DIVERSE SPECTRAL PROPERTIES IN A TEMPERATURE ESTUARY: FIRST RESULTS FROM NARRAGANSETT BAY, RHODE ISLAND

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1.0 INTRODUCTION

Coastal embayments and estuaries are important ecosystems containing a number of critical habitats and resources. They are currently threatened by changes to their surrounding watersheds. Although there has been a wealth of new knowledge generated over the last decade about these ecosystems, the spatial and temporal patterns of biologic and physical processes, as well as anthropogenic influences are not fully understood. Remotely sensed data offer a unique perspective on these processes because of the synoptic view and that quantitative algorithms can be used to extract geophysical and biophysical information from them. We are conducting a number of investigations using remotely sensed data to develop a better understanding of the visible-near infrared reflectance of water, substrate, and land components that will be used to develop algorithms and analytical tools for analysis of processes in the near shore and estuarine environment (patterns of productivity, spatial and temporal patterns of algal blooms, turbidity, etc.).

The study area for our work is Narragansett Bay, Rhode Island (Figure 1). The bay and coastal salt ponds are Rhode Island's premier natural resource and provide the state with numerous jobs ranging from tourism to shellfishing. The objectives of this proposal are complementary to many Bay Project initiatives and thus support a number of high quality goals. These include: effects of land use and land use change on estuarine systems, links between existing data sets for Narragansett Bay and coastal salt ponds with regional perspectives of remote sensing, and a better understanding of the relationships between physical and biological processes.

Visible-near infrared reflectance spectra of coastal and estuarine waters are a complex convolution of the optical properties of water, phytoplankton, gelbstoff, dissolved organic matter, and suspended sediment. Our long term goals are to develop quantitative methods for extraction of the physical abundances of these contributing constituents to the observed reflectance spectra. The work consists of observations with airborne sensors such as AVIRIS and insitu measurements using water samples, towed salinity, temperature, and fluorescence sensors, and field spectra obtained with portable spectrometers. In this abstract, we report on the first results of data obtained by AVIRIS on August19, 1997. The data discussed here were obtained at 11:22 EDT on a flight path from the north to the south along the eastern border of the bay (Figure 1). The solar zenith angle was 55.5° and the solar azimuth was 141°.

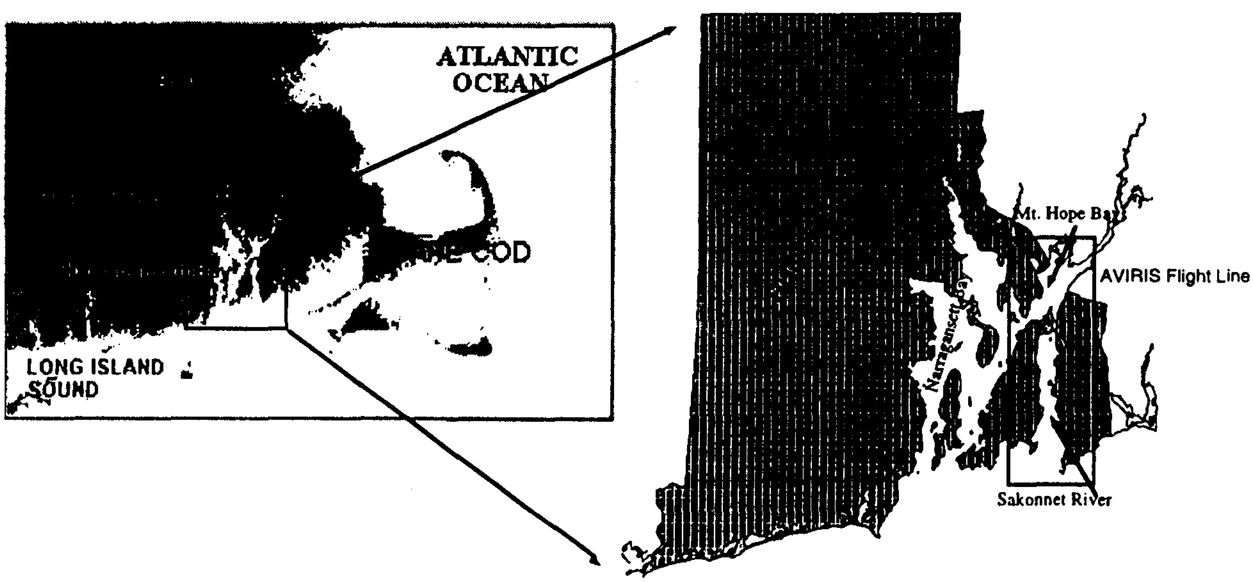


Figure 1. Location of Narragansett Bay and the AVIRIS flight line.

2.0 PHYSICAL CHARACTERISTICS OF MT. HOPE BAY

The Narragansett Bay estuary runs northward from the Rhode Island Coast into Rhode Island and Massachusetts (Figure 1), and has a drainage area of 4660 km^2 [Kremer and Nixon, 1978]. Its 2.6×10^9 m^3 of water are spread over an area of almost 350 km^2, with a mean depth of 7.8 m [Chinman and Nixon, 1985]. The mean tidal prism is much greater than the mean volume of river flow into the bay during an equivalent period of time, so that the estuary is generally well mixed, although occasionally stratified (measured by salinity gradients) in the upper bay [Kremer and Nixon, 1978]. The semi-diurnal tide ranges from 0.8 to 1.6 m [Chinman and Nixon, 1985], but the prevailing winds, northwest during the winter and southwest during the summer, frequently dominate short-term circulation patterns [Kremer and Nixon, 1978]. Water temperatures throughout the year range from below freezing up to the mid-20s (°C), and the annual water temperature cycle tends to lag solar radiation by about 40 days [Kremer and Nixon, 1978]. The Narragansett Bay ecosystem is phytoplankton based, and usually experiences a bay-wide winter-early spring bloom, several localized short term blooms throughout the summer, and a late summer bay-wide bloom [Kremer and Nixon, 1978]. The bay is inhabited by many commercially important fish species, and the benthos is dominated by clams which are harvested in limited areas. The Narragansett Bay ecosystem is significantly impacted by industrial and sewage-treatment effluents, as well as runoff from its intensely populated watershed.

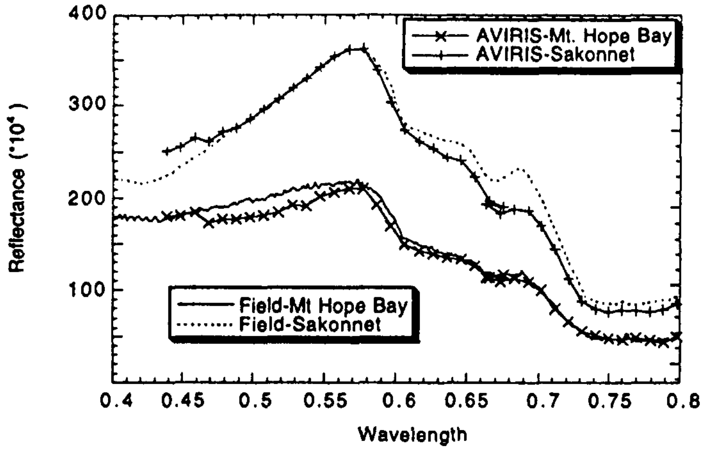
3.0 AVIRIS DATA CALIBRATION

A number of approaches were examined for reducing the AVIRIS calibrated radiance data to reflectance. The ATREM model was applied, but due to lack of adequate characterization of the atmosphere, the resulting spectral shapes were unsatisfactory. Though typical land cover units exhibited realistic spectral shapes (e.g. vegetation, soils), the spectra for the estuary were unlike any field spectra that we had obtained to date. An empirical line calibration was attempted. However, this resulted in systematic features in the water spectra unrelated to the spectral properties of water. In essence, the gain and offset corrections were weighted towards the noise statistics of the low albedo calibration target. Projection to the even lower albedo properties of water resulted in the unacceptable spectral features.

Fortuitously, several small low altitude cumulous clouds were present in the AVIRIS flight line. These cast shadows over both land and water. Radiance spectra were extracted from shadowed and unshadowed regions of approximately similar terrain cover and analyzed. Regardless of terrain cover, all the shadowed spectra exhibited a consistent spectral shape between 0.4-0.8 µm, and ratios of the various shadowed terrains to shadowed water produced a relatively flat ratio spectrum. Thus we propose that shadowed water can provide a first order estimate of path radiance. The cumulous clouds scatter light very efficiently in the 0.4-0.8 µm region without any significant absorptions. They can therefore provide a first order estimate of solar radiance. To provide a first order estimate of reflectance we therefore simply subtract the spectrum of shadowed water, with a small reduction to account for reflected sky irradiance (basically attenuate the spectrum by a factor of 0.95) from every pixel in the scene, and divide by the spectrum of a homogeneous cloud, which also has had the estimate of path radiance removed. Carder et al (1993) presented an approach based on the same concept but with a more thorough development of the radiance contributions for all sources. This was used to constrain a radiative transfer model for the calculation of reflectance and they showed the cloud-shadow approach has merit in the calibration of hyperspectral data in aquatic environments.

3.1 ASSESSMENT OF CALIBRATION

Simply put, the extremely simplistic approach to calibration provided remarkably clean spectra of the estuary that are highly consistent with reflectance spectra measured insitu. This is illustrated in Figure 2. The AVIRIS spectra are 3x3 pixel averages selected from regions representative of the typical estuarine waters. The field spectra were acquired with ASD portable spectrometers using a 20% reflective Spectralon target as a standard and corrected for the absolute reflectance of the standard. We see that the AVIRIS spectra reproduce the main important characteristics of the field spectra of the estuary: strong chlorophyll absorption between 0.4 and 0.55 µm, strong drop in reflectance after 0.58 µm due to increased water absorption, and the presence of a small chlorophyll absorption near 0.67 µm. These spectra are also comparable to estuarine spectra collected by other researchers (e.g. Roesler and Perry, 1995).



4.0 ANALYSIS

We have only just begun the analysis of these data, and many of the approaches will require refinement. Our objective is to use a number of approaches and compare them to insitu data of water optical and physical properties. Spectral ratios that are well known and used in the processing of ocean color sensors such as SeaWIFS will be used as the simple methods. However, such models are well known to have sensitivity problems in turbid inland waters. Since the AVIRIS data are of such high quality, we also plan to use more spectrally based approaches such as mixture modeling. Typical mixture models that are widely used in the analysis of terrestrial data (e.g. Adams et al, 1993) are not directly applicable to aquatic spectra and will have to be modified. One such approach that we are pursuing is the model of water reflectance presented by Roesler and Perry (1995) that relates the primary backscattering constituents to the primary absorbing constituents. Ultimately we plan to integrate these results into a 3-dimensional hydrodynamic model that has been successfully applied in our thermal modeling of Narragansett Bay (Mustard et al., 1997).

To illustrate the diversity in spectral properties in this estuary, and to point to the remarkable quality of the AVIRIS data, Figure 3 shows the reflectance at 560 nm of the eastern portion of Narragansett Bay covered by the AVIRIS flight line with the spectral properties of several distinct regions indicated on the left side of the diagram. We can clearly see a number of important spectra features related to the water constituents. The middle graph shows the spectra of two fresh water ponds which have extremely strong and well developed absorptions due to chlorophyll. The strength of the absorptions are variable, and related to the relative abundance of phytoplankton in these ponds. These are clearly eutrophic. In the upper plot, spectra from Mt. Hope Bay are shown. The most notable feature here is the variable in the 0.4-0.55 chlorophyll absorption, and the spectrum from waters affected by the sewage effluent along the eastern portion of the bay. This spectrum is relatively dark, but shows a high degree of backscatter as evidenced by the overall flat continuum properties. In the lower plot, the transition from the high phytoplankton abundance in the Narragansett Bay to the lower phytoplankton abundance in the coastal ocean is clearly seen. The coastal ocean spectrum is very bright in the blue with little chlorophyll evident. However, this spectrum is quite a bit darker than typical open ocean or blue water spectra (e.g. Roesler and Perry, 1995).

5.0 SUMMARY

The first analysis of data from the Narragansett Bay estuary are extremely promising. We recognize all the major water absorbing constituents related to chlorophyll and backscattering components. Though there are no riverine sources of suspended sediment, it is clear from many of the spectra that sediment has been suspended off the bottom. This will provide excellent data to attempt to remove the effects of suspended sediment from inland water spectra. There are dramatic variations in chlorophyll concentration, varying from the eutrophic ponds to the relatively chlorophyll-poor coastal ocean. The simple calibration approach employed here is remarkably good for revealing the relative spectral properties of these constituents. We are planning a number of analysis approaches to quantitatively extract physical and biophysical properties from these high quality spectral data acquired by AVIRIS.

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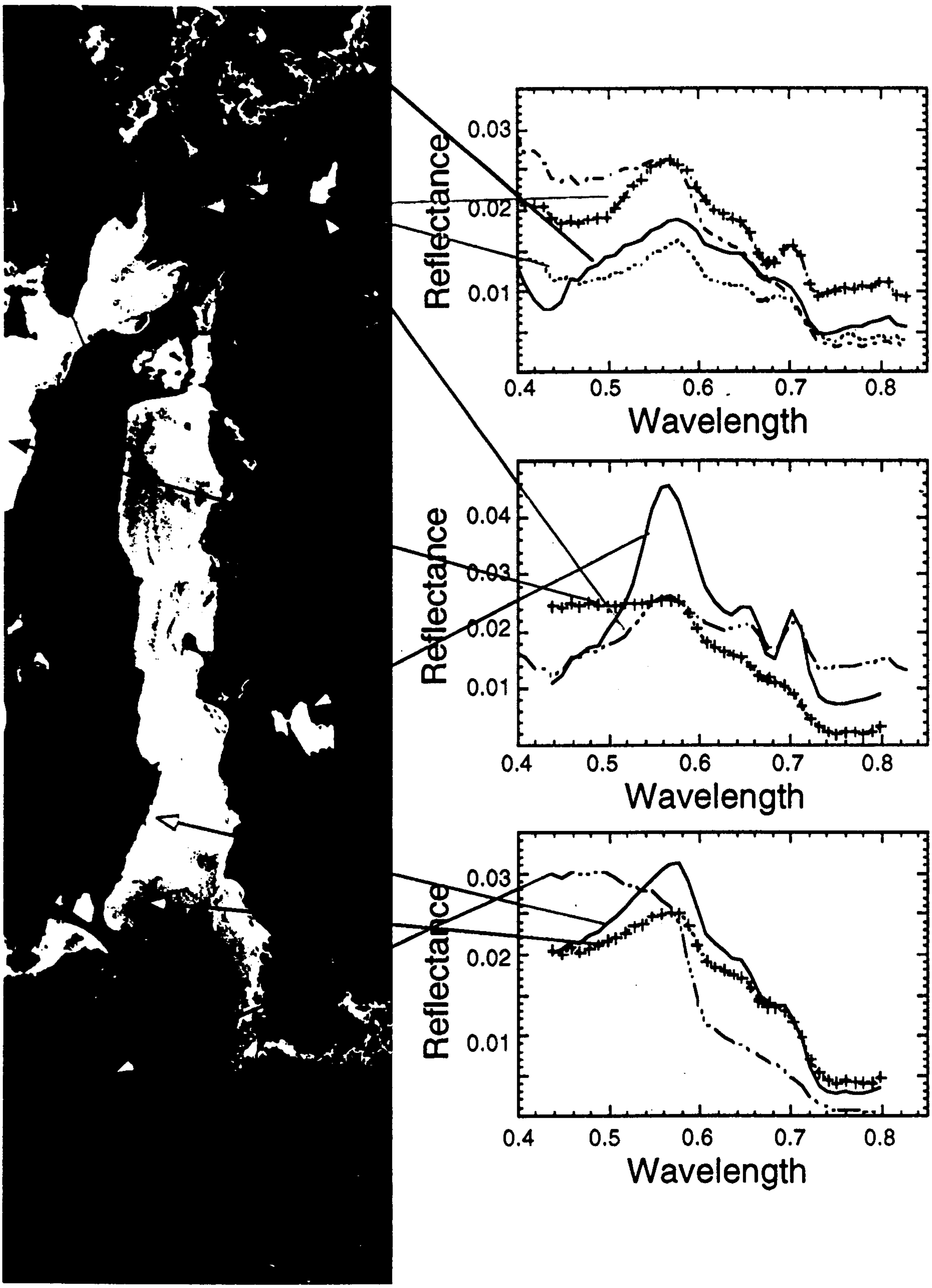

Figure 3. Reflectance at 560 nm (left) and representative reflectance spectra for a number of diverse regions covered by the scene.