Mapping a Texas Coastal Lagoon with Airborne Multispectral Imaging

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ABSTRACT

The US Army Corps of Engineers has a requirement to map the water depth and bottom type in the Laguna Madre coastal lagoon system near Corpus Christi, Texas. We used a small airborne imaging spectrometer [CASI] to acquire 11 spectral bands at 4 m ground resolution, on 109 flight lines averaging 20 km in length. The imagery was radiometrically calibrated, corrected for aircraft roll, pitch and yaw and mapped north-up using differential GPS. SPOT panchromatic imagery was used to adjust the final image positioning. Empirical atmospheric corrections were then applied to remove nadir path radiance and the effects of severe haze at the time of data acquisition, so that seamless mosaics could be created.

The original intention was to use the SHOALS lidar to map depth, but the presence of very turbid water and an extremely dense 'brown tide' plankton bloom in some parts of the lagoon prevented this. Using in situ depth and bottom type acquired with a staff from a shallow draught air-boat a ground truth, the image data was classified to produce maps of water depth and bottom type. A map of phytoplankton chlorophyll was produced from the image data by measuring the height of the remnant 'red edge' at 705 nm. This phytoplankton map was successfully used to mask those areas of the lagoon where phytoplankton prevented the sensor from seeing the bottom.

1. INTRODUCTION

The Laguna Madre is a system of shallow coastal lagoons along the southern coast of Texas, adjacent to the border with Mexico (Figure 1), which is subject to increasing urbanization, agricultural runoff and coastal ship traffic. In support of its mandate for management of coastal waterways, the US Army Corps of Engineers (USACE) had a requirement for a detailed description of the circulation, bottom depth and bottom type of the Laguna Madre. It was decided that the bottom depth information could be provided by a combination of active LIDAR and passive multispectral techniques. The USACE SHOALS ALH system (Lillycrop and Banic, 1992), a helicopter mounted system was to be used for areas deeper than about 1.5 m, and the Borstad Associates Ltd. Compact Airborne Spectrographic Imager (CASI, manufactured by Itres Instruments Inc) used for shallow bathymetry, bottom typing and vegetation classification.

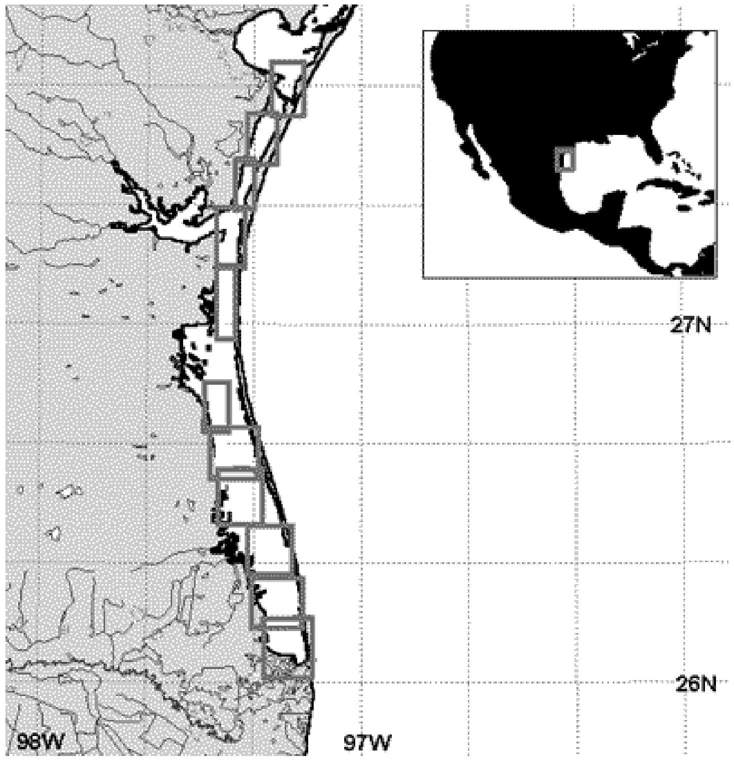

Figure 1. Laguna Madre and the eleven blocks of multispectral data acquired.

2. DATA COLLECTION

The Borstad CASI and two operators were flown by commercial airline to Austin, Texas where the system was installed in a locally chartered twin engine Cherokee aircraft on the evening of April 9, 1995. After installation and test flights the aircraft operated out of Corpus Christi and Harlingen nearer to the lagoon. Operating at approximately 3,300m (11,000') altitude and 50 m/s (100 knots), the flight lines over Laguna Madre were about 10 to 15 km long and about 2 km wide with 4 m pixels. The line spacing was 1 km to allow for a 50% overlap between flight lines. Figure 1 illustrates the geographic location of Laguna Madre and the 11 mosaic blocks within the lagoon system. On most days during a period of 10 days, one or two blocks were acquired. One each day, a series of flights over deep water offshore was also made at different altitudes to acquire data for an empirical atmospheric correction.. Eleven spectral channels were defined, each of relatively small bandwidth, with which to collect environmental data (Table 1).

Table 1. Multi-spectral bandset used.

BAND #	WAVELENGTH (nm)	BAND #	WAVELENGTH (nm)
1	470-515	7	670-686
2	540-560	8	704-714
3	575-586	9	745-758
4	600-615	10	775-800
5	625-635	11	855-874
6	640-655		

Global Positioning System (GPS) data were used to navigate the aircraft and the imagery. Differential correction of the GPS data gave approximately 5 m accuracy for the position *of the aircraft*, but the temporary nature of the instrument mount and misalignments of the camera and gyro system used to acquire attitude data for positioning, meant that absolute positioning could exhibit offsets of up to 100 m. In order to compensate for these offsets, each flight line was re-mapped to a SPOT Panchromatic image mosaic made of 3 separate scenes.

Conditions for data collection were not optimum. It was originally intended that the CASI fly contemporaneously with the SHOALS in order to enable depth calibration of the CASI passive data. Due to strict time constraints, the SHOALS had to keep to a tight schedule, and consequently the CASI was deployed as determined by SHOALS availability. However, the environmental conditions in the Laguna Madre in April 1995 were such that the SHOALS was not able to collect depth data adequately. The SHOALS withdrew from the field leaving the CASI to continue to collect data -- although the scientists involved in the data collection would have preferred a different season that would have presented better environmental conditions.

In the absence of SHOALS data, ground truth depth and bottom type data for the airborne operation was provided by a surface operation in which a shallow draught airboat made transits of the lagoon, sampling at approximately 1000m intervals with a staff equipped with a GPS antenna and receiver. At each station, bottom type and depth was recorded, as well as presence and type of vegetation.

Two primary environmental factors impacted the quality of the data received by the CASI over Laguna Madre. First, there was a persistent atmospheric haze layer with strong scattering that was dependent upon the angle and azimuth of the sun. This scattering added additional position dependent light noise to the imagery of the Laguna itself creating difficulties in later processing and image interpretation. In the south part of the lagoon strong near surface winds were blowing dust and sand about, further contributing to atmospheric scattering. Second, an intense 'brown tide' phytoplankton bloom of an unidentified chrysophyte obscured the Laguna in many places by adding increased attenuation to the water leaving, upwelling light field spectral radiances. This obscuration often represented actual data loss that could not be compensated for by later processing.

3. DATA PROCESSING

After calibration to radiance at the sensor altitude, correction for aircraft attitude, and mapping north-up using GPS positioning data, a multi-stage empirical atmospheric correction scheme was followed. Each flight line was first corrected for the nadir path radiance, calculated by regression from image data taken over deep water at several different altitudes. The image data were then 'flattened' in the cross-track [east to west] direction to compensate for the 'edge brightening' caused by anisotropic scattering. The scattering causes a cross-image brightness 'tilt' that manifested itself in different ways at different sun elevation and azimuths. There was also a differential in lighting between flight lines associated with changes in illumination during the day. Without the flattening step, the mosaic of a block of data would show strong 'seams' making it almost impossible to draw meaningful conclusion concerning bottom type or water depth. Following color matching, the flight lines were mosaicked together. Figure 2 illustrates the end result one band for Block 'G' [5th block from bottom in Figure 1). The ragged edges of the individual image swaths are due to roll, pitch and yaw movements of the aircraft caused by air turbulence.

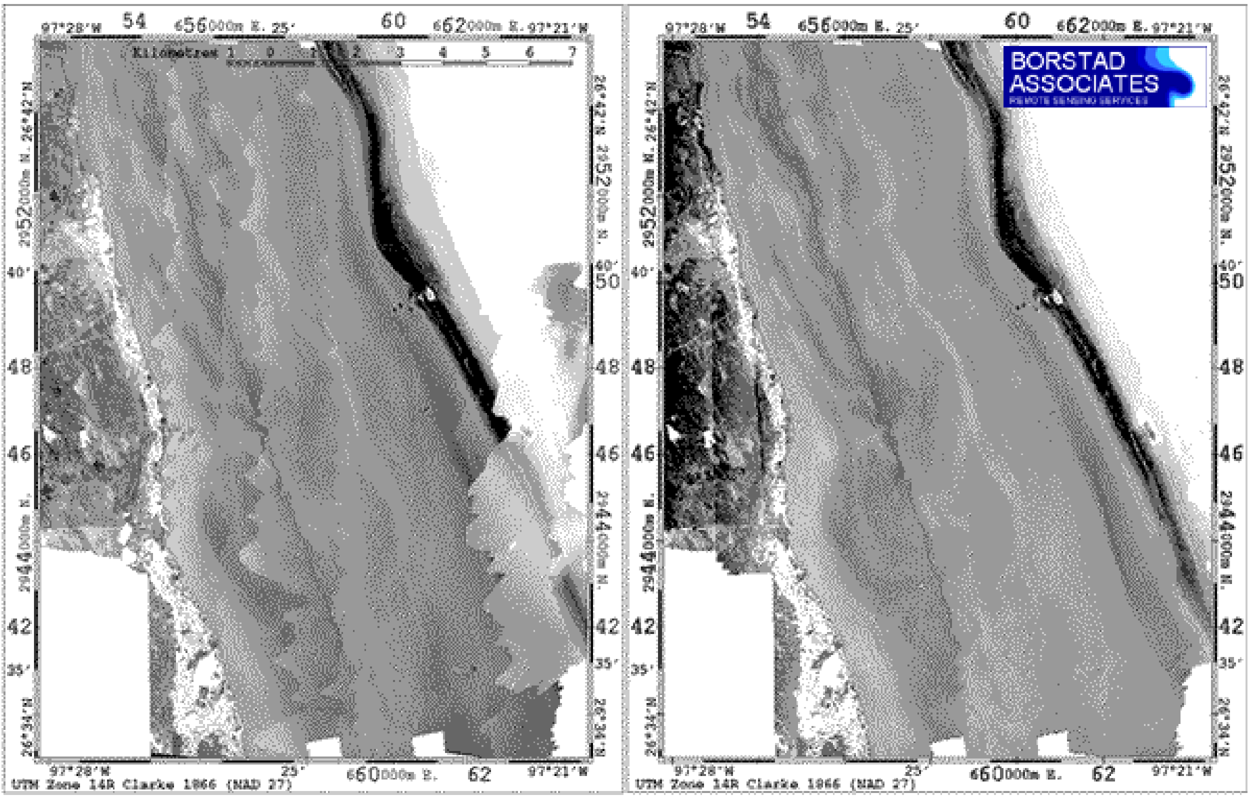

Figure 2. Block G before and after flattening to compensate for atmospheric scattering.

With the mosaics in hand, brown tide and land-water discrimination block imagery were the products first developed (Figure 3). This allowed a land mask and brown tide mask to be applied to the block imagery to be used to compute water depth and bottom type. (Figure 4) Where the brown tide was most intense, these areas of the imagery were masked out since bottom information would not survive transit through the brown tide attenuation in the water. With these masks completed, bottom type was determined using field collected water depth information with which to normalize the imagery. Standard approaches such a maximum likelihood classifier yielded poor results when compared to bottom type field information over specific region within each image block. Hence, a neural network approach with 'tracking' was developed. This method trains a neural network via back propagation to become a classifier and determine bottom type. Tracking refers to comparing field bottom type regions to those same regions in the image wherein the bottom type has been computed. Where there is a discrepancy with the field determined data a statistical analysis of the local region where there was agreement and the local region where there was disagreement is performed. Using a threshold technique, where there is sufficient agreement in the spectral summary statistics, the region where there is agreement with field data is grown to include those regions in disagreement with field data until the threshold value is exceeded. At this point, the area is not enlarged further.

Once the bottom type product was determined, a neural network was trained to compute the water depth. This was done using a three band input to the network. The bands were selected based on a knowledge of the spectral attenuation of marine waters.

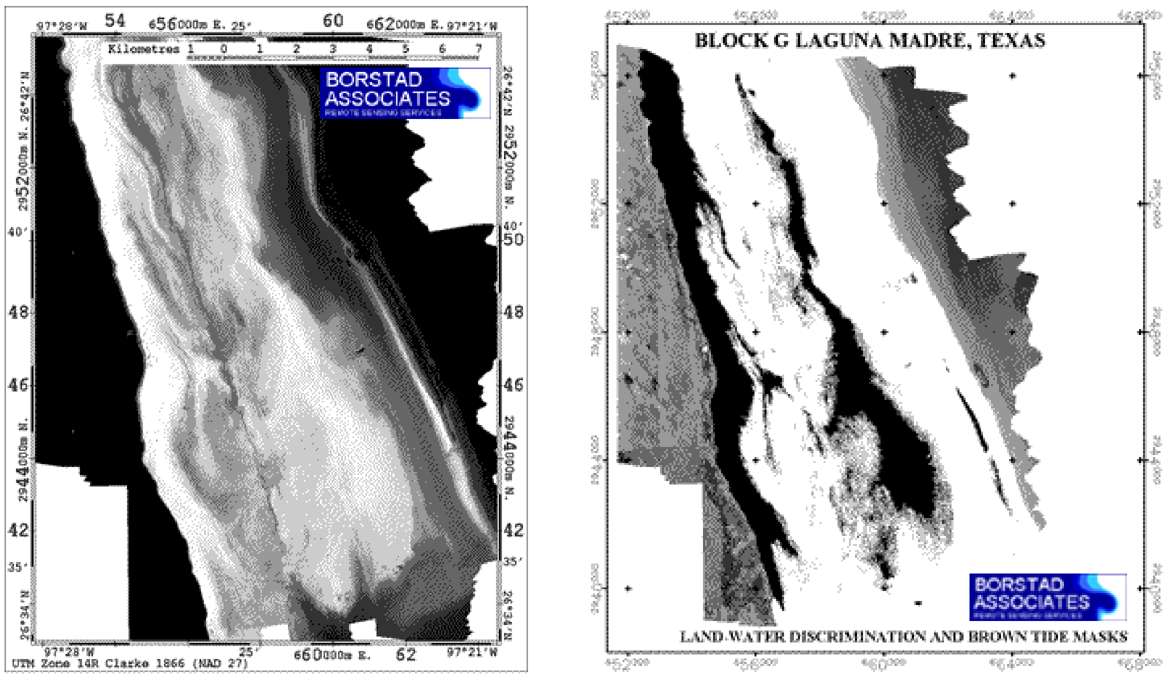

Figure 3. Brown Tide Image and Land-Water Discrimination/Brown Tide masks for Block G.

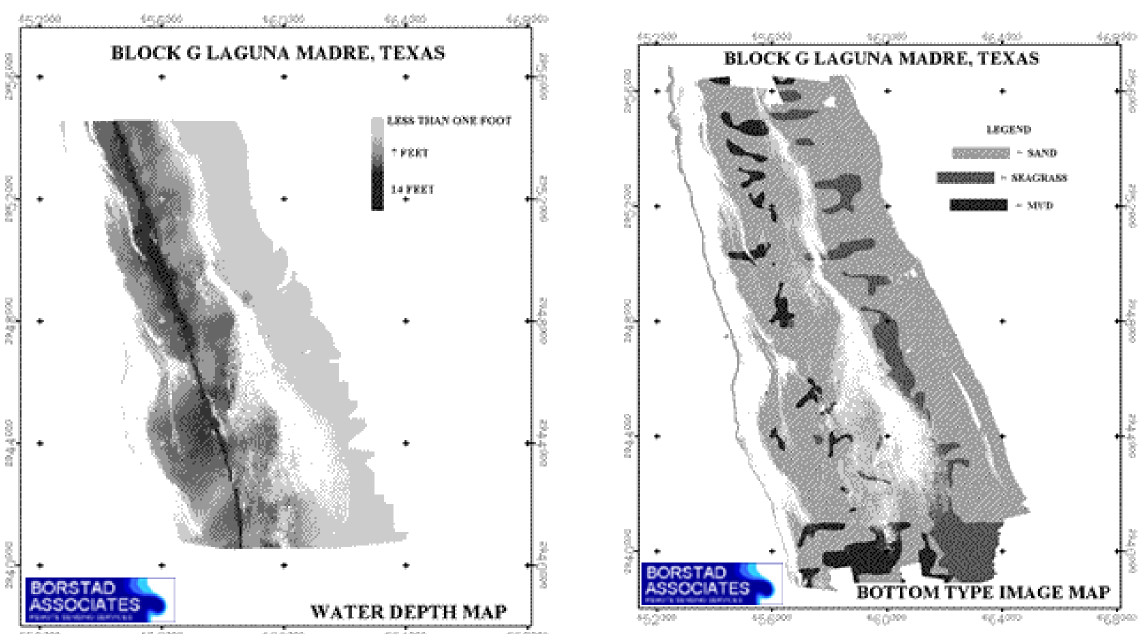

Figure 4. Example bottom type and depth products for Block G.

4. DATA PRODUCTS

Initially, the products desired were high resolution depth data (at 4 meter by 4 meter CASI ground resolution) and bottom type over the Laguna. However, it became clear that two other products could be developed that were of significance in the study of the Laguna environment. Land-water discrimination was one of these image products provided. This area has extremely low relief and a change of a few centimeters in water level can expose large areas. Since land boundary disputes can arise, it is important to know where water ends and land begins. Using a CASI image band in the reflective IR, land-water discrimination imagery was generated. Normally, a band at 864 nm was used for this purpose.

The 'brown tide' has been present in the lagoon since 1990, and there are concerns that the reduced light penetration resulting might have deleterious affects on sea-grasses. Robert Jones, Director of the University of Texas Marine Science Institute has pointed out that since sea-grasses provide nursery areas and habitat for juvenile fish and shrimp, a change from a sea grass ecosystem to one dominated by phytoplankton could have extreme effects on the recreational and commercial fishing in the Laguna (Anonymous). Chlorophyll concentrations can be determined using Fluorescence Line Height (Gower and Borstad, 1988) calculated via three bands of the bandset used to acquire this data. Figure 5 illustrates a relative map of brown tide for the upper lagoon made from 37 separate flight lines between April 11 and April 14, 1995. Absolute calibration of this image is not possible, since water borne chlorophyll concentration samples were not taken simultaneously with the CASI overflight.

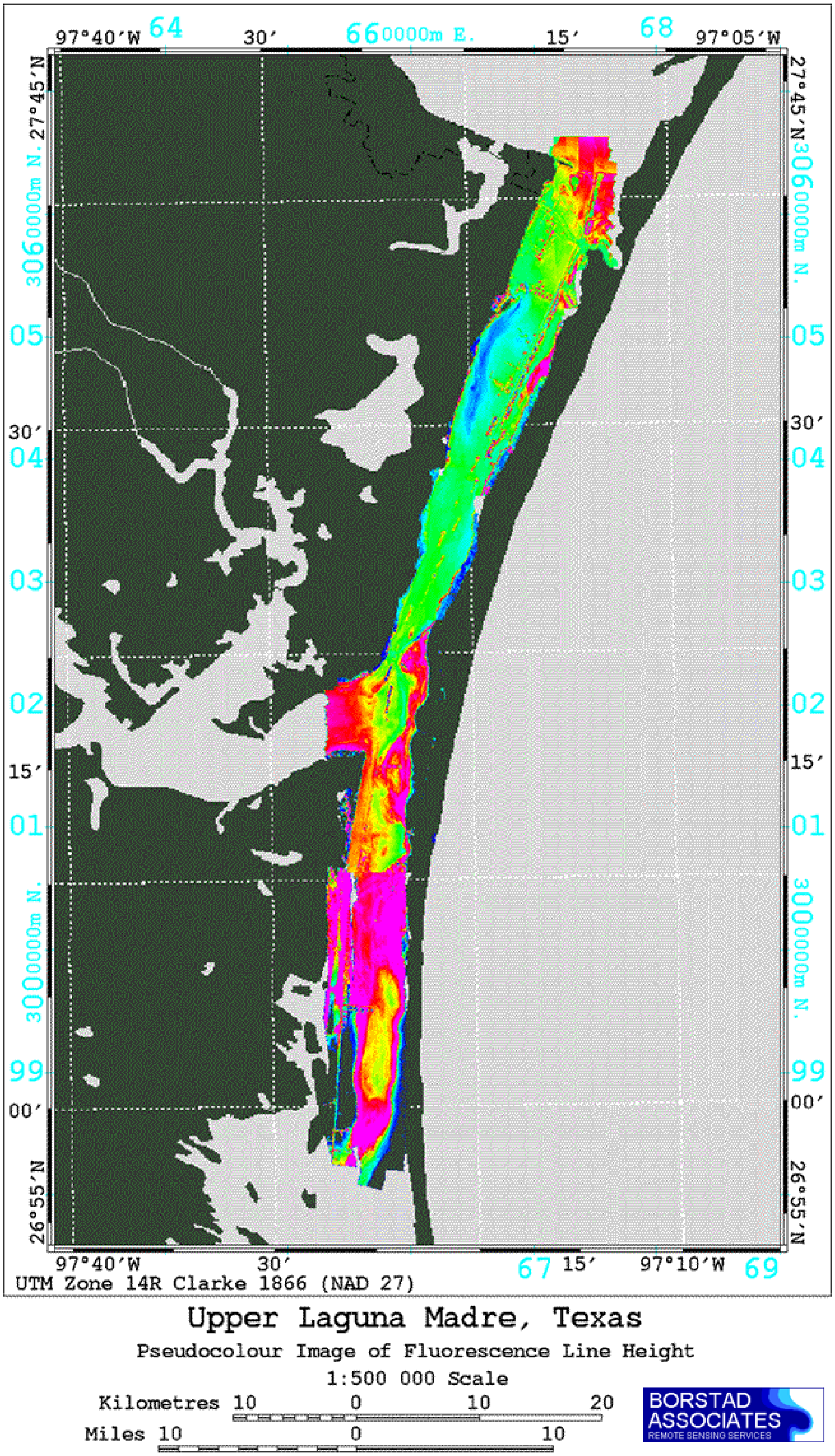

Figure 5. Relative map of Brown tide in the upper Laguna Madre.

In both the brown tide and land-water discrimination imagery, it is important to remember, for each block, that this is a snapshot in time. The brown tide distribution is subject to wind dispersal and coupled hydrodynamic regimes. The land-water discriminations affected by shifts in water levels affected by wind fields and runoff. Nonetheless, important information can be gleaned from these products.

5. REFERENCES

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