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A Comparison of SPOT Simulator Data with Landsat MSS Imagery for Delineating Water Masses in Delaware Bay, Broadkill River, and Adjacent Wetlands*

Abstract: *The radiometric and spatial qualities of SPOT simulator and Landsat-3 MSS data are compared as to their ability to distinguish different water masses within Delaware Bay and adjacent wetland areas. The SPOT simulator data contain a greater range of gray level values for all water areas than do the Landsat MSS data. The greater spatial resolution of the SPOT simulator data provides information about small-scale hydrodynamics not available on the Landsat MSS data. Both types of data show a plume of spectrally unique water flowing from Roosevelt Inlet into Delaware Bay. The plume is most visible in SPOT simulator band 1 (500-590 nm) and Landsat MSS band 4 (500-600 nm). In both bands, the plume appears dark relative to the surrounding Delaware Bay water. Recent hydrographic surveys characterize the plume as an ebb tidal feature with high concentrations of dissolved and particulate organic matter believed to originate from the adjacent Canary Creek Marsh and Great Marsh. SPOT simulator data are found to delineate water masses with a high degree of separation. Radiometrically degraded SPOT data produce similar results. Landsat-3 MSS data, although useful for delineating water masses, do not produce good separation because of sensor noise.*

Introduction

Research conducted in tidal wetlands and adjacent estuarine waters during the past 20 years has yielded much information concerning the ecological importance of salt marshes to coastal marine productivity. Evidently, nutrient flux from salt marshes can constitute a significant input to estuarine and coastal food chains. Because tidal wetlands tend to occupy areas ideal for such diverse human activities as industrial development, recreation, and even waste disposal, there is a need not only to delineate and monitor these areas from year to year, but also to make assessments based upon ecologic value.

Since 1972, the Landsat series satellites equipped with a relatively high resolution multi-spectral scanner have resulted in important advances in salt marsh and estuarine research. However, the use of Landsat MSS data has been limited to experimental applications for two reasons:

- the spatial resolution (1.1 acres) is not suitable for detecting small-scale water features or accurately delineating salt marsh boundaries, and
- the radiometric sensitivity is low, thus compressing the range of gray levels representing water to 10 count values or less.

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When the first SPOT satellite is launched, it will carry into orbit a high resolution scanner that will image the Earth in three bands, two visible and one infrared, that are spectrally similar to the Landsat MSS. However, the spatial resolution and radiometric sensitivity of the SPOT scanner will be much higher than the Landsat MSS. The purpose of this work is to compare SPOT simulator data collected over the south portion of Delaware Bay with Landsat-3 imagery of the same area. Emphasis is placed upon identifying estuarine water masses. The comparison will be based upon the ability to distinguish between river and salt marsh water with high concentrations of detritus and estuarine water with a lower organic content.

Background

Numerous researchers have used Landsat MSS imagery to deduce and monitor estuarine water quality. Typically, regression techniques are used to relate radiance recorded in the satellite data to water measurements of turbidity, suspended sediment load, chlorophyll-a concentration, and diffuse and beam attenuation. In Delaware Bay, Klemas *et al.* (1974) digitally processed ten Landsat-1 MSS images representing different portions of the tidal phase. Coincident with each overpass, water samples were collected and analyzed for suspended sediment concentration. Regression curves were developed and used to map suspended sediment concentration over the entire bay. By comparing sediment distribution with tidal phase, Klemas *et al.* were able to infer surface current circulation.

Ackleson (1981) expressed Landsat MSS count values in band 4 (500-600 nm) and band 5 (600-700 nm) in terms of the ratio of irradiance backscatter to diffuse attenuation within the surface waters of Delaware Bay and the coast of New Jersey. It was found that, within the Landsat imagery, at least two optically distinct water masses could be identified: one with high concentrations of dissolved and particulate organics, and one lower in organic concentration, although not necessarily lower in total seston. The organic-rich water was found to originate within wetland areas and enter coastal and estuarine waters as a result of tidal flushing.

Klemas *et al.* (1981) investigated the use of Landsat MSS to identify organic and inorganic material within the near-surface waters of Delaware Bay and along the coast of New Jersey. Although the results are promising, the Landsat data proves to be of insufficient resolution to detect the small-scale variations common in Delaware Bay.

Study Site Description

Roosevelt Inlet is located on the southern shore of Delaware Bay just north of Lewes, Delaware. As seen in Figure 1, the Broadkill River, Canary Creek, and the Lewes-Rehoboth Canal converge at the Inlet. Although currents through the Inlet are tidal-dominated, there is a net flux of water from the Inlet to Delaware Bay as a result of fresh water input to the Broadkill River and, to a lesser extent, Canary Creek. The mean tidal range at Roosevelt Inlet is 1.3 m with a spring range of 1.6 m.

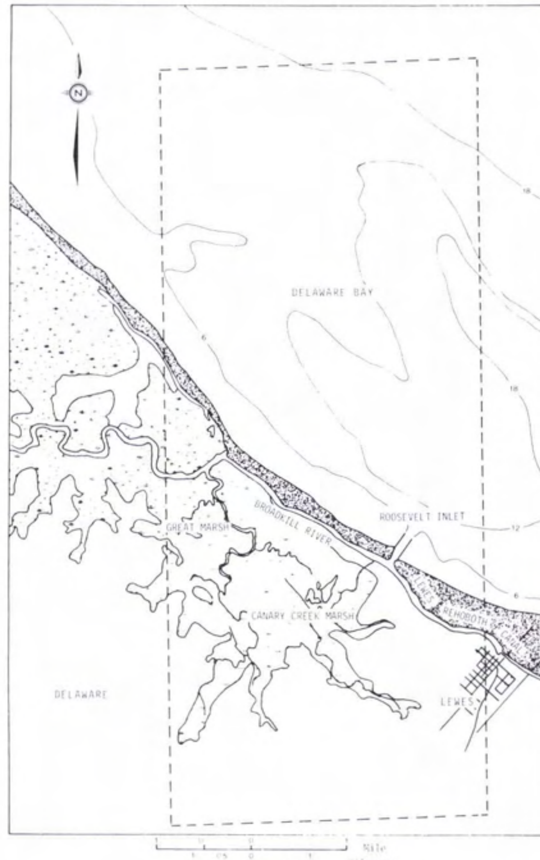

FIG. 1. Canary Creek study site. The dashed lines delineate the area imaged during the SPOT simulation overflight.

DeWitt and Daiber (1973) studied the hydrology of the Broadkill River and estimated that 85 percent of its 17.4-km length was bordered by salt and fresh water marshes. It is apparent that these tidal wetlands contribute significant amounts of organic materials to the Broadkill River and ultimately to Delaware Bay via Roosevelt Inlet. Roman (1981), monitoring detrital flux at the mouth of Canary Creek, reported that 10 percent of the aboveground biomass within the *Spartina*-dominated Canary Creek is exported annually to Delaware Bay in the form of particulate carbon. Another 31 percent enters Delaware Bay in the form of dissolved organic carbon. These detrital fluxes are manifested during ebb tide as a plume of spectrally unique water emerging from

Roosevelt Inlet. The plume typically appears dark relative to the ambient bay water.

Methodology

SPOT simulator and Landsat-3 MSS data are digitally processed and compared based upon the ability to distinguish different water masses in Delaware Bay. The SPOT simulator data was collected over Canary Creek Marsh, Delaware, on 7 July 1983. The flight line, shown in Figure 1, was 12.6 km in length and centered 2.3-km northwest of Roosevelt Inlet (N38°48′29″, W75°10′31″). The data were collected from an altitude of 21,000 feet and the cross-track field of view of the scanner was 42.96°. This resulted in a swath width of 4.7 km. The sky was free of clouds and low in atmospheric haze. At the time of the overflight, the tide at Roosevelt Inlet was beginning to flood; low slack tide occurred 1.7 hours prior to the overflight.

The Landsat-3 image was generated on 3 July 1979 and selected for comparison because it represents seasonal, atmospheric, and tidal conditions at Canary Creek that are similar to those represented in the SPOT data. The sky was free of clouds and low in atmospheric haze. The tidal phase at Roosevelt Inlet was flood, 1.2 hours past low slack tide.

The approach is to use an unsupervised classifier to group the data into a limited number of water classes based upon spectral and spatial characteristics. Because the SPOT simulator and Landsat-3 data differ in spatial resolution and radiometric sensitivity, it is important to identify the contributions that each makes to differences in classification. This is accomplished by degrading the SPOT simulator data spatially and radiometrically to approximate Landsat-3 MSS data prior to applying the classifier. All data processing is performed using an ERDAS 400 computer system together with software either supplied by ERDAS, Inc. or developed at the University of Delaware.

Data processing applied to the SPOT simulator and Landsat-3 MSS data is shown schematically in Figures 2A and 2B, respectively. The analysis is divided into two geographical regions based upon the degree of spatial degradation applied to the SPOT data. Roosevelt Inlet refers to a 235 pixel by 240 line subregion of the SPOT image centered at Roosevelt Inlet. The ground resolution is 20 metres. Canary Creek refers to the entire SPOT image after having been spatially degraded to 60 metres. This is accomplished by averaging blocks of 9 pixels, 3 pixels per side. Geographically similar regions are subsetted from the Landsat image and geometrically corrected to approximate 60-metre resolution.

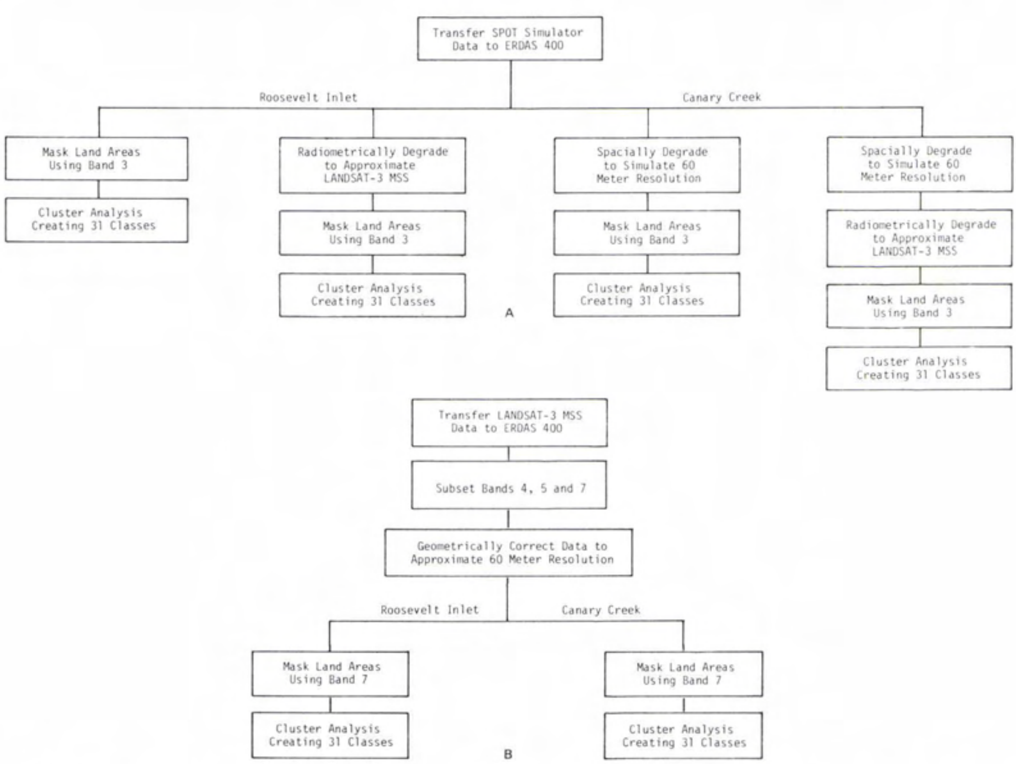

FIG. 2. Diagrams showing the progression of machine processing applied to the SPOT simulator (A) and Landsat-3 MSS (B) data.

The SPOT simulator data are degraded radiometrically to approximate the Landsat-3 MSS data by regressing geometrically similar pixels within the two data types. Because the Landsat data are not atmospherically corrected, the regression analysis also simulated the same atmospheric effects within the data. SPOT band 1 is regressed with the spectrally similar Landsat band 4, SPOT band 2 with Landsat band 5, and SPOT band 3 with Landsat band 7. The regression equation for each band pair is of the form

$$\hat{C}_{Li} = \frac{C_{Si} - B_i}{M_i} \tag{1}$$

where

$\hat{C}_{Li}$ = approximated Landsat count value for band i;
C_{Si} = SPOT simulator count value; and
M_i and B_i = regression coefficients.

The regression coefficients generated for each band pair are shown in Table 1.

Before applying the unsupervised classifier, all land areas are masked by choosing a threshold value within the infrared band; SPOT simulator band 3 or Landsat band 7. Pixels with count values greater than the threshold value are assigned a value of 255 within all bands. This procedure causes the classifier to use one class to represent all land pixels, thereby forcing all other classes to be assigned to water features.

The unsupervised classifier consists of a clustering routine developed by ERDAS, Inc. The user is required to enter the maximum number of classes to be created (N), the minimum distance allowed between cluster centers (C), and the maximum radius of each cluster (R). The values selected for N, C, and R are the only control the user has over the program. Because it is the classification that will be used to compare data types, the derivation of N, C, and R must be consistent. We begin by defining $N = 31$. This value is selected because it is the largest number of classes that can be easily manipulated on the ERDAS 400.

The minimum distance between clusters and maximum cluster radius are both distance measures in spectral space. We define these values as $C = D/31$ and $R = C/2$ where

$$D = [(L_b - L_d)^T(L_b - L_d)]^{1/2} \tag{2}$$

and L_b and L_d are mean count value vectors for bright water and dark water, respectively.

Upon completion of the classification program, the 31 classes are grouped into five categories:

- Land
- Marsh Water Plume
- Tidal Creeks
- Nearshore Bay Water
- Offshore Bay Water

This is accomplished by overlaying each class onto the raw image and comparing the distribution with aerial photography collected during the SPOT simulator overflight. The aerial photography is 1:42,000 scale color infrared transparencies showing the entire area imaged in the SPOT simulator data.

TABLE 1. LINEAR REGRESSION COEFFICIENTS CALCULATED FOR RADIOMETRICALLY DEGRADING THE SPOT SIMULATOR DATA

Band Pair (SPOT:Landsat)	M_i	B_i (Counts)	r
1:4	3.75	54.84	0.96
2:5	2.49	52.01	0.98
3:7	2.18	16.48	0.98

RESULTS

The SPOT simulator data were collected during a time of day when the sun was high in the western sky; altitude 54°, azimuth 254°. Consequently, water features in the western half of the image are totally obscured by sun glint. Data analysis is therefore confined to the central and eastern half of the image where surface reflection is minimized.

Both the SPOT simulator and Landsat-3 MSS data indicate a plume of spectrally unique water emanating from Roosevelt Inlet. The plume is most evident in SPOT band 1 (500-590 nm) and the spectrally similar Landsat MSS band 4 (500-600 nm). In each case, the plume appears dark relative to the surrounding bay water. Both images also indicate a decrease in volume reflectance from the ambient bay water with increasing distance from shore. In SPOT band 2 (610-680 nm), the plume appears less visible, although it still appears darker than the ambient bay water with distance from shore.

Results of the unsupervised classification are shown in Figure 3. In Figure 3a, the raw SPOT data clearly show a plume emanating from Roosevelt Inlet and progressing northwest along the bay shoreline. Spectrally similar water is shown located offshore, but this is believed to be an effect of sun glint. The classification shows good separation of water masses with little confusion between classes. Contrary to these results, the classified Landsat MSS data, shown in Figure 3b, indicates confusion between classes. Although a plume is suggested emanating from Roosevelt Inlet and progressing southeast along the bay shoreline, numerous pixels located offshore are also classified as plume, suggesting confusion with the two bay classes. Neither the plume, nearshore bay, or offshore bay classes are as spatially homogeneous as in the classified raw SPOT data. Applying the classifier to the radiometrically degraded SPOT data resulted in class

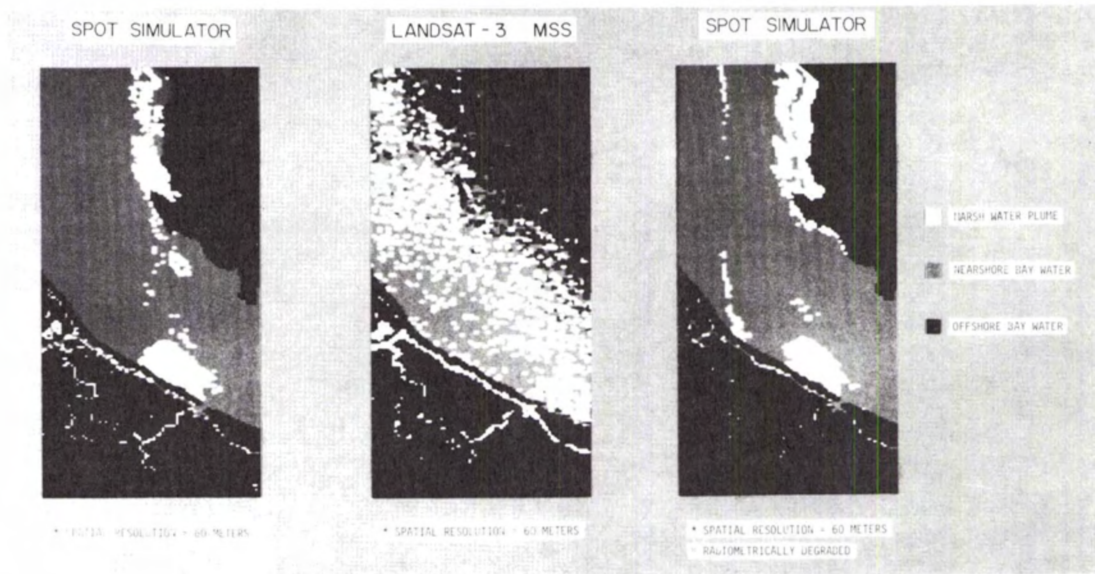

Fig. 3. Cluster analysis, Canary Creek.

distributions and homogeneity surprisingly similar to those of the raw SPOT data. This implies that the decreased radiometric sensitivity of the Landsat MSS sensor data does not, in itself, account for the apparent confusion among water masses.

The spectral distance parameter (*D*) is calculated between classes for each Canary Creek classification. The results are presented in Table 2. Values of *D* are proportional to degrees of separability of classes. The raw SPOT simulator data resulted in values significantly higher than the radiometrically degraded SPOT data and the Landsat MSS data. In all three cases, plume water is most similar to nearshore bay water. This is where most of the confusion occurs within the Landsat classification. The radiometrically degraded SPOT data resulted in *D* values similar to those representing the Landsat classification. This appears inconsistent when comparing the amount of confusion between water masses within the two classifications. However, upon comparing the two unclassified images, it is evident that a significant amount of banding is present within the Landsat data. Because the SPOT data have no banding and lower levels of sensor noise, a *D* value between classes can be quite small, yet the classes remain separable. It is anticipated that banding will not be a problem within the operational SPOT data because of the linear array configuration of the sensor.

The results of the unsupervised classifier applied to the Roosevelt Inlet images, shown in Figure 4, are much the same as in the previous discussion. The SPOT data, both raw and radiometrically degraded, produced water classes that were well-defined and spatially homogeneous. However, because the SPOT data are now at 20-metre resolution, the classifications show more detail. The 60-metre SPOT data indicate a change in volume reflectance along the axis of the Broadkill River, while the 20-metre data show variations across the river. The outline of tidal creeks are more clearly shown in the higher resolution data, although the water classes here show various degrees of edge effect. Once again, the Landsat data suggest confusion between classes.

The spectral distance parameter is calculated be-

Table 2. Spectral Distance Between Classes for the Canary Creek Classifications

		Nearshore Bay	Offshore Bay
SPOT Simulator	Plume	5.58	17.48
	Nearshore Bay		21.23
SPOT Simulator Radiometrically Degraded	Plume	1.98	5.71
	Nearshore Bay		7.23
Landsat-3 MSS	Plume	1.42	5.32
	Nearshore Bay		5.54

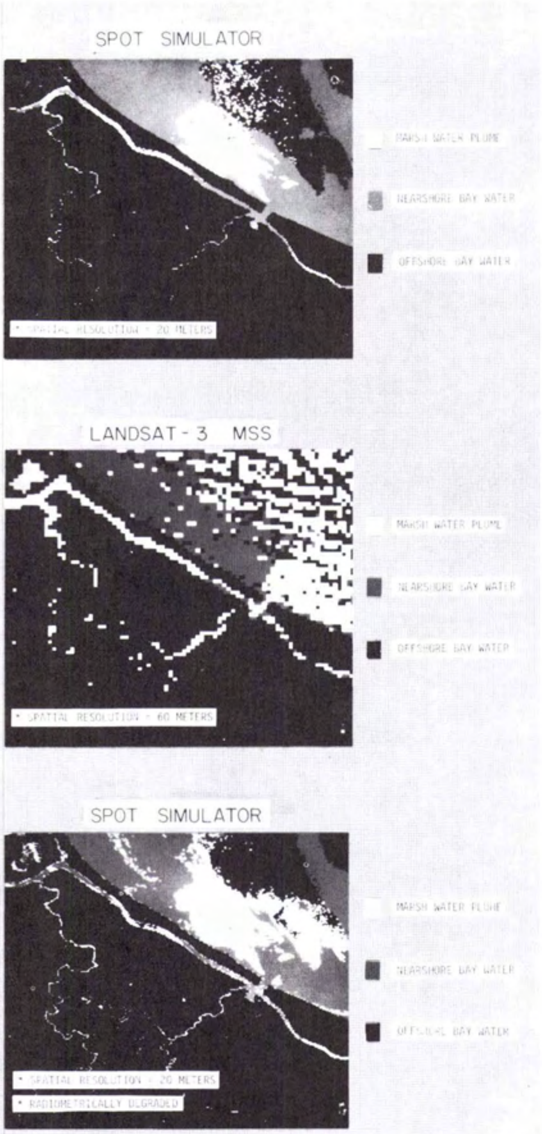

FIG. 4. Cluster analysis, Roosevelt Inlet.

tween classes for each Roosevelt Inlet classification and the results are shown in Table 3. Again, the raw SPOT data produced the largest values for all class pairs, indicating superiority in separating the spectral signatures of water masses. The smallest value of D was calculated between the plume and offshore bay classes. Values of D between these classes representing radiometrically degraded SPOT data and Landsat MSS data were quite similar, 2.24 and 2.32, respectively. However, the manner in which apparent confusion occurs is different. Within the Landsat image, pixels classified as plume occur throughout the offshore bay area, while pixels classified as offshore bay occur throughout the plume region. Most often the misclassified pixels are oriented along diagonal lines similar to the banding. Within the radiometrically degraded SPOT data, there is evidence of confusion only along the boundary of these two classes. Pixels in this area are spectrally similar and the higher radiometric sensitivity of the raw SPOT data is required to separate the two classes. In the Landsat data, this effect is undoubtedly occurring, but sensor noise appears to be the dominant cause of misclassification.

CONCLUSIONS

SPOT simulator and Landsat MSS data are shown to be effective in delineating water masses in Delaware Bay and, to a lesser extent, Broadkill River. The SPOT simulator holds several advantages over Landsat MSS data:

- The greater radiometric sensitivity of SPOT data produces better separation of spectrally similar water masses,
- The SPOT data contain less noise resulting in fewer misclassified pixels, and
- The higher ground resolution of SPOT data provides indications of small-scale hydrodynamics not possible within Landsat data.

SPOT imagery promises to be of significant value to the estuarine and coastal hydrographer. It is anticipated that the most useful attribute of the data will be the 20-metre resolution of the multispectral data and the 10-metre resolution of the panchromatic band. Here, the data will aid the researcher in understanding dynamic processes in surface waters such as estuarine circulation and detrital flux from coastal wetlands.

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TABLE 3. SPECTRAL DISTANCE BETWEEN CLASSES FOR THE ROOSEVELT INLET CLASSIFICATIONS

		Nearshore Bay	Offshore Bay
SPOT Simulator	Plume	11.77	6.84
	Nearshore Bay		10.49
SPOT Simulator Radiometrically Degraded	Plume	3.08	2.24
	Nearshore Bay		4.44
Landsat-3 MSS	Plume	5.99	2.32
	Nearshore Bay		4.38

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ANNOUNCEMENT AND CALL FOR PAPERS

Remote Sensing Applied to Monitoring and Management of Wetlands

Louisiana State University, Baton Rouge
4-5 October 1985

This Annual Fall Meeting of the Mid-South Region is being organized by the Mid-South Region of the American Society for Photogrammetry and Remote Sensing and the Remote Sensing and Image Processing Center of the Louisiana State University. It will be preceded by a one-day workshop on Photointerpretation of Wetlands on 3 October, conducted by LSU faculty and specialists from the USGS.

Those wishing to present papers on "Remote Sensing Applied to Monitoring and Management of Wetlands" should submit a 200-word abstract before *1 August 1985* to

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INVITATION AND CALL FOR PAPERS

Tenth Canadian Symposium on Remote Sensing

Edmonton, Alberta, Canada
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This Symposium—sponsored by the Canadian Remote Sensing Society of the Canadian Aeronautics and Space Institute, the Canadian Institute of Surveying, and the Canada Centre for Remote Sensing—will feature all aspects of Remote Sensing, including

- Sensors
- Data Acquisition
- Processing and Analysis
- Environmental Monitoring

with special emphasis on

- Value of Remotely Sensed Data in Operational Use.

Those interested in presenting a paper should submit a 200-word (maximum) abstract by *2 December 1985* to

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