea surface dating back to these eras reflecting the shifting sea level.

Rooted plants along the coasts of Altınova protect this coastal environment from the pounding waves, stabilizing dunes through their root systems. Tractors entering Altınova beaches for stealing sand at night are not only removing these plants together with the sand but are also damaging their roots while driving over them and causing the beaches to recede.



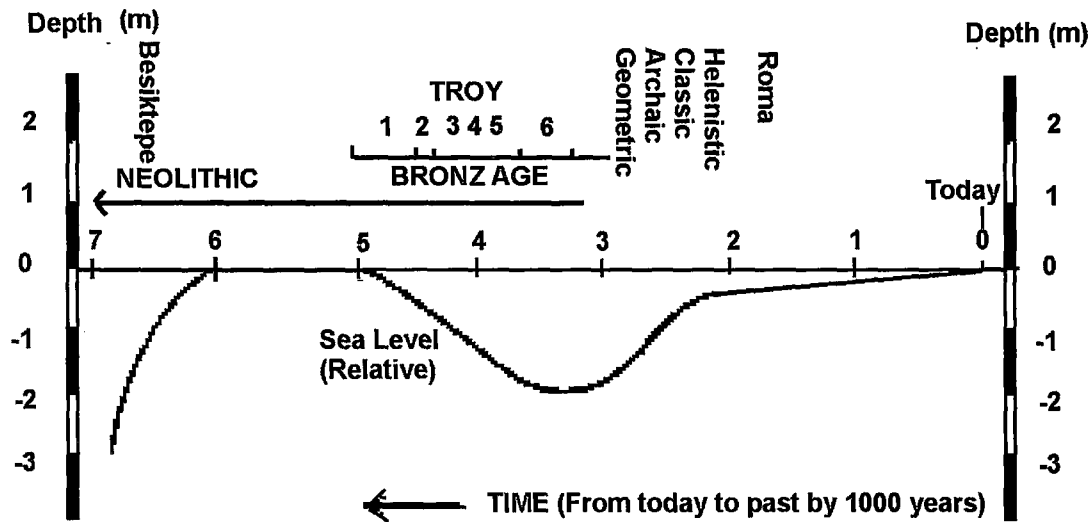


Figure 4.3: Sea-Level Change curve of the Western Anatolian coasts at Middle and Late Holocene (Kayan, 1997).

Local characteristics

While the same dynamic processes cause continuous change on every coast, each coast responds uniquely. Interaction between the different processes and the degree to which any of these specific processes controlling the change depend upon local factors. These factors include the coast's proximity to sediment-laden rivers and tectonic activity, the topography and composition of the land, the prevailing wind and weather patterns, and the configuration of the coastline and nearshore geometry (NOAA Technical Report NMFS 123, 1996)

The Altınova coasts are characterized by elongated sandy beaches, which may also be categorized as mainland beach. This coast typifies characteristics of mainland beach: it stretches unbroken for many kilometers along the edges of the Western Anatolian basin, some areas of this coast are low standing and prone to flooding, and it receive sediment from the nearby Madra Creek.

The Altınova plains are formed with layers of loose sand, silt and pebbles which were deposited by transgression 6,000 years ago, followed by the deposition of roughly conformable sediment sequences transported by the stream of the Madra Creek catchment basin covered these layers. This may be easily observed in the

Madra Creek bed and in the sand-pebble quarries along this bed. A meter-thick plant soil which was followed by thin alluvial and then thick, marine-originated material sequences may be observed in 10-meter deep outcrops.

Traditionally, the Aegean coasts are considered seismically active; however, the Altınova region has generally not been very active even though there is a N-W directional fault passing through the Altınova shores originating from the sea (Figure 4.4). It is known that the shores border active tectonic regions subject to extensive sediment movement by the means of slumps that also have considerable effect on the adjacent beaches. There is not enough information concerning this fault, therefore, it is difficult to determine the present effect of this fault on coastal erosion. A bathymetric study was conducted on the Altınova coasts as part of the “Madra Creek Region Coastal Erosion Study” Project conducted by the Institute of Marine Sciences and Technology (IMST) (ANON. 1997c). As a result of this study, a 10-12 meter long very steep depression was discovered close to the shore. It is still hard to determine the effect of this depression on the sediment movement of the Altınova coasts. Further geophysical studies, especially extensive seismic studies, need to be conducted to determine the behavior of the fault or to explain this depression.

Human intervention

Human activities are the major source for coastal erosion of the Altınova coasts. These activities are often conducted without an adequate understanding of coastal geology and the processes resulting by the unforeseen degradation of the Altınova coast. Even human actions intended to save or improve the coast have inadvertently increased erosion along this coast. These activities are causing sediment starvation, sediment trapping, coastal degradation and water-level changes.

In the Altınova coast, a large part of the sediment budget is supplied by Madra Creek. Madra Dam, which was built for water catchment and flood control along Madra Creek leading to the Altınova coasts, inhibits the transport of large-grained sediments. Damming of a river like Madra Creek has reduced the movement

of sediment. Due to the decrease in the sediment transport, Altinova coasts are eroding and travelling inland as a result of the lack of new material deposition.

Altinova and environs rapidly developed because of the touristic characteristics of the region. The popularity of this region caused a boom in the construction sector. Construction contractors use the bed of Madra Creek as a convenient and low-cost solution for their sediment needs. Illegal sediment removal from the bed of Madra Creek and also from the Altinova coasts has not only stopped sediment enrichment of the coast but also caused the beaches to shrink.

Private construction contractors are not the only ones who are removing sediments illegally. Public construction contractors, who were working for the government also plundered the bed of Madra Creek; however, assisted by government economic planners, their destructive actions have been ignored. A report concerning the erosion of the Altinova coasts (DSİ, 1997) clearly states that “ The economics of the Madra Dam project were based on the collection of the aggregate material necessary for the construction of an irrigation network”.

Structures built along the banks of the Madra Creek, as a part of erosion control work at the Kozak Plateau, also eliminated the supply of sediment to the Altinova coast.

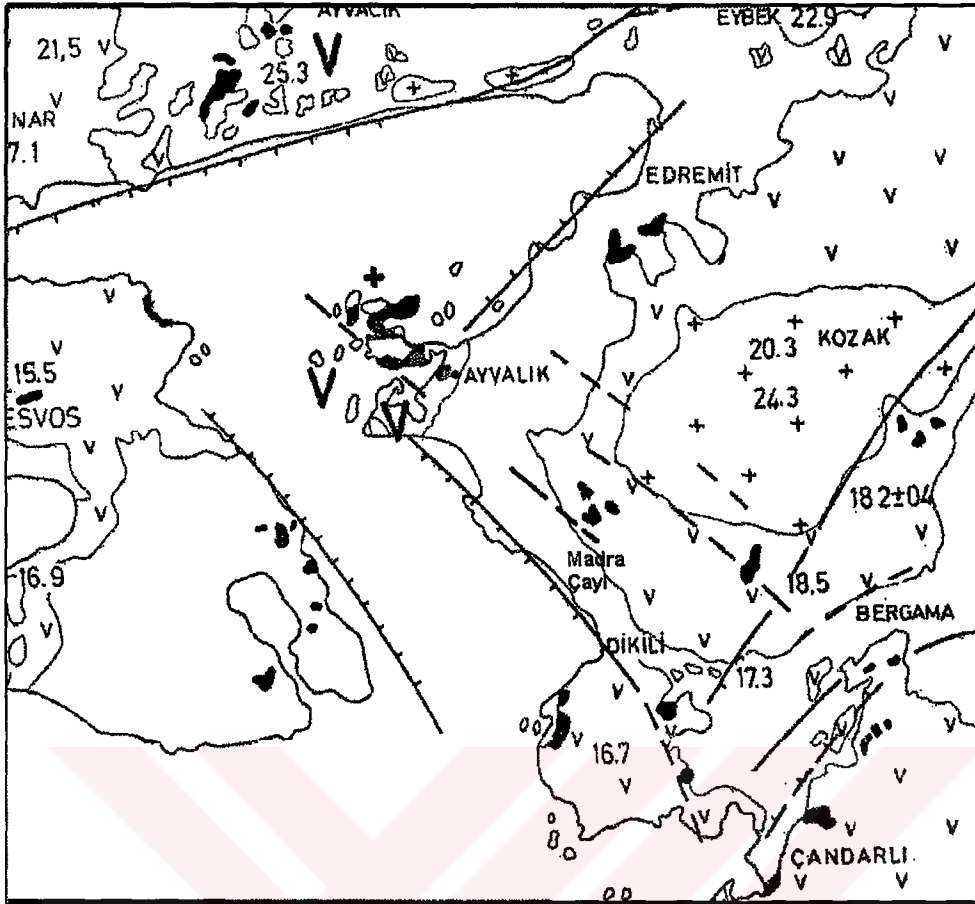


Figure 4.4 Tectonic map of the region. Scale 1:500000 (Savaşın, 1990)

The natural movement of sand is at best a nuisance for owners of beachfront property along the Altınova coasts. For a long time this movement had resulted in a net loss of sand from the beach; however, this natural process being aggravated by human intervention is considered by owners as a serious threat to their properties. To prevent beach loss, the property owners along the Altınova coast constructed groins out into the water. These solid structures barricade the littoral drift of sand caused by longshore currents. The beach then expands on the updrift side of the groin; however, the downdrift side of the groin loses sand because of continuing longshore movement. Property owners on the Altınova coast constructed these groins without any planning or consideration of the problem as a whole. The lack of any professional coastal engineering consultation and the misplacement and design of the groins have inadvertently augmented downdrift erosion.

The Altinova Municipality is also considering the construction of seawalls to protect property along retreating beaches, however, this often exacerbates beach erosion. Seawalls confine the wave energy and intensify the erosion by concentrating the sediment transport processes in an increasingly narrow zone. Eventually, the beach disappears, leaving the seawall directly exposed to the full force of the waves.

Human actions that lead to the destruction of dune grasses and the disturbance of coastal landforms promote increased erosion and movement of beach materials. Tractors and foot traffic on the sand dunes are responsible for the sand becoming compact, resulting in the destruction of plant roots and animal burrows.

Human activities also cause the water budget of the Madra Creek to change alarmingly. The damming of the Madra Creek has not only reduced the movement of sediment but has also cut down the water intake. Irrigation channels have diverted the water and caused the discharge in the Madra Creek to drop.

4.2. Determination of the Coastal Change with Remote Sensing and Geographic Information System (GIS)

The study utilized satellite imagery (primarily Landsat Thematic Mapper-TM), digital color aerial photography in conjunction with global positioning system (GPS) systems and field data which were interpreted, classified, analyzed, and integrated with digitized topographic maps in a GIS technology to monitor changes along the shores and adjacent lands.

The GIS base inventory of coastal features was developed in order to assess past and current rates of the Altinova shoreline change and to provide a scientific data base that includes those variables known or expected to contribute to coastal change.

4.2.1. Satellite Images and Image Processing

A successful remote sensing study for coastal change detection requires specific attention to:

- Sensor systems,
- Environmental characteristics and
- Geodetic control.

A remote sensor system should hold the following characteristic constant;

- Temporal resolution,
- Spatial resolution,
- Spectral resolution and
- Radiometric resolution.

To perform the Altinova coastal change detection through the use of remotely sensed data acquired on multiple dates, the most important consideration was satellite passes which coincided with the same time of the day and the same time of the year. The first aspect of the problem was automatically solved since the Landsat satellite always passes at the same time of the day over the Altinova region so, the diurnal sun angle effects could not create any problems. Due to monetary and time limitations, the precise anniversary date images were unobtainable. The Thematic Mapper images which were used for this study were dated December 31, 1989 and, July 7, 1996.

The spatial registration of these two images did not create any problems either, since both images were obtained with the same instantaneous-field-of-view (IFOV) on each date by the same sensor (30 x 30m spatial resolution).

Spectral (7 band) and Radiometric resolution (8-bit data) images were both obtained by the same sensor (Landsat TM), so no discrepancies were discovered through the use of these data.

The atmospheric conditions were almost perfect in both images due to 0% cloud cover.

In this study, the first image was geocoded and considered as a base image, then a non-geocoded second image was directly rectified on this base image. In general, the RMS (root-mean square error -a measure of the variability of measurements concerning their true values) ± 1.0 was considered a very successful rectification. This RMS was estimated by taking a sampling of measurements and comparing them to their true values. In this study, the RMS was ± 3 , which means a 90 meter shift between the two images.

4.2.1.1 Image Processing

For a visual interpretation of Madra Creek and the surrounding areas and also, for visual detection of the coastal changes between 1989 to 1996, false color composite images were produced using ERDAS Imagine image processing software. Red to TM Band 4, green to TM Band 5 and blue to TM Band 3 were assigned for the generation of a false color composite image for 1989 (Fig. 4.5a) and 1996 (Fig. 4.5b). The combination of these three bands works well together in the interpretation of the cultural landscape, natural and vegetated surfaces from remotely sensed data.

The first striking difference between these two images was the general appearance of Madra Creek. In the 1989 image, Madra Creek is well-defined, traced from the hills of Madra Mountain, along the Altınova plains to Dikili Strait. However, in the 1996 image, it is difficult to trace Madra Creek all the way down to Dikili Strait. It can be observed between the hills of the mountain, then it disappears from the plains of Altınova, and reappears on the coast at Dikili Strait. Inexplicably, the flow rate of Madra Creek dropped and the bed became considerably narrow, therefore it could not reflect the energy of the sun as compared to the image in the 1989 image.

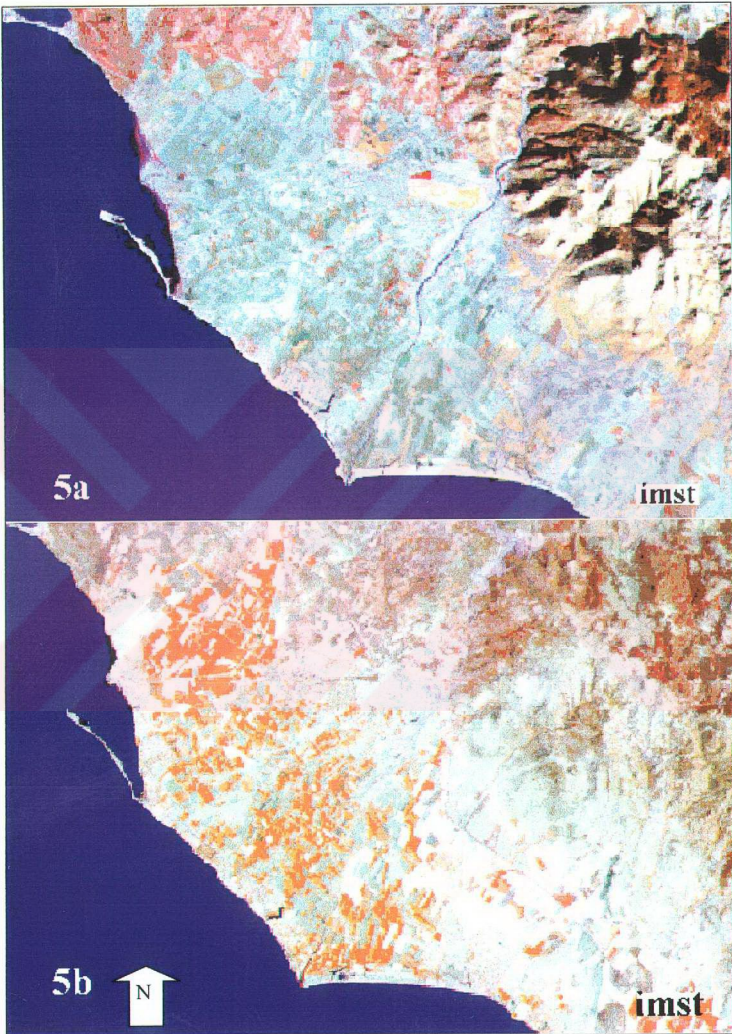


Figure 4.5a False Color Composite image of the Altinova, 1989 (1cm=1070m).

5b False Color Composite image of the Altinova, 1996 (1cm=1070m).

The second noticeable difference between these two images was the physical appearance of the mouth of Madra Creek. In the 1989 image (Fig. 4.6a), the mouth appears as a lump. It seems that this lump has eroded away in the 1996 image (Fig. 4.6b). Another discrepancy was the width of Madra Creek at the mouth, which was wider in the 1996 image than in the previous image.

In the second phase of the image processing work, two sets of new images were produced to detect differences at the shore and in the sea between these two dates. Red to TM Band 3, green to TM Band 2 and blue to TM Band 1 were assigned for the generation of natural color composite images for 1989 (Fig. 4.7a) and 1996 (Fig. 4.7b).

The combination of these visible bands works well in the interpretation of bodies of water since they can penetrate the water surface. Therefore, the suspended sediment load of the Altınova shore may be clearly observed. In the 1989 image, dense sediments that diffused from the mouth of Madra Creek towards İskele Yarımadası were obvious. This pattern of sediment transportation may also be observed in the 1996 image; however, the suspended sediment density changed and became much lighter; therefore, the reflectance of the water became weaker. The only known structural difference taking place between these two dates that may explain this difference was the construction of the Madra Dam in 1991.

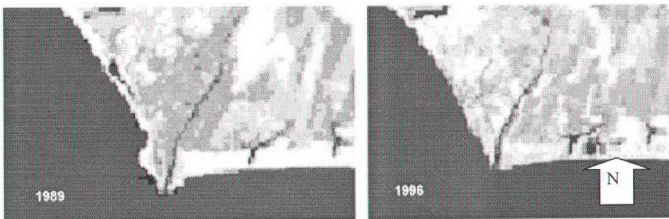


Figure 4.6a. Madra Çayı Mouth, 1989. Figure 4.6b. Madra Çayı Mouth, 1996
(1cm=1070m)

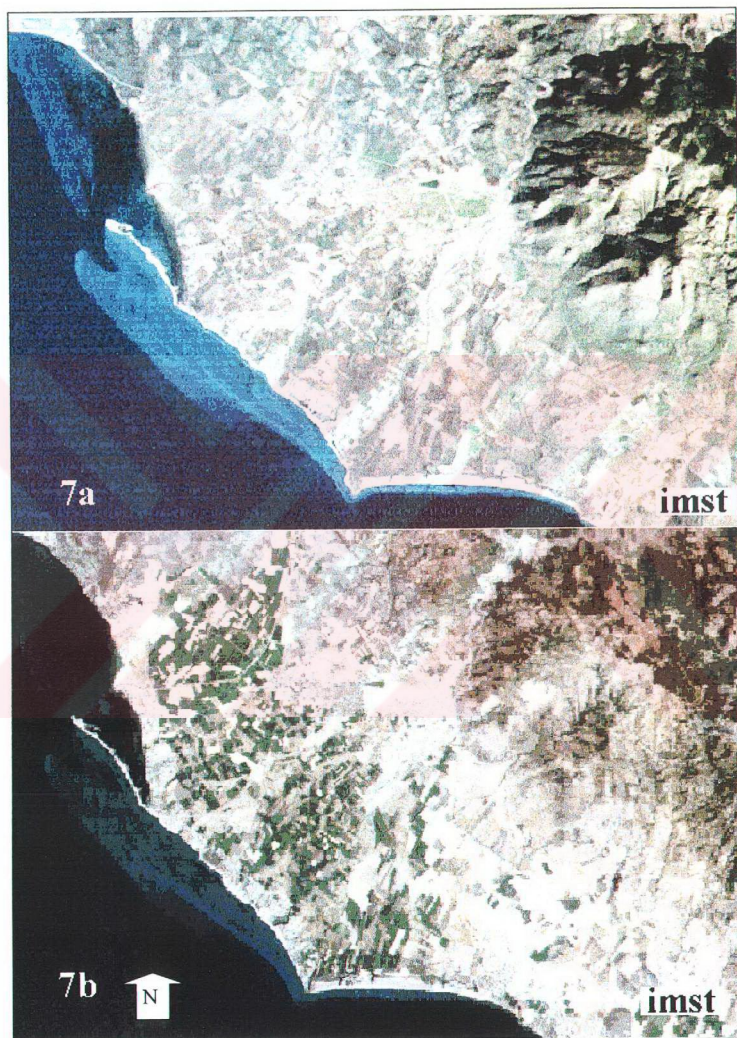


Figure 4.7a Natural Color Composite image for 1989 (1cm=1070m)
b Natural Color Composite image for 1996 (1cm=1070m)

Creating land use/land cover images was an important factor for monitoring any change detection. To create these types of images, supervised classification techniques were used. Through this technique, computer-assisted interpretations were conducted on Fig. 4.5a and Fig. 4.5b. Seven categories of land use (training sites) were selected and the computer was trained to look for similar surfaces with resembling reflectance characteristics of these seven areas within the image. As a result of this procedure, two sets of images were classified for 1989 (Fig. 4.8a) and 1996 (Fig. 4.8b). The most important difference between these two classified images was the construction boom to beachfront properties.

In order to determine the effect of the sea on Madra Creek, further investigations were conducted. Currents create temperature variations in the sea; therefore, this characteristic and the use of TM Band 6, where this characteristic could be best observed, were used to produce a map of the currents at Dikili Strait.

The map of the currents that was produced of Dikili Strait (Fig. 4.9a) used the thermal band for the year 1989. The counter-clockwise direction of the currents and their formation of gyres are the most apparent characteristics of this image. The light-blue water is the original Aegean Sea water. The dark-blue water is the original Dikili Strait water. The gray water is formed due to the interaction between the Aegean Sea water and Dikili Strait water. Another interesting feature of this image is the striking temperature difference of the water at the mouth of Madra Creek (red colored features which enter the seawater like the edge of a knife). Cold fresh water, coming from the mountains, together with the sediments create a contrast when they come in contact with the relatively warmer seawater. With the help of long shore currents, Madra Creek water is carried to the northern shores. The green color features appear as a result of the relatively colder sediment dispersion.

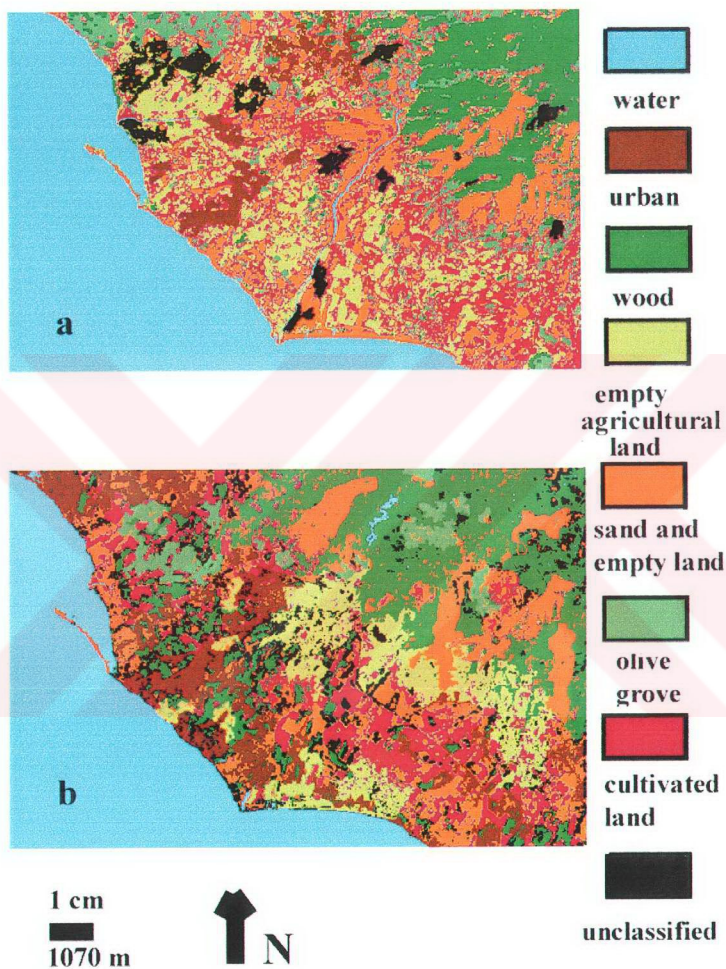


Figure 4.8a Classified image for 1989
 b Classified image for 1996

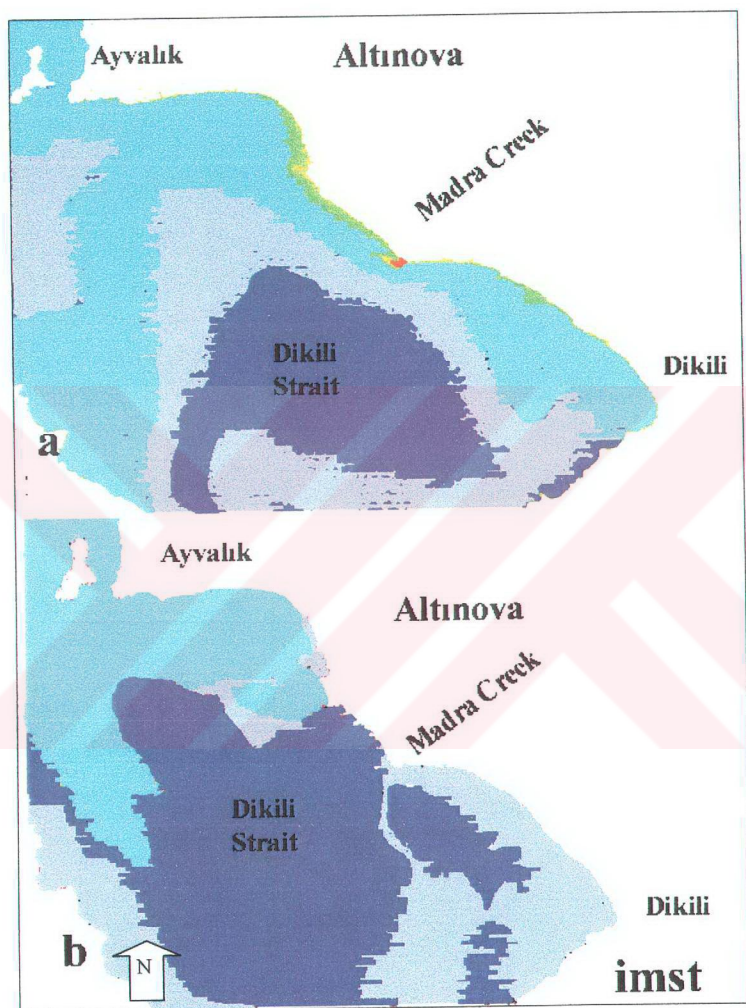


Figure 4.9a Current map of Dikili Straits for 1989 (1cm=2500m)
 b Current map of Dikili Straits for 1996 (1cm=2500m)

The general water movement of the Dikili Strait could still be observed in the 1996 image of the currents (Fig. 4.9b). However, the cold fresh water coming from the mountains together with the sediments cannot be differentiated in this image. The non-existence of temperature differences could be explained as the seasonal temperature differences of the images (taken in July). However, it is hard to explain the missing sediments as being due to the seasonal temperature differences. The characteristic structure of the Dikili Strait water movement could not be observed in this image. It appears that the Aegean Sea water could not penetrate all the way down to Dikili Bay. Most probably this penetration was disturbed by WSW directional winds which are the major cause for storm formations around this region. This disturbance also affected water movements. The gyre mostly found on the center regions of the Dikili Strait (dark blue water on the image) has now moved down to the Altınova shores and is affecting the beaches in this region. Another interesting structure of this image is the locally formed gyre in Dikili Bay, which was a by-product of the storm. As a result of the physical structure of the southern shores, there is no doubt that this gyre moves the water in a counter-clockwise direction and increases the erosion of the southern shores at the mouth of Madra Creek.

Shoreline changes over time are one of the best determinations for coastal erosion. This determination was realized by comparing the shorelines of both images. The shorelines of both images (Fig. 4.5a and Fig 4.5b) were vectorized with the help of the screen digitizing function of the ERDAS Imagine and two new sets of data were produced. Then these two new sets of data were digitally placed one on top of another and a new image was produced to determine the shoreline changes between 1989 to 1996 (Fig. 4.10). The most noticeable change between the two images occurred along the northern shores of Madra Creek. It seems that literally the entire upper part of the Madra Creek mouth disappeared over these 7 years.

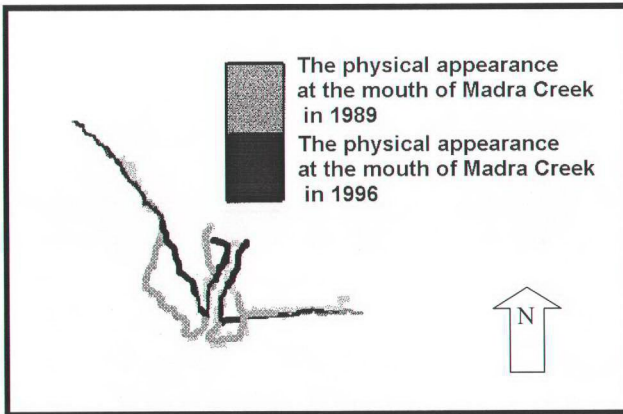


Figure 4.10 The shoreline changes from 1989 to 1996 (1cm=1070m).

The dimensions of the eroded shore were calculated with the help of these two images. The digital subtractions, of these two images, were given as 1,700 pixel differences. According to this data, just the mouth region of the Madra Creek lost $1,700 \times 30^2 = 1\,530\,000 \text{ m}^2$ of sand on account of the erosion. The same data shows that, from 1989 to 1996 the sea moved approximately 200 to 250 meters inland. Local residents (personal communications), who have been witnessing this erosion for over more than 15 years could not comment on the total amount of beach sand lost, however, they noted that the sea had moved approximately 300 to 350 meters inland. There were approximately 100 meters of differences between the actual sea movement and the digitally obtained value. This error may be due to the continuation of the RMS error (90 meters) which resulted during the registration of the two images.

Therefore, this study showed that satellite remote sensing techniques together with in situ data are very effective in the implementation of comparative analysis for detecting coastal changes.

4.2.2 Digital Air Photos

Digital color aerial photography has advantages (and disadvantages) when compared to satellite images and traditional aerial photography, especially when the coastal change detection study concerns a very limited shoreline. Digital aerial photography has a greater spatial resolution than satellite imagery and is almost comparable with regard to its spectral resolution. Satellite images and digital aerial photographs are both stored in a digital format; however, in order to drive information from traditional aerial photography, it needs to be digitized. The coverage area of aerial photography is limited. Over 100 aerial photographs are needed to cover the same area covered by one Landsat image. Aerial photography is generally used as ground truth when rectifying satellite imagery.

Digital color aerial photographs of Altınova coasts were taken using a hand held Kodak Digital Science DC50 Zoom Camera in conjunction with GARMIN GPS90 global positioning system (GPS) systems, which were mounted to a Cessna airplane owned by Türk Kuşu.

The digital color aerial photographs were taken on January 19, 1997, at elevations of 1,000 and 1,500 meters. The low elevation photographs were taken for a detailed study of the Madra Creek mouth and the higher elevation photographs were taken to determine the general physical layout of the Altınova coastline.

Figure 4.11, is a high elevation photo of the general physical layout of the Madra Creek and Altınova coasts illustrating where the beaches are being continuously eroded. The previously mentioned (Fig. 4.8b) dense beach front property construction on the northern part of the Madra Creek mouth may be seen easily. However, there were not any noticeable housing complexes to be observed at the southern part of the Madra Creek.



Figure 4.11 High elevation photo of the Altinova coasts

Figure 4.12 is a digital mosaic of the northern part of the Madra Creek. As seen in this digital photo, in general, the construction on the northern part is housing complexes, which were recently built and that are further inland. Single houses, which are the oldest buildings on this coast, were built close to the seashore.

In the detailed photograph of the northern part of the Madra Creek (Fig. 4.13), dimensions of the erosion are easily seen. The single houses were built on the shores, where heavy erosion was occurring; they are under threat of destruction at any time. In the field studies of this region, it was observed that some of the houses lost their gardens and the waves started to pound some of the garden fences surrounding the houses.



Figure 4.12 Digital mosaic of the northern part of the Madra Creek (1cm=200m)

Another interesting feature which could be observed in the field is the location of the lighthouses. They are very good indicators and witnesses to the enormous dimensions of the erosion at the Madra Creek mouth. According to local people, the lighthouses were rebuilt three times over a span of thirty-five years. The original lighthouse was completely destroyed so it is almost impossible to determine its exact location. However, the submerged ruins of the second lighthouse can be located as they lie 120 to 150 meters away from the shore. The most recently built lighthouse is located 20 meters inland away from the shore.



Figure 4.13 Detailed photograph of the northern part of the Madra Creek
(1cm=200m)

As previously mentioned, the natural movement of sand is considered by property owners as a serious threat to their properties. As a result of this threat, property owners along the Altinova Coast have constructed groins out into the water.

These groins were built over various time periods and they are one of the best examples of human activity that has resulted in the further increase of coastal erosion. Fig. 4.14a and Fig 4.14b show two different locations of groins which were constructed in different time periods.

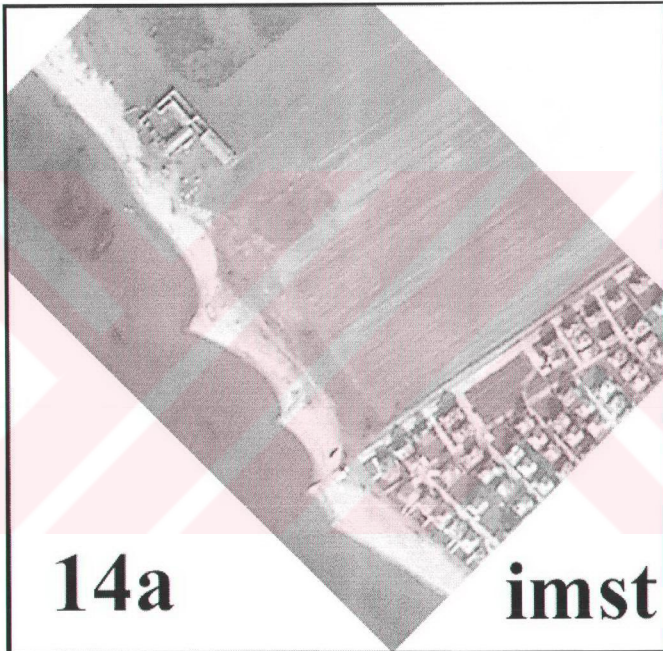


Figure 4.14a Old groins (1cm=200m)



Figure 4.14b Recently constructed groins (1cm=200m)

The typical effects of erosion are easily observed in the groins in Fig. 4.14a. The beach expanded on the updrift side of the groin; however, the downdrift side of the groin lost sand due to the continuing longshore movement of the sea. Therefore, coastal erosion moved further up the coastline and forced the beachfront property owners of that location to also construct their own private sets of groins (Fig. 4.14b). This photograph clearly shows that the newly constructed groins resulted in no differences from the previously-built downshore groins.

Figure 4.15 is a digital mosaic of the southern part of the Madra Creek. The most intriguing part of this image is the absence of any kind of construction for 3 kilometers along the southern shores of the Madra Creek. Traces of the coastal erosion were not observed on this coast. Even small lakes (such as Çatal Lake,

Sülüklü Lake and Donbay Lake), which are illustrated on historic maps, were still observed in this photograph. Also, housing complexes were constructed much further inland than the housing complexes on the northern coast. Thus illustrating the converse effect of causative factors.

4.2.3 Historical Maps

Two sets of topographical maps and one set of navigational maps were used for this study. The first map was dated 1993 and belongs to İller Bankası (Fig. 4.16) and was produced as a Altınova (Balıkesir) Sewer Project Location Plan with a scale of 1:25,000. However, this map is nearly a carbon copy of the map produced by the Harita Genel Müdürlüğü (General Directorate for Mapping) in 1963 with a scale of 1:25,000 (plate # AyvalıkJ17-c1). The only difference between these two maps is the illustrated location of the planned waste water treatment plant in Büyükçayır region. As the original 1963 map was not available, the 1993 map was considered as the original map. The second map was also produced by the Harita Genel Müdürlüğü containing the same name and scale in 1978 (Fig. 4.17). The last map was produced by T.C. Deniz Kuvvetleri Komutanlığı, Seyir, Hidrografi ve Oşinografi Dairesi Başkanlığı (Turkish Republic, Naval Hydrographical and Oceanographical Office) in 1989 as a navigational map with the scale of 1:50,000 (Fig. 4.18).

These maps were scanned using a HP ScanJet Ilcx and were then transferred into the computer in order to be quantitatively analyzed using a digital format.

The visual comparison of the 1963 and 1978 topographical maps clearly shows the dimensions of the coastal erosion at Altınova. There was a 500 meter long and 50 meter wide sand bar located at the northern shores of the mouth of the Madra Creek in the 1963 map (Fig. 4.16). This structure covered the entire mouth region of the creek and formed a 50 meter wide and 500 meter long inlet. In the 1978 topographical map that was compiled 15 years later, this sand bar, which was formed by sediments carried by Madra Creek, had completely disappeared and a new creek mouth had been formed which resembles the beak of a bird (Fig.4.17).



Figure 4.15 A digital mosaic of the southern part of the Madra Creek (1cm=200m)

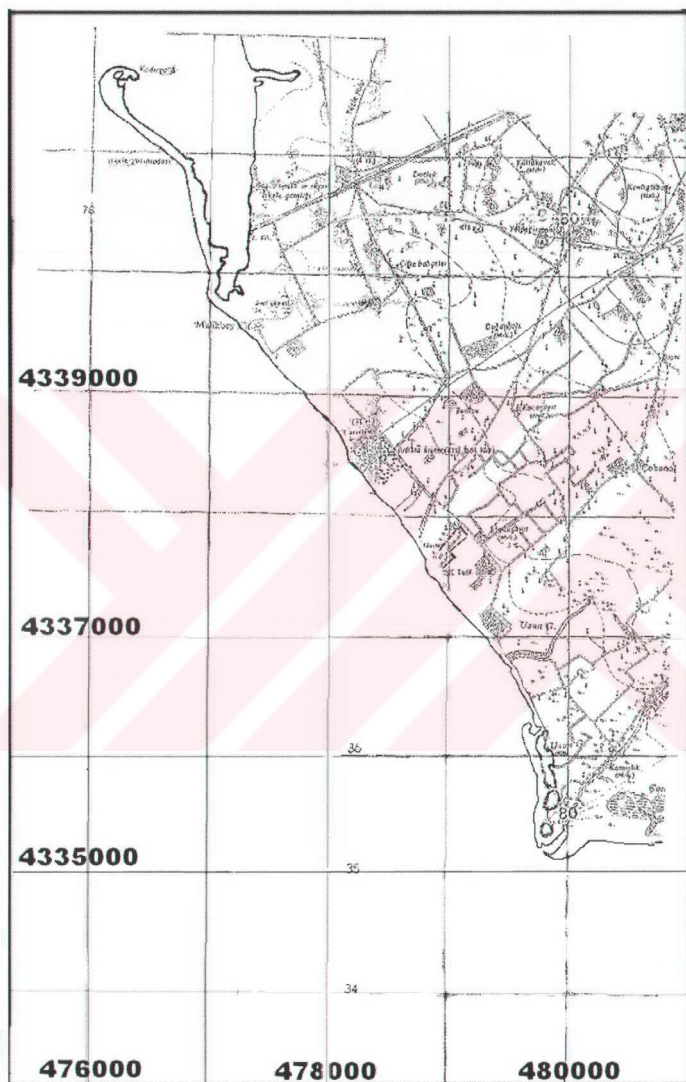


Figure 4.17 Topographic map from 1978 (Scale 1:25000)

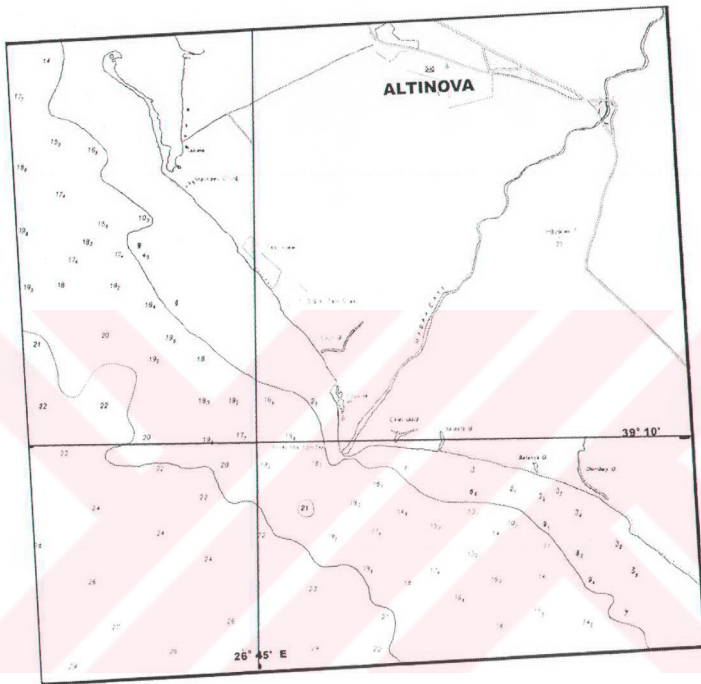


Figure 4.18 Navigational map from 1989 (Scale 1:50000)

The scanned and then vectorized maps were digitally registered and compared to determine the actual amount of erosion from 1963 to 1978 (Fig. 4.19). This comparison showed that the erosion that had occurred over the last 15 years was not only limited to the mouth of the Madra creek, but that it had also destroyed the sand bar, as well as 4 kilometers of shore to the north of the Madra Creek mouth.

The comparison of these two shorelines also showed another fundamental variation at the creek mouth. In the 1963 map, the shores to the north of the mouth curved southwards and extended towards the shores to the south of the creek mouth. However, in the 1978 map, this formation reversed itself and the southern shores curved towards the north and extended towards the northern shores. Anomalies in the wind direction over time may explain the formation of this structure.

It is important to mention one last variation between these two maps concerning the Kadirga Cape also known as İskele Peninsula which is located 6-kilometers north of the Madra Creek. This peninsula was 1 kilometer long in the 1963 map (Fig. 4.16). Fifteen years later, the same peninsula had lengthened to 2 kilometers (Fig.4.17) through the deposition of sediments that had been transported from the south as a result of coastal erosion.

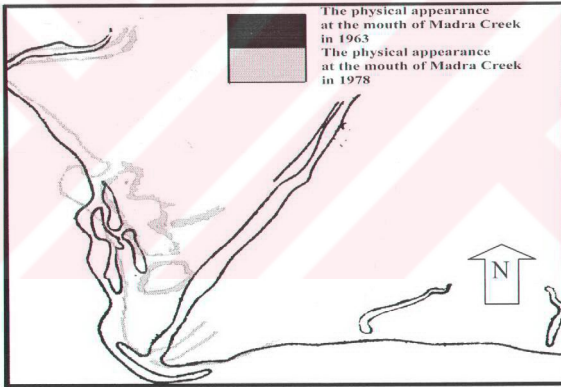


Figure 4.19 The physical appearance at the mouth of Madra Creek between 1963 to 1978 (Scale 1:25000)

The navigational map of 1989 (Fig. 4.18) was considerably more up-to-date than the two topographical maps. However, the scale (1:50,000) and the end-use purpose for the compilation of this map (navigational aid for ships) render no useful information illustrating any possible erosional changes that may have occurred to the coastline over the time span that had elapsed from 1978 to 1989.

4.3. Results

The problem of coastal erosion along the Madra Creek and the coastline of Altinova was evaluated through the use of image processing and GIS techniques on several different sets of data. As a result of these evaluations, three main causes were determined for coastal erosion.

(1) The sediment transport capacity of Madra Creek was decreased due to:

- Erosion control work in the Kozak Plateau,
- Damming of the Madra Creek which reduced the downstream movement of sediment,
- Illegal removal of sediment from the creek bed for use in the construction sector (the Madra Dam, housing complexes, etc.).

(2) Damming of the Madra Creek not only reduced the sediment load of the creek but also cut down the downstream discharge. As a result, the creek water was no longer an opposing force against the sea water that was progressing inland.

(3) Human activities like:

- Illegal removal of the sand from the beaches not only caused the beaches to recede but also caused considerable damage to the delicate root systems of the plants which anchored the sand in place;
- Construction of groins by property owners with the intention of preventing beach loss along the Altinova coast inadvertently contributed to beach erosion.

Image processing and GIS techniques helped to determine the actual amount of erosion which occurred from between 1963 and 1997 (Fig. 4.20). Over these 34 years, the sea had moved approximately 200 to 250 meters inland at the mouth of the Madra Creek and had also been the defining force in the destruction of a 50 meter wide and 4,000 meter long shore in the northern sections (Fig. 4.21).



Figure 4.20 Shoreline changes between 1963 to 1997 (1cm=200m)

As a result of this destruction, a total of over 1,530,000 m² of beach land was lost at the Altınova coast. According to the local municipality, this is equal to 3,000,000 m³ of beach sand (Hürriyet, 1996). The comparison of the two images dated 1989 and 1996 showed that 50% of the erosion occurred over a scant 7-year time period.

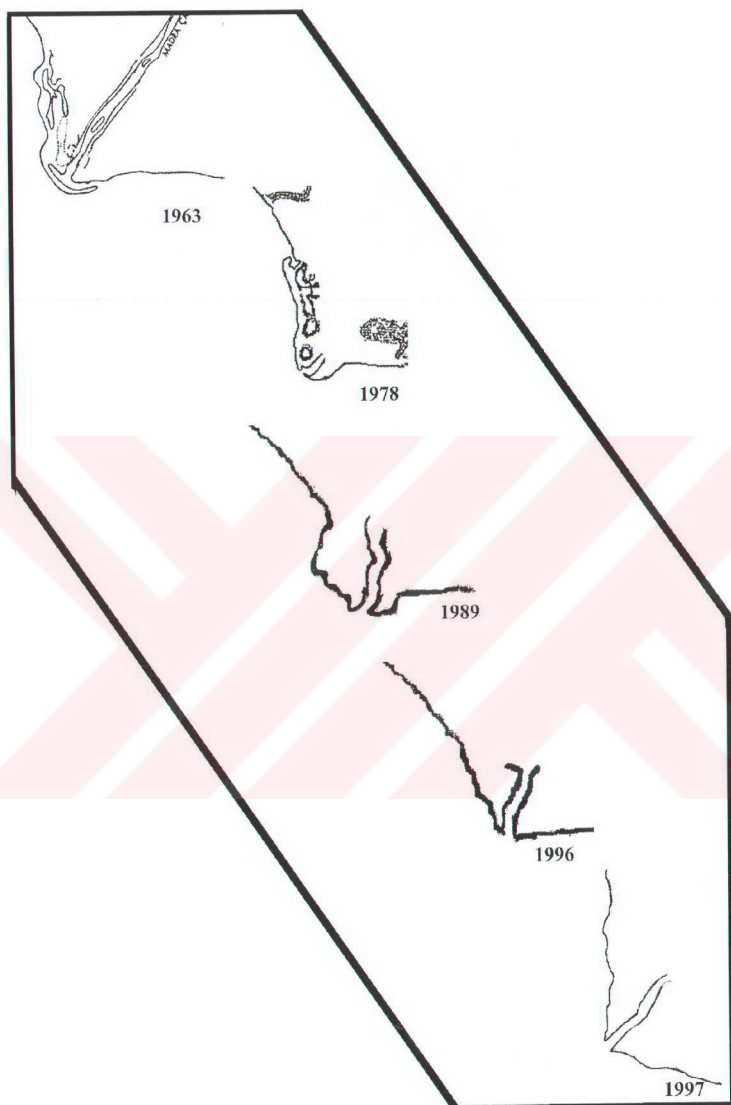


Figure 4.21 A 34-year history of shoreline change

CHAPTER FIVE

PHYSICAL AND ECOLOGICAL STATE OF THE TURKISH COASTS

The Turkish coastline, encompassing the Aegean Sea and Izmir Bay, is home to numerous economic and recreational activities. However, these areas are threatened by dramatic environmental problems. Adequate tools are needed to investigate the space/time heterogeneity of the complex mosaic of ecological situations that occur along this coastline. The use of optical remote sensing for monitoring this coastal zone has been rapidly growing over the past decade.

5.1 Location, Division and Oceanographic Characteristics of the Study Area

Izmir Bay is located on the Anatolian side of the Aegean Sea. Traditionally, the Bay has been divided into three sections according to their position and natural characteristics. These sections are shown in Fig. 5.1. The total volume of these sections is $16.365.4 \times 10^6 \text{ m}^3$ and the total surface area is 666 km^2 . Detailed volume and surface area information concerning these sections is summarized in Table 5.1.

Physically, the Izmir Bay is a typical Mediterranean Bay, with a limited fresh water intake and subtropical climate characteristics. The Gediz River is the main source of freshwater for the Bay. Average salinity values change between 37.2-39.16 from winter to summer (ANON, 1997b).

Average sea surface temperature values (SST) change from a maximum of 26.6°C in July a minimum of 11.2°C in January (Uslu & Saner, 1998). A thermocline forms in the summer months as a result of the surface water warming and strong evaporation.

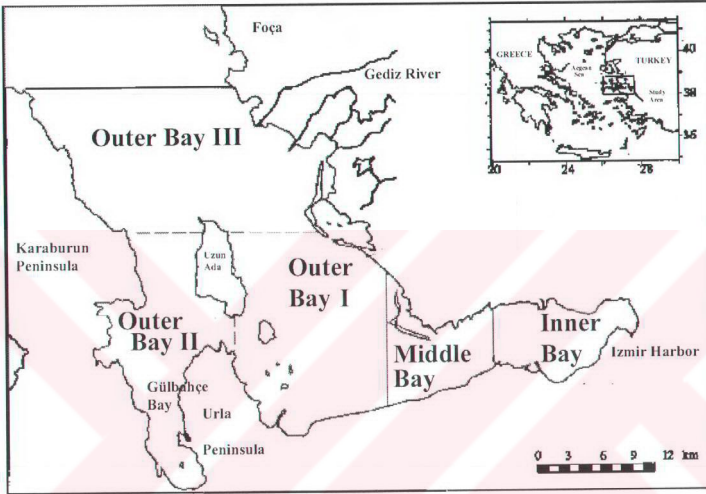


Figure 5.1 Section of the Izmir Bay (modified from Uslu & Saner, 1998)

Table 5.1: Volume and surface areas of the sections of Izmir Bay (from Uslu & Saner, 1998)

Bay Sections	Volume (10^6 m^3)	Surface Area (km^2)	Avrg. Depth (m)
Inner Bay	407.7	57	7.2
Middle Bay	703.8	70	10.0
Outer Bay I	4,862.7	168	28.9
Outer Bay II	2,007.7	136	14.8
Outer Bay III	8,383.5	235	35.7
Outer Bay Total	15,253.7	539	28.3
TOTAL	16,365.4	666	24.6

According to Sayın (personal com., 1999) Izmir Bay has a two-layer character in the summer season. The two-layer stratification starts to form in late May and continues until the end of September. The thermocline depth is about 25 m in the summer months and is 35 m in the fall months. There is no vertical stratification during the winter months. The water column is homogeneous from surface to bottom due to wind driven mixing.

5.2 Sea Surface Temperature and Normalized Difference Vegetation Index of Izmir Bay from NOAA Satellites

Satellite images of SST taken from 1995 to 1997 were analyzed as part of a study of the temperature variability of Izmir Bay. Raw HRPT data were calibrated, temperatures were calculated, clouds were masked and the images were rectified to a map projection resulting in SST maps of Izmir Bay. These SST maps were used to understand the monthly temperature changes observed in the Bay. The obtained data are given in Table 5.1 and Figure 5.2 to 5.6.

Only daytime images were used to determine the SST values of Izmir Bay. The main reason for this was to compare the thermal conditions with visible conditions. The daytime MCSST algorithm (APP. A) and a 0.50°C temperature interval were used to determine the SST maps.

All the images are sub-sampled, geometrically corrected (Georeferenced to Geographic Lat./Lon. with Spheroid WGS 72) and the clouds were masked for atmospheric correction, therefore, in most of the images, areas covered with land and clouds were automatically detected and these areas were filled in with black.

Visible images were also used to determine the observed high reflectance values (suspended sediments, pollutants, planktons, algae etc.) in connection with the SST values.

Radiation was measured in channels 1 and 2 of the AVHRR in terms of an “Albedo” which relates the measured radiance to the filtered extraterrestrial solar irradiance in the passband of the given channel (Cracknell, 1997).

To produce atmospherically corrected visible images, channel 2 has been subtracted from channel 1 with the assumption that the ocean volume reflectance within channel 2 is zero. Hence, any radiance recorded over water within channel 2 is due totally to the atmosphere (Ackleson & Holligan, 1989).

Table 5.2 Satellite driven monthly average SST values of Izmir Bay

Month	Inner Bay Min/Max (°C)	Middle Bay Min/Max (°C)	Outer Bay I Min/Max (°C)	Outer Bay II Min/Max (°C)	Outer Bay III Min/Max (°C)
April	17-18	16-17	15-16	15-16	15-16
May	23-24	20-21	18-19	19-20	18-19
June	24-25	24-25	22-23	22-23	20-22
July	27-28	27-28	25-27	26-27	23-24
August	25-26	24-26	23-25	23-24	23-24
September	25-26	25-26	24-25	24-25	24-25
October	20-21	20-22	19-21	18-19	17-19
November	17-18	18-19	16-18	16-18	17-18
December	10-12	10-12	13-14	14-15	15-16
January	10-13	12-14	14-15	15-16	16-17
February	10-12	11-12	12-14	13-14	14-15
March	13-14	14-15	14-15	14-15	14-15

Prangma and Roozkrans (1989) used normalised difference vegetation index NDVI algorithm to study large areas of blue-green algae. Since,

$$NDVI = \frac{Ch.2 - Ch.1}{Ch.2 + Ch.1}$$

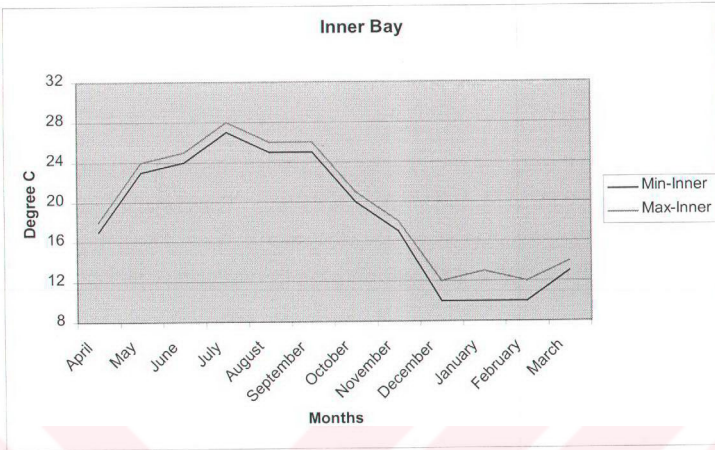


Figure 5.2 Minimum and maximum temperatures of the Inner Bay

and since clear water is nearly a blackbody for near-infrared radiation, the value of Ch.2 will be zero and the NDVI will be negative for a clear water surface – indeed the value of the NDVI will be close to -1 . However, if blue-green algae are floating near the surface, the reflectance in Ch.2 will be dramatically increased, due to the large concentration of chlorophyll, and the value of the NDVI will be increased, probably enough to make it have a positive value (Cracknell, 1997).

Under the guidance of these assumptions, areas, which gave high reflectance were not only studied with atmospherically corrected Ch.1 images but also with NDVI which was used to determine if these high reflectance values were due to pollution or algae.

Comments on the remotely obtained SST values start in April because it was considered the seasonal breakpoint for the thermal change in Izmir Bay.

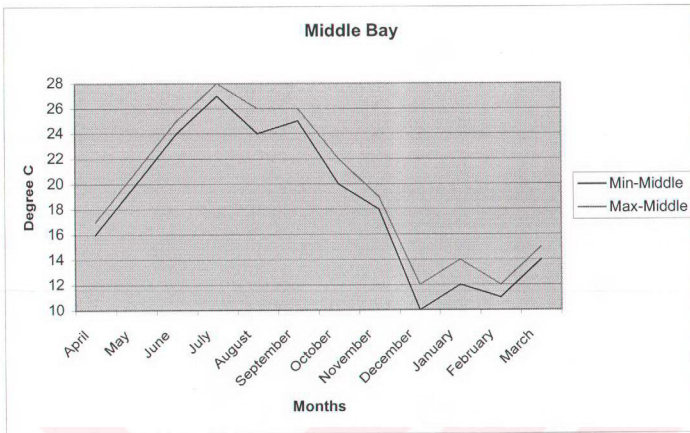


Figure 5.3 Minimum and maximum temperatures of the Middle Bay

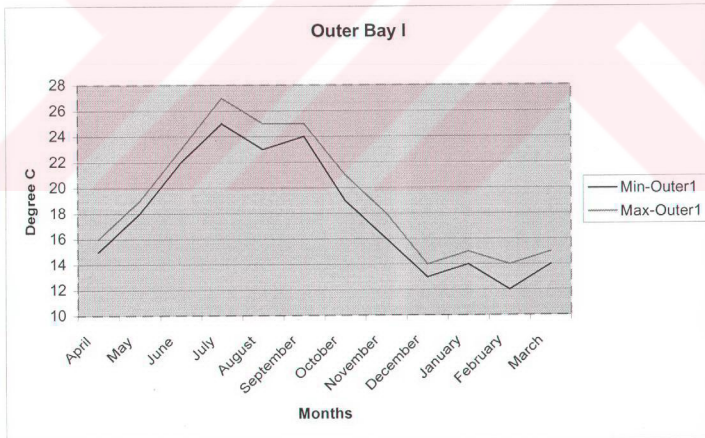


Figure 5.4 Minimum and maximum temperatures of the Outer Bay I

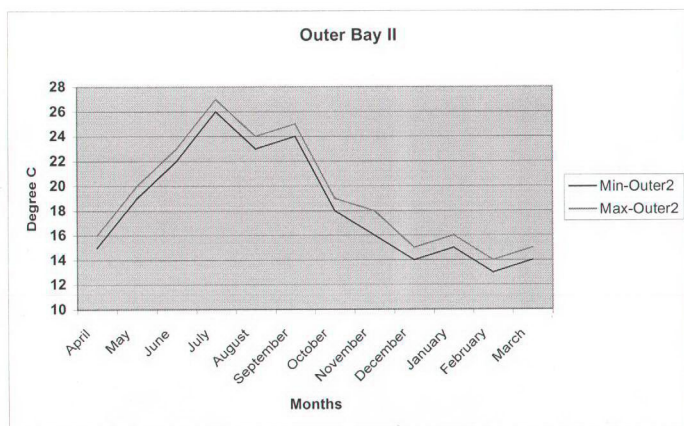


Figure 5.5 Minimum and maximum temperatures of the Outer Bay II

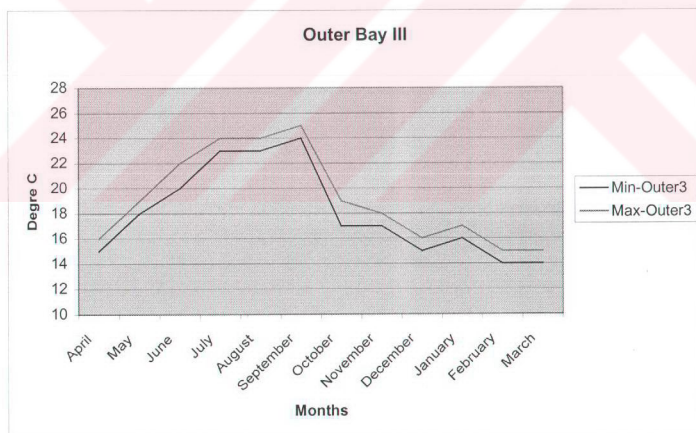


Figure 5.6 Minimum and maximum temperatures of the Outer Bay III

5.2.1 April

It was observed that this month was one of the most thermally stable months of the year. For the first time, there was a very minimal ($1-2^{\circ}\text{C}$) temperature difference between the Inner and Outer Bay. There was a water penetration from the Aegean Sea all the way down to Outer Bay II with a constant water temperature of 16°C . Due to the constant temperature values, this penetration is not very clearly shown on the SST images. However, it was clearly observed on the atmospherically corrected Ch.1 images. This water penetration does not show any high reflectance values as in the other sections (Fig. 5.7a&b).

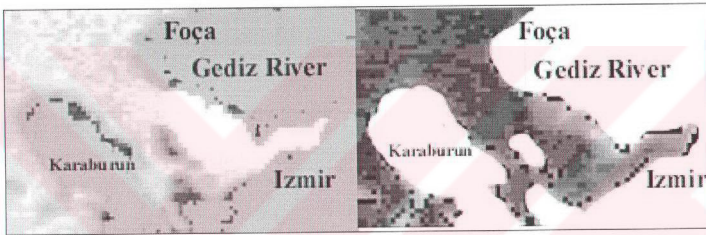


Figure 5.7a&b SST and Ch.1 images of the April

5.2.2 May

The typically warmer Inner Bay water and colder Outer Bay water conditions could be clearly observed. The temperature differences between the Inner and Outer Bay III noticeably increased by $2-3^{\circ}\text{C}$.

The atmospherically corrected Ch.1 images show dense horizontal stratification in Outer Bay I and II which could be traced all the way up to the mouth of the Gediz River. This stratification could easily be related to sediment loads and cold water (18°C) coming from the Gediz River. This situation was also a good indicator of the movement of water in the Bay.

The most interesting feature observed during this month (May 25, 1995) was an upwelling spot as a result of the NE directional wind flow which was easily detected with thermal data because the deeper, cooler water was forced to rise to the surface. Therefore, the SST of this area was much colder than the surrounding water temperature. This upwelling area was shown on the atmospherically corrected Ch.1 image because the upwelling also brought nutrient rich, deep water to the surface which was easily detected through the use of the high reflectance values. The area was located (Long. 26 40 44.83, Lat. 38 34 41.81) in the middle of the Outer Bay III with a temperature of 12.5°C (the surrounding temperature was 18°C). The condition of the upwelling could not be traced on May 26, 1995 due to lack of data. On May 27, 1995; the upwelling was not observed at all (Fig.5.8a&b).



Figure 5.8a&b SST and Ch.1 images of May

5.2.3 June

The typical thermal appearance of a warm Inner Bay and cold Outer Bay continued into this month.

Three continuous days of SST images were analyzed to determine the behavior of the upwelling areas during this month.

When the June 4, 1995 image was studied, two upwelling areas were observed. The first upwelling area (19°C) was located in the south-western part of the Outer

Bay II which had surrounding waters of 22-23°C and a second upwelling/cold spot was observed further east of the Urla Peninsula with the same warmer temperature value (21°C).

The thermal conditions on June 5, 1995 were an excellent example of the water movement along the bathymetric contours. Water coming from the Aegean Sea created a 20-21°C and 8 km thick cold thermal belt along the deeper side of the 50m bathymetric contour line, which originates from the shores of Karaburun and continues towards Foça along a curve. Along the Karaburun shores, on the shallower side of the 50m bathymetric contour line, an upwelling area with a temperature of 16°C occurred and continued all the way down to the Mordoğan Straits of Outer Bay II, reaching a peak of 19°C. Most probably, this upwelling area was also the source for the cold thermal belt. This situation was a clue for the west to east directional water movement at the Outer Bay II. A cold spot of 19°C located in the western part of Outer Bay II, which had surrounding waters of 22-23°C, moved further to the north. A second cold spot which was observed on the eastern shores of the Urla Peninsula with a temperature of 21°C and surrounding water of approximately 23-24°C, moved towards the west. Movements of these upwelling /cold spot areas were also a good indicator of the EW and SN directional water exchange between sections of Izmir Bay (Fig. 5.9a&b).

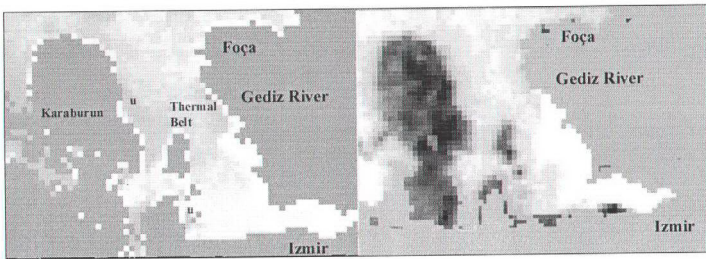


Figure 5.9a&b SST and Chl.a images of June

These upwelling areas, cold thermal belt and cold spots were also observed in the atmospherically corrected Ch.1 images. However, the Inner, Middle and Eastern part of Outer Bay I shows higher reflectance values than the other sections and could be traced up to the mouth of the Gediz River. Again, these high reflectance values could be associated to the sediment load of the Gediz River water. This situation also proves that the Gediz River water flows south when certain atmospheric and current conditions are aroused (i.e., northerly wind direction etc.).

When the June 6, 1995 image was studied, none of these cold spots were observed. Rapidly changing surface water conditions show that, Izmir Bay has very dynamic oceanographic characteristics, which could not be observed by only using traditional oceanographic tools (i.e., research vessels). Satellite data should be used to complete *in situ* data. After the calibration of remotely obtained data with *in situ* data, the resulting images could be used in other parts of the research area which do not have actual physical data.

This cold water penetration from the Aegean Sea all the way down to the Middle Bay showed that physical oceanographers studying the physical state of Izmir Bay should not limit their research only to the traditionally accepted sections (Fig. 5.1). Marine scientists should not consider the Bay as a closed basin and should not evaluate it on these grounds. Researchers should consider the Aegean Sea as one of the main sections of the Bay and evaluate their Bay data in correlation with Aegean Sea data.

With the occurrence of suitable conditions (for example, appropriate wind force and direction); Izmir Bay may be affected by different water masses coming from the Aegean Sea. Although, they do not have borders with one another, the less saline and colder water mass coming from the Black Sea through the Strait of Bosphorus and Strait of Dardanelles may enter Izmir Bay and alter the water characteristics.

A different water mass coming from the Aegean Sea could also be observed with CCD data obtained by the R/V Piri Reis, however, it is difficult to determine the origin of this water mass solely through ship observations. The possibility of this water penetration may be seen in the PELAGOS Project Synthesis of Results (Balopoulos et al., 1997, Fig. 3) and also this possibility was analyzed in a different perspective by the Ukraine Marine Hydrophysical Institute Report (Stashchuk, 1997).

The entrance of the water masses, which had similar characteristics with Black Sea water (less saline and colder) was observed on the images obtained from June 20, 1996 to June 22, 1996.

An unusual water movement which can be traced across the Aegean Sea in a NE to NW direction was observed on the SST and visible images of June 20, 1996 (Fig. 5.10a&b). It was possible that, this water movement carried a portion of the Black Sea water coming from the Strait of Dardanelles to the middle sections of the Aegean Sea. This water movement showed similar physical characteristics to the NE to SW directional water movement that was observed in the Adriatic Sea on June 18, 1996 (Fig. 5.10c). Therefore, these water movements could be related to the unusual atmospheric conditions (instantly changing NW to NE wind directions) that affected the eastern Mediterranean surface water during that time. It was observed that, in the visible image of June 21, 1996 (Fig.10d) a structure of this water was fragmented by the effects of Aegean Sea surface circulation patterns (Bethoux et al., 1997). Most of these patches moved southwards and some patches eastwards (which is the western part of the Outer Bay) rather than moving into the Bay by the effects of the local currents. Then, on the 22nd of June (Fig. 5.10e), this water mass completely mixed with the Bay water. The work done by R/V K. Piri Reis between June 19-21, 1996 (ANON, 1997b) in the northwest section of the Outer Bay clearly state the existence of this water mass which had different characteristics than Izmir Bay water as far as its temperature and salinity deviate.

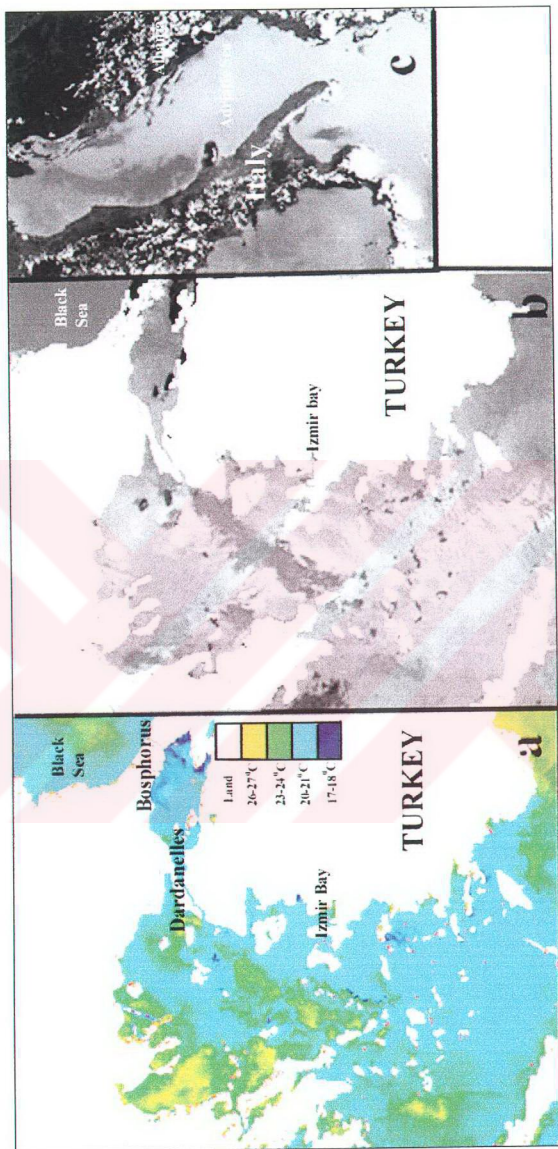


Figure 5.10a, b, & c SST and Ch.1 images of Aegean Sea and Adriatic Sea

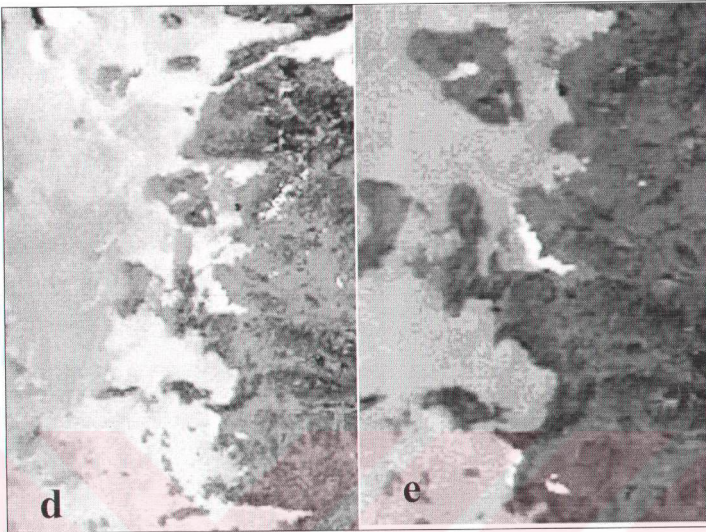


Figure 5.10d&e Visible images from June 21, 1996 and June 22, 1996

When SST images of June 18 to 22 dates were investigated, it was found that these extensive upwelling occurrences was also closely related to unusual atmospheric condition/water movement in the Sea of Marmara (Fig. 5.10f) and the entire coasts along the Anatolian side of the Aegean Sea (Fig. 5.10a).

Figure 5.10f was also a very good example for the Black Sea water entrance from the Straits of Bosphorus and its distribution into the Sea of Marmara.

Upwelling areas and related temperatures are summarized below:

Upwelling Temperature (°C)

Sea of Marmara

Bay of İzmit	18
Bay of Gemlik	17
Bay of Erdek	17

Aegean Sea

Bozcaada	18
Bay of Edremit	18
Bay of Çandarlı	17
Island of Samos	17
Island of Limnos	17
Datça	17

All of these upwelling areas are located along the southern coastal sections of the above mentioned locations.

5.2.4 July

The typically warm Inner Bay and colder Outer Bay thermal appearance again continued into this month. However, the colder water penetration from the Aegean Sea reaches close to the Middle Bay region.

One extraordinary event was observed in the thermal image of July 9, 1996. The SST value rose up to 30°C on the patch for the first time in the Outer Bay I while the surrounding water temperature was still at 28°C (Fig. 11a).

One possible explanation for this high temperature without confirmed supporting data (CTD measurements, *in situ* data etc.) was polluted waters resulting from a bilge water discharge of a passing ship. This idea was justified through the visible image (Fig. 11b) which gave a high reflectance value at the above-mentioned area.

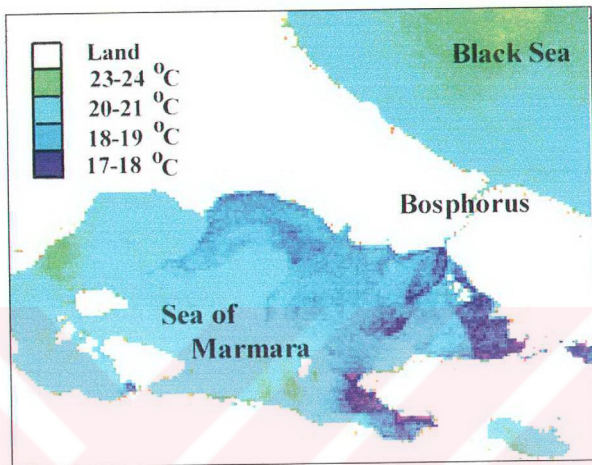


Figure 5.10f SST image of the Sea of Marmara

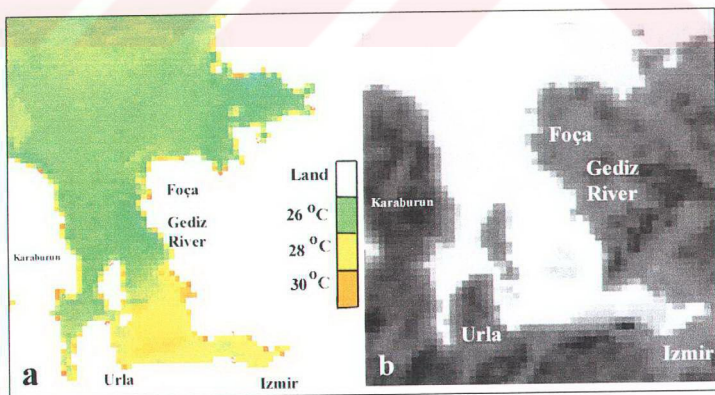


Figure 5.11a&b SST and Ch.1 images of July 9, 1996

However, when CTD data (Sayın, 1998) of the concerning area was studied, the salinity and density, together with the temperature increases which were coming from the deeper water, were also observed. This situation again occurred at various times during the past (Sayın, personal com., 1999). The source of this temperature (also salinity and density) increase could be traced to the bottom waters of the Outer Bay I. Therefore it can be concluded that, there is a “hot spot” at the bottom of the Outer Bay which produces a thermal water discharge as a possible result of tectonic activities which are common knowledge in the Izmir Bay and surrounding regions.

As a result of these high temperature values, biochemical reaction rate increased in the sea water and together with appropriate ecological parameters (high values of $\text{NO}_3\text{-N}$ and $\text{o.PO}_4\text{-P}$ (ANON, 1997b)) algal blooms were observed in some parts of the Bay. These blooms were detected by the NDVI images of the related dates (Fig. 12). The algal bloom areas also showed reasonably high temperature values (30°C) due to the existence of algae at the surface, which caused strong surface water heating several degrees higher than the neighboring waters due to the presence of these biological activities. Thermal characteristics of the bloom area were extensively used for the monitoring of the bloom of the toxic *Chrysochromulina polylepis* (Johannessen et al. 1989). Prangma and Roozekrans (1989) used the same characteristics to detect floating blue-green algae in The Netherlands.

5.2.5 August

The temperature differences between sections were beginning to diminish again. The only noticeable thermal feature of this month was at the mouth of the Gediz River. This colder water mass (21°C) could be traced up to the north along the Foça shores (Fig. 13a&b). This situation was also a good indicator of the effects of the changing seasonal wind and current directions and also bathymetric structure on the movement of the surface waters.

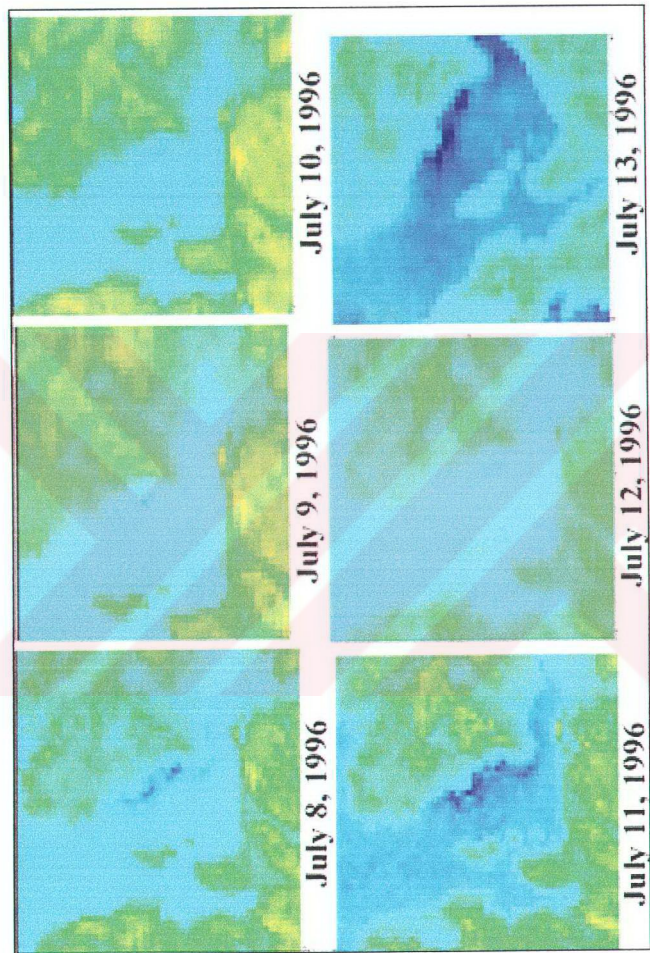


Figure 5.12 NOAA-14 NDVI images of July 8, 1996 to July 13, 1996.

5.2.6 September

Typical summer thermal appearance of the Bay also continued in this month. Even though temperature differences were not so distinct, the Outer Bay was still colder than the Inner Bay. The Outer Bay I water temperature increased by 1-2°C.

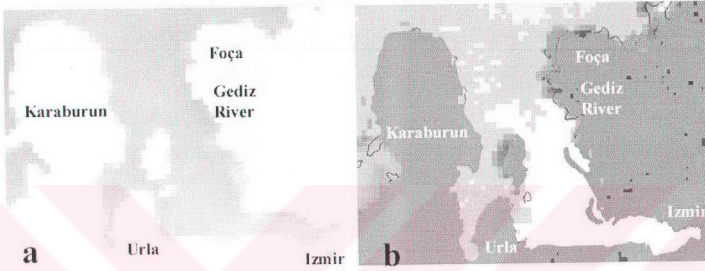


Figure 5.13a&b SST and Ch.1 images of August

Atmospherically corrected Ch.1 images also do not show any noticeable difference between the sections. However, water masses of the Inner, Middle and part of the Outer Bay show high reflectance due to pollution (Fig. 5.14a&b).

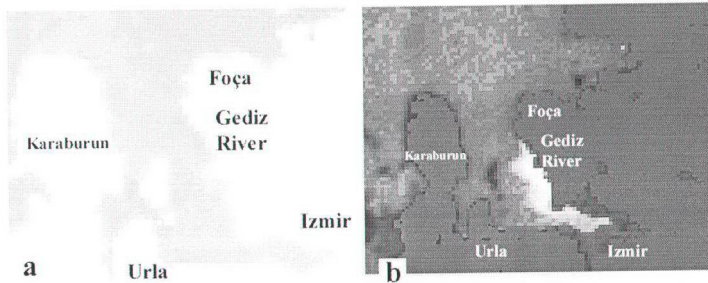


Figure 5.14a&b SST and Ch.1 images of September

5.2.7 October

Noticeable temperature changes began to occur in this month in all sections of the Bay. The water temperature decreased by a 3-4°C average in all sections of the Bay. The highest temperature decrease occurred in the Outer Bay with a range of 7-8 °C differences from the previous month. However, temperature differences between the sections did not exceed 1-2°C.

NDVI images of October 7 and 8, 1996 (Fig. 5.15a&b) show some activities on the Outer Bay II section of the Bay. Most probably, this activity was due to the presence of biological organisms and occurred as a result of the high values of NO₃-N and o.PO₄-P (ANON, 1997b). In this month, the average water temperatures were between 18-19°C in the Outer Bay II, however, at the location of the biological activity, this temperature rose up to 21°C. As in July, the activity of the biological organisms caused some temperature increases on the surface waters.

5.2.8 November

Noticeable water temperature decreases continued. As in the previous month, there was a very small (1-2°C) temperature difference between the Inner and Outer Bay which means that Izmir Bay thermally stabilized itself. This condition was also shown in the atmospherically corrected Ch.1 images. The reflectance values were almost uniform for the entire Izmir Bay. However, there was water penetration from the Aegean Sea to Outer Bay II, which was distinct from the rest of the sections (Fig. 5.16). It was observed that on the SST image, this water penetration did not create any noticeable temperature difference on the surface waters.

5.2.9 December

It was observed at the beginning of this month, due to the changing atmospheric conditions, the dominant thermal characteristics of Izmir Bay (warmer Inner Bay and

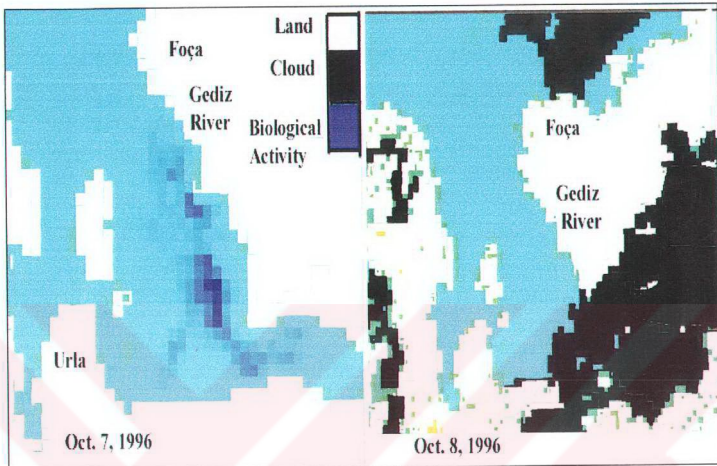


Figure 5.15 NDVI images of October 7-8, 1996

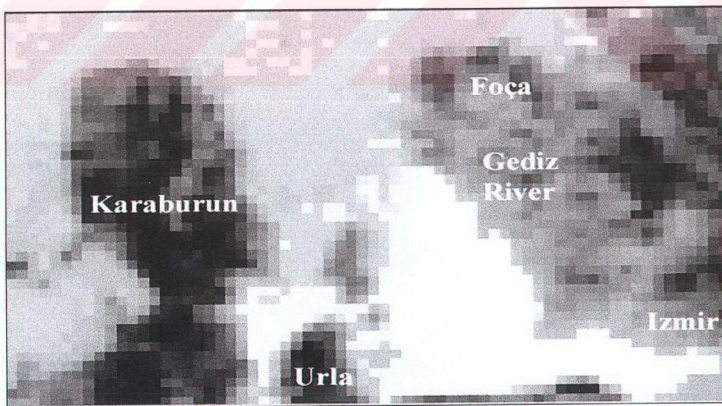


Figure 5.16 Ch.1 image of November

colder Outer Bay III) reversed themselves and the Inner Bay became 4-5°C colder than the Outer Bay.

Another interesting thermal feature of this month was a warm belt (15-16°C) extending from the Karaburun peninsula to Foça that was trapped between the colder water masses of the Outer Bay I and the Aegean Sea (13-14°C). There was also a cold spot (11°C) at the mouth of the Gediz River. It can be stated that the colder water mass of the Outer Bay I was a product of this cold spot, which was forced towards the south and mixed with the Outer Bay I water mass (Fig. 5.17).

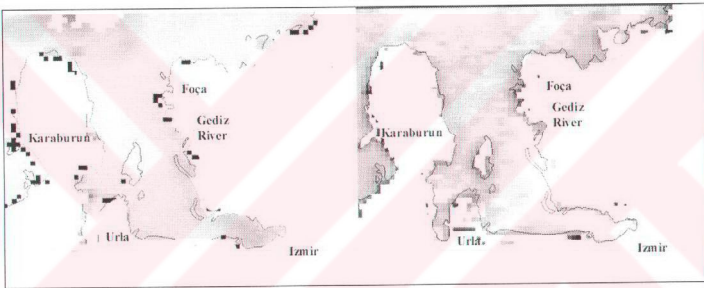


Figure 5.17 Ch.1 image of December

5.2.10 January

The changed conditions of the previous month continued and the temperature differences between the Inner Bay and Outer Bay increased up to 5-6°C. It is important to mention that heavy atmospheric conditions (heavy rain and strong winds) might have had some effects on these temperature differences. And the bathymetric structure of the Bay also had considerable influence on the temperature decreases due to the shallow sections becoming cooler more quickly than the deeper sections. The cold spot, at the mouth of Gediz River (10-12°C) was also seen in this month. It can still be stated that the colder water mass of the Outer Bay I was a product of this cold spot, which was forced towards the south and mixed with the Outer Bay I water mass.

5.2.11 February

Thermal conditions coming from the previous month continued to affect the Bay. The Inner Bay was still colder than the Outer Bay, however, temperature differences between these two sections dropped a few °C. Cold water discharge from the Gediz River continued to effect the Middle and Inner Bay and made those water masses colder than other sections (Fig. 5.18).

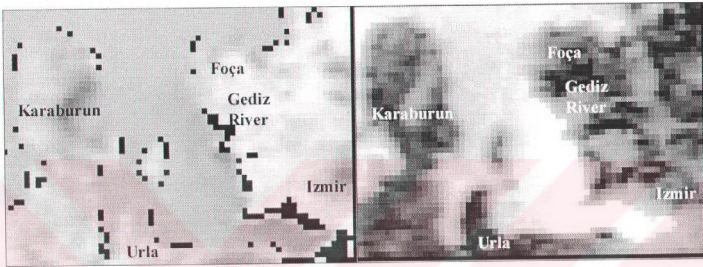


Figure 5.18 SST and Ch.1 images of February

Differences between Inner Bay, Middle Bay and part of the Outer Bay I were not limited with temperature. Atmospherically corrected Ch.1 images also show surface stratification between these sections. Polluted Inner and Middle Bay water could be traced in some parts of the Outer Bay II.

5.2.12 March

The typical condition of the winter months did not change in March. However, sea surface temperatures began to warm up 1-2°C and also temperature differences between sections became less.

The differences between these two images (Fig. 5.19a&b) were a good example of how the atmospheric corrections worked on Ch.1 images.

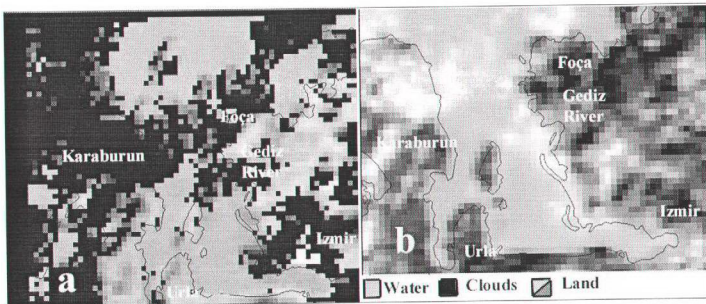


Figure 5.19 Raw and atmospherically corrected Ch.1 images

5.3 Results

This study was conducted by using AVHRR data and showed that when suitable atmospheric and oceanographic conditions arouse, Black Sea originated water could travel through the Aegean Sea and can penetrate İzmir Bay and affect its water characteristics.

In this study, satellite driven SST values for İzmir Bay also showed that there was a time when the temperature values reached 2-3°C above the seasonal maximum temperature values. This observation was also supported by the R/V K. Piri Reis *in situ* observations. This increase above the normal temperature may have been a result of a thermal discharge coming from the bottom of the Outer Bay I.

This study shows that, there is a close correlation between the satellite driven SST and *in situ* measurements (ANON, 1997b) obtained by R/V K.Piri Reis. Therefore, in certain cases, where *in situ* SST data cannot be obtained for some parts of İzmir Bay, calibrated satellite driven SST can be used.

CHAPTER SIX

CONCLUSIONS

6.1 Conclusions

In this study, remote sensing applications were conducted on the sources of erosion and pollution which affected the Turkish coastal waters. They were discussed in two case studies. In the first case erosion effects on the Altınova coastal zone were studied; in second case, physical state of Izmir Bay were investigated by using satellite driven sea surface temperatures.

In the first case study, the problem of coastal erosion along the Madra Creek and the coastline of Altınova was evaluated through the use of image processing and GIS techniques on several different sets of data which were obtained at different times.

The evaluation of these data showed that;

- The sediment transport capacity of Madra Creek was decreased,
- Damming of the Madra Creek not only reduced the sediment load of the creek but also diminished the downstream discharge and ,
- Human activities such as illegal removal of sand for construction and the construction of groins by property owners were the main reasons for the erosion on the Altınova coasts.

It was determined that a total of over 1,530,000 m² of beach land, which is equal to 3,000,000 m³ of beach sand, were lost to the sea over a period of 34 years. It was also determined that 50% of the erosion occurred over the last seven years, which was in coincidence with the beginning of the construction of Madra Dam.

The construction of the Madra Dam, for the sake of development, without planning and/or consideration to its effects on the balances of nature combined with the human desire for second housing arose as the main sources for the beginning of a series of man-made disasters along the Altınova shores.

In the second case study, which was completed by using AVHRR data, showed that when certain atmospheric and oceanographic conditions occur, water originally coming from the Black Sea may travel all the way through the Aegean Sea then enter the Bay of İzmir.

The same data was also supported by the R/V K. Piri Reis *in situ* data during times when the temperature values reached 2-3°C above the seasonal maximum temperature values that proved the existence of a thermal water source heating the Bay of İzmir waters.

This study shows that, even though there was not sufficient data for all months, there is a high correlation between the satellite driven SST and *in situ* measurements obtained by R/V K. Piri Reis.

In general, studies where very accurate SST data is not necessary, satellite driven SST data is sufficient. However, in cases where very detailed temperature data is needed, remotely obtained SST values will never replace *in situ* observations. Satellite derived data use can improve the interpretation of thermal measurements in general.

The marine scientist can design a sampling program previous to the scientific cruise on the basis of the past experience obtained by analyzing earlier images. At the time of the actual cruise, the research vessel can be directed towards the changing or unusual oceanographic event that was observed on the most recently obtained image. At the end of the scientific cruise, the marine scientist can calibrate SST image maps with *in situ* data, therefore, these calibrated images can be used for research in the places where *in situ* data may not be obtained and/or where it is needed to confirm data validation.



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ACRONYMS

APT	Automatic Picture Transmission
AMSU	Advanced Microwave Sounding Units
AVHRR	Advanced Very High Resolution Radiometer
CNES	Centre National d'Etudes Spatiales
CZCS	Coastal Zone Color Scanner
FOV	Field Of View
IFOV	Instantaneous Field Of View
GAC	Global Area Coverage
GIS	Geographical Information Systems
HRPT	High Resolution Picture Transmission
IR	Infrared
IMST	Institute of Marine Sciences and Technology
LAC	Local Area Coverage
MCSST	Multi-Channel Sea Surface Temperatures.
MSS	Multi-Spectral Scanner
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
SST	Sea Surface Temperature
SSU	Stratospheric Sounding Unit
TIROS	Television Infrared Observation Satellite
TM	Thematic Mapper

APPENDICE A

NOAA-12&14 AVHRR DAY & NIGHT SST

EQUATIONS

NOAA-12 AVHRR day & night SST equations

(From NOAA Technical Momerandum 3/8/1994)

Regression Output:MCSST TRIPLE night

Constant -271.971

Std Err of Y Est 0.476915

R Squared 0.99384

No. of Observations 761

Degrees of Freedom 757

Features T3.7-T12 T11 SEC0-1

X Coefficient(s) 0.911173 1.000281 1.710028

Std Err of Coef. 0.015322 0.003874 0.103441

Regression Output:MCSST DUAL night

Constant -279.846

Std Err of Y Est 0.567181

R Squared 0.991287

No. of Observations 761

Degrees of Freedom 757

Features T3.7-T11 T11 SEC0-1

X Coefficient(s) 1.288548 1.031355 2.265075

Std Err of Coef. 0.026994 0.004349 0.121913

Regression Output:MCSST SPLIT night

Constant	-263.94
Std Err of Y Est	0.511227
R Squared	0.992921
No. of Observations	761
Degrees of Freedom	757
Features	T11-T12 T11 (T11-T12)*(SEC0-1)

X Coefficient(s) 2.384376 0.967077 0.480788

Std Err of Coef. 0.049375 0.004568 0.061476

Regression Output:NLSST TRIPLE night

Constant	-260.854
Std Err of Y Est	0.469015
R Squared	0.994042
No. of Observations	761
Degrees of Freedom	757

Tsfc*

Features (T3.7-T12) T11 (SEC0-1)

X Coefficient(s) 0.033139 0.963368 1.731971

Std Err of Coef. 0.000546 0.004158 0.101668

Regression Output:NLSST DUAL night

Constant	-276.9
Std Err of Y Est	0.537463
R Squared	0.992176
No. of Observations	761
Degrees of Freedom	757

Tsfc*

Features (T3.7-T11) T11 SEC0-1

X Coefficient(s) 0.050549 1.021468 2.201377

Std Err of Coef. 0.000987 0.004195 0.115597

Regression Output:NLSST SPLIT night

Constant	-240.229
Std Err of Y Est	0.475031
R Squared	0.993888
No. of Observations	761
Degrees of Freedom	757

Tsfc*

Features (T11-T12) T11 (T11-T12)*(SEC0-1)

X Coefficient(s) 0.081646 0.888706 0.576136

Std Err of Coef. 0.001537 0.005243 0.056038

Regression Output:NLSST SPLIT Day

Constant	-236.667
Std Err of Y Est	0.483151
R Squared	0.98784
No. of Observations	419
Degrees of Freedom	415

Tsfc*

T11 (T11-T12) (T11-T12)*(SEC0-1)

X Coefficient(s) 0.876992 0.083132 0.349877

Std Err of Coef. 0.009262 0.00166 0.073627

Regression Output:MCSST SPLIT Day

Constant	-263.006
Std Err of Y Est	0.540754
R Squared	0.984767
No. of Observations	419
Degrees of Freedom	415

T11 T11-T12 (T11-T12)*(SEC0-1)

X Coefficient(s) 0.963563 2.579211 0.242598

Std Err of Coef. 0.009217 0.058894 0.082973

Revised NOAA 12 AVHRR Day and Night SST Equations)

MCSST=linear Multi-Channel Sea Surface Temperature algorithm.

NLSST=Non-linear Sea Surface Temperature algorithm.

All equations based on December 1993 drifting buoy matchups.
 T3.7,T11,T12=AVHRR channels 3,4,5 brightness temperatures (Deg.K)
 SEC0=secant of satellite zenith angle.

Tsfc is an apriori estimate of surface temperature (degrees Celsius). It can be based on a satellite only or blended or climatological based field analysis, or derived from the actual satellite measurements using one of the MCSST equations. In operational use Tsfc is limited to the range between 28 and -2 Deg Celsius. NOAA 11 continues to be used operationally at NESDIS for operational global processing.

Example of use:

Night MCSST SPLIT Eqn.= $0.967077 * T11 + 2.384 * (T11 - T12) + 0.481 * (T11 - T12) * (SEC0 - 1) - 263.94$ (Deg. Centigrade).

NOAA 14 AVHRR Day and Night SST Equations

(From NOAA Technical Momerandum 3/20/1995)

MCSST=linear multi-channel Sea Surface Temperature algorithm.

NLSST=Non-linear Sea Surface Temperature algorithm (SST).

All equations based on March 1995 global drifting buoy and tropical Pacific fixed buoy matchups. T3.7, T11 and T12 =AVHRR channels 3, 4 and 5 brightness temperatures (Deg. K). SEC0=secant of satellite zenith angle. Tsfc is an apriori estimate of surface temperature (Deg. Celsius). Preferably, It should be based on a satellite only or blended or climatological based field analysis but may be derived

from the actual satellite measurements using one of the MCSST equations. In operational use, Tsfc is limited to the range between 28 and -2 Deg. Celsius. NOAA 14 replaces NOAA 12 for operational processing of SST on March 20,1995. The new day and night operational equations are denoted by asterix.

Example of use:

Night NLSST Split SST = $0.0781 * Tsfc * (T11 - T12) + 0.9331 * T11 + 0.7381 * (T11 - T12) * (SEC0 - 1) - 253.43$ (Deg. Celsius).

Regression Output:Night NLSST Split

Constant	-253.428		
Std Err of Y Est	0.480436		
R Squared	0.993766		
No. of Observations	1055		
Degrees of Freedom	1051		
	$Tsfc * (T11 - T12)$	$T11$	$(T11 - T12) * (SEC0 - 1)$
X Coefficient(s)	0.078095	0.933109	0.738128
Std Err of Coef.	0.001017	0.004392	0.03915

Regression Output:Night MCSST Split

Constant	-282.24		
Std Err of Y Est	0.535959		
R Squared	0.992242		
No. of Observations	1055		
Degrees of Freedom	1051		
	$(T11 - T12)$	$T11$	$(T11 - T12) * (SEC0 - 1)$
X Coefficient(s)	2.275385	1.029088	0.752567
Std Err of Coef.	0.033812	0.004022	0.043759

Regression Output: * Night NLSST Triple *****

Constant	-266.186		
Std Err of Y Est	0.427116		
R Squared	0.995073		
No. of Observations	1055		
Degrees of Freedom	1051		
	Tsfc*(T3.7-T12)	T11	SEC0-1
X Coefficient(s)	0.031889	0.980064	1.817861
Std Err of Coef.	0.000316	0.003461	0.069577

Regression Output:Night MCSST Triple

Constant	-275.364		
Std Err of Y Est	0.411102		
R Squared	0.995438		
No. of Observations	1055		
Degrees of Freedom	1051		
	T3.7-T12	T11	SEC0-1
X Coefficient(s)	0.920822	1.010037	1.760411
Std Err of Coef.	0.008757	0.003153	0.067026

Regression Output:Night NLSST Dual

Constant	-276.813		
Std Err of Y Est	0.461235		
R Squared	0.994255		
No. of Observations	1055		
Degrees of Freedom	1051		
	Tsfc*(T3.7-T11)	T11	SEC0-1
X Coefficient(s)	0.050086	1.019182	2.039266
Std Err of Coef.	0.000541	0.003496	0.074861

Regression Output:Night MCSST dual

Constant	-273.914		
Std Err of Y Est	0.432718		
R Squared	0.994943		
No. of Observations	1055		
Degrees of Freedom	1051		
	(T3.7-T11)	T11	SEC0-1
X Coefficient(s)	1.409936	1.008751	1.975581
Std Err of Coef.	0.01419	0.003332	0.070296

Regression Output:* Day NLSST Split *****

Constant	-255.165		
Std Err of Y Est	0.507031		
R Squared	0.994647		
No. of Observations	865		
Degrees of Freedom	861		
	Tsfc*(T11-T12)	T11	(T11-T12)*(SEC0-1)
X Coefficient(s)	0.076066	0.939813	0.801458
Std Err of Coef.	0.00148	0.004885	0.048744

Regression Output:Day MCSST Split

Constant	-278.43		
Std Err of Y Est	0.570485		
R Squared	0.993223		
No. of Observations	865		
Degrees of Freedom	861		
	(T11-T12)	T11	(T11-T12)*(SEC0-1)
X Coefficient(s)	2.139588	1.017342	0.779706
Std Err of Coef.	0.049017	0.004365	0.055699

APPENDICE B

SMART ANTENNA SYSTEM SPECIFICATIONS

SMART Antenna System Specifications:

Antenna Type:	Solid Parabolic Aluminum
Antenna Diameter:	1.2 meters (4 feet)
Gain:	24.7 dBi at 1700 MHz
Beamwidth:	10.3 degrees typical
Finish:	White powder coat
Acquisition Elevation (10-6 BER):	3.5 degrees
Azimuth Range:	380 degrees
Elevation Range:	180 degrees
Azimuth & Elevation Peak Torque:	95 Nm (70 ft.-lbs.)
Backlash (both axes):	0.15 degrees
Overall Positioning Accuracy:	0.3 degrees
Azimuth & Elevation Speed:	10 degrees/second
Protection:	Az/El Limit Switches
Stowing:	Automatic to vertical position
Antenna/Positioner Weight:	53 kg (116 lbs.)
Winds (Survival):	145 km/hour (90 mph)
Winds (Operational, no radome):	75 km/hour (45 mph)
Tracking Control:	Internal microprocessor running SGP4 model
Antenna Interface:	Via RS-422 (SMARTrak Users Guide, 1993)

Integrated Feed / LNA / Downconverter: IFD 1700

RF Input Frequency:	1690 - 1710 MHz
RF Input Bandwidth:	35 MHz (3 pole filter)
Image Rejection:	60 dB typical
Downconverter Gain:	45 dB typical
Downconverter Noise Figure:	0.8 dB (60K) typical
IF Output Frequency:	125.0 - 145.0 MHz
Power Requirements:	+12 to +16 VDC @ 500 mA max
Polarization:	RHCP (Dual RHCP / LHCP
(optional) Frequency Stability:	+ / - 2 KHz typical
IF Output Connector:	type 'N' female
Environmental:	-30 to +60 degrees C
IF Cable Length:	Up to 100 meters (SMARTrak Users Guide, 1993)

HRPT Receiver: BPSK 1700

IF Input Frequency:	120 - 170 MHz
IF Input Connector:	BNC Female
Bit Rate:	DC to 2.5 Mbps
Loop Bandwidth:	0.003% to 3.0% of center frequency
Capture Range:	3 X loop bandwidth
Image Rejection:	60 dB typical
IF Rejection:	60 dB typical
Adjacent Carrier Rejection:	1 dB maximum BER degradation
Parasitic Interference Rejection:	60 dB typical
Input Level:	-10 to -30 dBm (70mV to 7 mV @ 50 ohms)
Input Impedance:	50 ohms
Implementation Loss:	<1 dB
Demodulator Type:	PSK & BPSK-PLL

Demodulators Output: Clock and Data RS-422 (NRZ & Manchester)

(SMARTrak Users Guide, 1993)

Combined Bit / Frame Synchronizer: IBFS 1700

Input:	Serial, TTL, RS-422NRZ or Manchester
Bit Rates:	5 bps to 2.5 Mbps
Clock Recovery:	DPLL with real time correlator
Insertion of Decryption / Recorder:	Via 5-channel SMART Decryption Interface
Data Path Selection:	Automatic via SMARTrack through Bus
Automatic Tracking Range:	+ 12% of specified bit rate
Loop Bandwidth:	1.0% standard
Bit Error Rate:	+ 1.5 dB of theoretical
Threshold:	SNR > 6 dB
Jitter:	> 1 dB for jitter amplitudes <1.0% of bit rate
Output:	8 to 64-bit words to Workstation
Bus BUS Interface:	64-bit PCI Bus

(SMARTrak Users Guide, 1993)

APPENDICE C

KODAK DC50 SPECIFICATIONS

Kodak DC50 Specifications:

Resolution:	756 x 504 pixels
Color:	24-bit, millions of colors
Compression levels:	3 levels selectable from camera best level (near glossless): 7 pictures/MB better (glossy): 11 pictures/MB good (glossy): 22 pictures/MB
Storage:	1 MB internal non-volatile flash EPROM or PCMCIA-ATA removable storage card, Type I and II (fully compatible)
Lens:	3x motorized zoom (auto focus range normal mode: 29 in. to infinity close-up mode: 19 in).
Lens focal length:	37 to 111 mm
Focusing method:	auto focusing with multi-beam or single-beam active infrared
Viewfinder:	real-image optical
Built-in flash:	3 modes: automatic, always on, always off, range to 14 ft.
Exposure:	Programmed automatic with ± 1 stop exposure compensation override
ISO equivalent:	84
Aperture range:	f/2.5 to f/24
Shutter speed range:	1 / 16 to 1 / 500 second
Self-timer:	10 seconds
Tripod mount:	standard threaded

Power: 4 AA batteries lithium included), optional power supply available

(1) up to 500* exposures with lithium batteries

(2) up to 150* exposures with NiCad batteries (can also use alkaline batteries)

(3) Amount varies based on number of flash pictures taken and number of pictures downloaded to computer.

Connector: RS232 serial

Weight (with batteries installed): 22 oz.

Dimensions: 5.9 in (d) x 4.3 in (w) x 2.4 in (h)

Compatibility: IBM PC or compatible computer with 80386 or higher CPU and 6 MB available RAM, Windows software 3.1 or later (including Windows 95) and MS-DOS 3.3 or (later. Apple Macintosh II computer or higher with 6 MB available RAM, operating software 7.1 or later.

(From KODAK WEB Site)

APPENDICE D

GPS 90 SPECIFICATIONS

GPS 90 Specifications:

Jeppesen Database

Coverage:	Americas, Atlantic International, or Pacific International
Airports: ID,	city/state, name, latitude/longitude, runways, communication frequency, elevation
VORs: ID,	city/state, country, name; latitude/longitude, frequency, co-located DME (or TACAN)
NDBs: ID,	city/state, country, name, latitude/longitude, frequency
Intersections: ID,	country, latitude/longitude
Comm Freq:	ATIS, tower; ground, unicom/multicom
Runways:	Designation, length, surface, lighting, pilot controlled lighting frequency, graphically displayed runway configuration
SUA: US Class	B&C with sectors, International CTA & TMA with sectors; all SUA's including MOAs, Prohibited and Restricted
	Performance
Receiver:	MultiTrac8™ tracks up to 8 satellites to compute and update position
Acquisition Times:	
	Warm: approx. 15 seconds
	Cold: approx. 2 minutes

Autolocate TM: approx. approx.7.5 minutes

Accuracy:

Position: 15 meters (49 ft) RMS* 1-5 meters with DGPS corrections
 Velocity: 0.1 kt RMS steady state
 Antenna: Detachable with standard BNC connector
 Emergency Search: 9 nearest airports, VORs, NDBs, intersections or user way points
 User Way points: 250 alphanumeric
 Routes: 20 reversible with 30 way points
 Map Datums: 69
 Coordinates: 11 position formats including latitude/longitude, UTM/UPS, six grid systems

Physical Specification

Size: 6.15 x 2 x 1.23 inches 15.6 x 5.1 x 3.1 cm
 Weight: 9 oz 255G with batteries
 Display: 2.2 x 1.5 in (5.6 x 3.8 cm) high contrast LCD with back lighting
 Power Source: (4}AA batteries - 8 to 40 VDC
 Battery Life: Up to 15 hours (normal mode), Up to 20 hours (battery saver mode)
 Temp. Range: 5F to + 158F {-15C to 70C)

Standard Components:

GPS 90 unit with detachable antenna o Suction cup mounting bracket o Universal yoke mount

4 AA batteries o Carrying case

Power/data cable

Users manual

Quick reference card

Optional: o Cigarette lighter adapter (From GERMIN WEB Site)

APPENDICE E

NOAA-KLM, SeaWiFS & LANDSAT-7

NOAA-KLM

According to the NOAA-KLM Users Guide the following changes and modifications will be made to the NOAA series satellites.

The Advanced Very High Resolution Radiometer (AVHRR/2) has been modified. The new instrument, AVHRR/3, adds a sixth channel in the near-IR, at $1.6\mu\text{m}$. This will be referred to as channel 3A and will operate during the daylight portion of the orbit. Channel 3B corresponds to the previous channel 3 on the AVHRR/2 instrument and will operate during the night portion of the orbit. The operational scheduling of the channel 3A/3B switching has not been precisely determined at the moment. A flag (Word 7, Bit 10) of the telemetry will indicate which of the two channels is operating. Splitting channel 3 in this way maintains the HRPT data format, which was designed to handle five AVHRR channels. Channels 3A and 3B are output from the same telemetry locations

Automatic Picture Transmission (APT) users will receive AVHRR/3 channel 3A the same as channel 3B, with an ID wedge equivalent to the gray scale wedge 3.

The AVHRR/3 visible channels (1, 2, and 3A) all have “split gains” or “dual slopes” that require the use of two calibration equations per channel, where previously one was sufficient. The split gains, if there is an effect, will increase the sensitivity at low light/energy levels. The prime reason for these changes is to

improve ice, snow and aerosol products reflection that is produced from the visible channel data. The visible channel ramp voltage calibrations also have dual slopes.

The Microwave Sounding Unit (MSU) and Stratospheric Sounding Unit (SSU) instruments have been deleted. The NOAA-K will fly with Advanced Microwave Sounding units AMSU-A1, AMSU-A2 and AMSU-B. The AMSU-A is a 15-channel microwave radiometer in two separate units. For AMSU-A1 and AMSU-A2, the word 0001H will be used as fill data most of the time in the telemetry stream. The new AMSU data is expected to provide improved temperature and humidity soundings. Additionally, window channels 1, 2 and 15 will provide information related to precipitation, sea ice and snow cover. The AMSU-B is a five-channel microwave radiometer; three of the channels are centered on the 183.31 Ghz water vapor line. The other two channels are at 89 Ghz and 150 Ghz

The Solar Backscatter Ultraviolet Radiometer (SBUV) is carried on the satellites with an afternoon orbit. The NOAA-K will most likely be launched into a morning orbit and will carry the SBUV/2, which has only minor changes from similar instruments carried on previous spacecraft. While NOAA-K will be tested in an afternoon orbit configuration, it will be capable of being launched as a morning or afternoon spacecraft to meet operational needs.

The new High Resolution Infrared Radiation Sounder (HIRS/3) calibration sequence will be changed. On the HIRS/2, the calibration mode required the use of three calibration targets (space view, cold target, and warm target). On the HIRS/3, the cold target will not be routinely used in the calibration sequence, resulting in one additional scan line of Earth data (38 Earth scans per 256 second cycle).

The Argos Data Collection System (DCS) aboard the NOAA polar orbiting satellites will be improved for NOAA-K. The DCS/2 will have an increased data transmission rate (from 1200 to 2560 bits per second), and the onboard data recovery units (DRUs) will be increased from four to eight.

An improved Space Environment Monitor (SEM-2) has been added for in-flight calibration capabilities and for improved particle detection. The Total Energy Detector (TED) will measure at a lower energy (0.05 keV versus 0.3 keV on NOAA-J). The Medium Energy Proton/Electron Detector (MEPED) has a fourth, omnidirectional, proton sensor for greater than 140 MeV. More data will be included in the telemetry stream.

The Search and Rescue Processor (SARP) has added capabilities for the handling of distress messages. The number of Data Recovery Units has been increased from two to three.

With the new instruments, data formats will be slightly changed. Within the HRPT Minor Frame format, the first Minor Frame will be TIP data, the second Minor Frame will be spare, and the third Minor Frame will be the AMSU-A1, -A2, and B data.

SeaWiFS

The SeaWiFS mission is a part of NASA's Mission to Planet Earth (MTPE), which is designed to observe our planet from space so as to better comprehend it as a system in both behavior and evolution.

SeaWiFS is actually attached to a satellite known as Seastar, which was launched in August 1, 1997 by a Pegasus rocket carried aloft on a modified L-1011 aircraft. The SeaWiFS' mission is to illuminate the role of oceans in distributing carbon through the land, sea, and life here on Earth. It will measure the violet, blue, yellow, and green hues of the ocean, as well as the intensity of red light scattered by atmospheric dust, haze, and by land surfaces. SeaWiFS hopes to determine the mean and variable bio-optical reflectance characteristics of the upper ocean.

Table E1 The SeaWiFS sensor records the following bands

Band	Wavelength	Bandwidth	Color	Measurement
1	412 nm	20 nm	Violet	Dissolved organic matter (violet absorption)
2	443 nm	20 nm	Blue	Chlorophyll (blue absorption)
3	490 nm	20 nm	Blue/ green	Chlorophyll (blue/green absorption)
4	510 nm	20 nm	Green	Chlorophyll (green absorption)
5	555 nm	20 nm	Green/Yellow	Chlorophyll (green reflection)
6	670 nm	20 nm	Red	Atmospheric aerosols
7	765 nm	40 nm	Near-IR	Atmospheric aerosols
8	865 nm	40 nm	Near IR	Atmospheric aerosols

The SeaWiFS instrument has been modified to produce a bilinear response in which the original sensitivity is maintained up to approximately 80% of the digital output range and is then changed discontinuously to substantially extend the dynamic range. The net result is no expected saturation over clouds (or bright sand, ice, etc.). For example, in the original design, the Band 1 saturation (1023 counts) corresponded to an input radiance of about 13.6 mW per (cm μ m sr), with a linear response. Now the response is linear up to a radiance of approximately 10.9 (about 817 counts), and changes slope past this point so that saturation is reached at about 60.1. The instrument has scanning mechanisms to drive an off-axis folded telescope and a rotating half-angle mirror that is phase-synchronized with, and rotating at half the speed of, the folded telescope. The rotating scanning telescope, coupled with the half-angle scan mirror arrangement, provide a design configuration that permits a minimum level of polarization to be achieved, without field-of-view rotation, over the maximum scan angle requirement of 58.3 degrees. The absence of field-of-view rotation permits the use of a multi channel, time-delay and integration (TDI) processing in each of the eight spectral bands to achieve the required SNR. This capability, in turn, allows a relatively small sensor collecting aperture resulting in a smaller and lighter instrument than would otherwise be required.

Incoming scene radiation is collected by the folded telescope and reflected onto the rotating half-angle mirror. The collected radiation is then relayed through dichroic beam splitters to separate the radiation into four wavelength intervals---each wavelength interval encompassing two of each of the eight SeaWiFS spectral bands. The radiation in the four separate wavelength intervals is directed by four corresponding aft-optics assemblies through two separate spectral bandpass filters that further separate the radiation into the eight required SeaWiFS spectral bands. The aft-optics assemblies also image each of the resultant defined bands of radiation onto four detectors that are aligned in the scan direction. Preamplifiers then amplify the detected radiation signals for TDI processing in the electronics module.

The off-axis scanning telescope rotates at six revolutions per second in the cross-track direction, for HRPT format compatibility, to provide contiguous scan coverage at nadir from a 705 km (380 nmi) orbital altitude with the SeaWiFS spatial resolution of 1.6 mrad (1.13 km or 0.6 nmi at nadir). A scanner tilt mechanism enables the instrument to be oriented in the along-track direction to +20, 0 -20 degrees to avoid any sun glinting from the sea surface. Tilting the entire scanner, rather than only a section of the optical train, assures that the SeaWiFS calibration, polarization, and angular scanning characteristics will be identical for all tilt positions and, thereby, simplifies the ground processing of in-flight data.

The monitoring of sensor calibration over the period of a few orbits, to several months or years, is accomplished using solar calibration for the former and lunar calibration for the latter. Solar calibration uses a solar radiation diffuser and an input port located in a fixed position outside of the 58.3 degrees SeaWiFS scene-scan interval. The diffuser is located on the inside of a baffle pointed in the +y (minus velocity vector) direction. The diffuser will be covered with an aperture plate with numerous small holes that will adjust the diffuser system output to the required level and minimize the diffuser surface degradation from contamination or ultraviolet exposure. The diffuser is located so that calibration will take place near the southern terminator.

Lunar calibration is accomplished by a spacecraft maneuver to view the moon when the spacecraft is in the nighttime portion of the orbit. The spacecraft is oriented so that the SeaWiFS scene-scan interval is 180 degrees from the normal Earth oriented position, i.e., looking outward. The lunar observation may, therefore, be accomplished under nearly full lunar conditions through the identical SeaWiFS optical path as that of Earth scenes. The detected and amplified signals are routed from the scanner to the electronics module where they are further amplified and then filtered to limit the noise bandwidth. The filtered signals are digitized by a 12 bit analog to a digital converter, and the digitized signals are directed to a processor that may be commanded, where the TDI operation is performed in real time as data are generated.

The consequent summed signals are divided by four and rounded to 10 bit numbers, and then sent from the processor to the spacecraft data system at 1.885 Mbps during the data acquisition period of each scan line. The angular momentum wheel compensates for the instrument angular momentum, which is necessary to avoid nutation coupling when the instrument is tilted. Implementation will consist of a brushless DC motor driven synchronously at approximately 2,000 rpm. The accurately controlled frequency derived from the instrument clock will ensure compliance to the 1 oz-in-sec uncompensated angular momentum requirement for the spacecraft attitude control system (SeaWiFS Technical Report Series, 1996).

This instrument is designed to monitor ocean physics, chemistry, and biology from space, and will provide the fast, repeated global coverage necessary for advanced global studies of marine phytoplankton, ocean surface currents, and global climate changes.

The purpose of the SeaWiFS Project is to provide quantitative data on global ocean bio-optical properties and the exchange of carbon and other biogenic elements between the atmosphere and the ocean to the earth science community.

The SeaWiFS program goals are as follows:

- To determine the spatial and temporal distributions of phytoplankton blooms, along with the magnitude and variability of primary production by marine phytoplankton on a global scale;
- To quantify the ocean's role in the global carbon cycle and other biogeochemical cycles;
- To identify and quantify the relationships between ocean physics and large-scale patterns of productivity;
- To understand the fate of fluvial nutrients and their possible effects on the carbon budget;
- To identify the large-scale distribution and time of spring blooms in the global ocean;
- To acquire global data on marine optical properties, in association with a better understanding of the process associated with the mixing along the edge of eddies and boundary currents.

From an altitude of 705 km, SeaWiFS will scan a 2,800 km wide swath , completing one polar orbit every 99 minutes.

This project is unique in that it is a partnership between NASA and a private business called Orbital Sciences Corporation (OSC). NASA developed and now operates the data collecting system and is responsible for the data and its distribution. However, all other aspects of the mission, such as satellite construction, launch, command, control, and tracking of the satellite, are the responsibility of OSC. The Seastar satellite, which carries the SeaWiFS sensor, was developed by the Santa Barbara Research Center of Hughes Aircraft in California, under an OSC subcontract.

In 1996, the Institute of Marine Sciences and Technology completed an agreement with NASA to become one of the authorized receiving ground stations for SeaWiFS data. Through this agreement, IMST will collect and store SeaWiFS data

and make it available to NASA upon request. Also, IMST agreed to supply in situ data to NASA, which has been obtained by the Institute's research vessel K.Piri Reis.

As for SeaWiFS data-gathering capacity, a five year mission is planned, and the sensor is capable of gathering , in two minutes, more ocean-surface data than any one ship could gather in a decade.

LANDSAT-7

The main service of this satellite is to supply data to users worldwide at low cost, with multi-purpose, land (and oceanographic) remote sensing data, into the twenty-first century.

In 1992, the US Congress authorized the procurement, launch and operation of a new Landsat satellite. This new system, Landsat 7, is now under construction and is scheduled for launch in late 1998. It will be the latest in a series of earth observation satellites dating back to 1972. The twenty-two year record of data acquired by the Landsat satellites constitutes the longest continuous record of the earth's continental surfaces. Preservation of the existing records and continuation of the Landsat capability were identified in the law as critical to land surface monitoring and global change research.

Landsat 7 will have a unique and essential role in the realm of earth observing satellites in orbit by the end of this decade. No other system will match Landsat's combination of synoptic coverage, high spatial resolution, spectral range and radiometric calibration. In addition, the Landsat Program is presently committed to providing Landsat digital data to the user community in greater quantities, more expediently and at a lower cost than at any previous time in the history of the program.

The earth observing instrument on Landsat 7, the Enhanced Thematic Mapper Plus (ETM+), replicates the capabilities of the highly successful Thematic Mapper instruments on Landsats 4 and 5*. The ETM+ also includes new features that make it a more versatile and efficient instrument for global change studies, land cover monitoring and assessment, and large area mapping than its design forebearers.

The primary new features on Landsat 7 are:

- a panchromatic band with 15 m spatial resolution;
- on board, full aperture, 5% absolute radiometric calibration; and
- a thermal IR channel with 60 m spatial resolution.

Table E2 Landsat 7 and ETM+ Characteristics:

Band Number	Spectral Range(μm)	Ground Resolution(m)
1	.450 to .515	30
2	.525 to .605	30
3	.630 to .690	30
4	.750 to .90	30
5	1.55 to 1.75	30
6	10.40 to 12.5	60
7	2.09 to 2.35	30
Pan	.52 to .90	15

The following are the special technical qualities of the Landsat 7 satellite: a swath width of :185 kilometers; a repeat coverage interval of 16 days (233 orbits); an altitude of 705 kilometers; quantization of Best 8 of 9 bits; on-board data storage of~375 Gb (solid state); inclination of Sun-synchronous, 98.2 degrees; equatorial crossing of Descending node; 10:00 am $\pm$ 15 min. The launch vehicle is a Delta II rocket and the launch date is scheduled for late 1998.

The instrument will be supported by a ground network that will receive ETM+ data via X-band direct downlink at a data rate of only 150 Mbps (the ETM+ is similar to the ETM instrument on Landsat 6. Landsat 6 was launched in October, 1993, but failed to obtain an orbit.). The primary receiving station will be at the US Geological Survey's (USGS) EROS Data Center (EDC) in Sioux Falls, South Dakota. Substantially cloud-free, land and coastal scenes will be acquired by EDC through a real-time downlink and by playback from an on-board, solid state, recording device. The capacities of the satellite, instrument and ground system will be sufficient to allow for continuous acquisition of all substantially cloud free scenes at the primary receiving station. In addition, a world wide network of receiving stations will be able to receive real-time, direct downlink of image data via the X-band. Each station will be able to receive data only for that part of the ETM+ ground track where the satellite is in sight of the receiving station.

The Landsat 7 system will insure continuity of Thematic Mapper type data into the next century. These data will be made available to all users through the EDC at the cost of fulfilling user requests. Browse data (a lower resolution image for determining image location, quality and information content) and metadata (descriptive information on the image) will be available, on-line, to users within 24 hours of the acquisition of the image by the primary ground station. The EDC will process all Landsat 7 data received to "Level 0R" (i.e., corrected for scan direction and band alignment but without radiometric or geometric correction) and archive the data in that format. A systematically corrected product (Level 1G) will be generated and distributed to users upon request. The user will then have the option of performing further processing on the data on user-operated digital processing equipment or having this process performed by a commercial, value-added firm.

The construction of the Landsat 7 spacecraft contract was awarded to Lockheed Martin, of Valley Forge, Pennsylvania. The ETM+ instrument is a product of Hughes Santa Barbara Remote Sensing. The construction of both items is being managed through their respective manufacturers and the NASA Goddard Space Flight Center, in Greenbelt, Maryland.

The Landsat Program, as defined by Congress in 1992 and amended by Presidential Decision Directive/NSTC-3 in May 1994, is managed cooperatively by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS). Responsibility for construction of the spacecraft and instrument is under the direction of NASA. The Landsat Program is part of NASA's global change initiative, the Earth Observing System, administered by the NASA Office of Mission to Planet Earth. The Landsat 7 satellite will be operated under the guidance of NOAA. Data processing, archieving and distribution will be performed by the USGS with assisting direction from NOAA. These functions will be executed in coordination with the EDC Distributed Active Archive Center (EDC DAAC) of NASA's Earth Observing System Data and Information System (EOSDIS) at EDC.



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