# FINAL REPORT

**NASA Ames Research Center**
**Joint Interchange Agreement Grant**
**Award No. NCC 2-5134**

**December 10, 1998**

# Mapping Northern Exposure With POLDER: Application for Circumpolar Methane Exchange

**Submitted by:**


**Susan L. Ustin**
**Associate Professor of Resource Science**
**Hydrologic Science Program**
**Department of Land, Air, and Water Resources**
**University of California**
**Davis, CA 95616**

*ABSTRACT* --Three images types from POLDER airborne imagery, nadir looking multi-spectral bands, multiple view-angle images of the red band, and combined datasets, were used to classify land cover types at the NASA southern BOREAS study site in Saskatchewan, Canada. We found that combining multiple view-angle imagery with nadir viewing multi-spectral bands provided the greatest accuracy and discrimination of the largest number of inundated and non-inundated land cover classes. While the nadir looking multi-spectral band data correctly separated open water from other land cover classes it did not separate the inundated vegetated regions that define boreal wetlands. Multiple view-angle data could separate two upland vegetation types and open water but only one inundated vegetation type.

## Introduction

Wetland classifications have been performed using different remote sensing techniques, for both radar and spectral-based images. The discrimination among different land covers types using optical remote sensing data is currently done by employing nadir looking spectral images. In these images each band corresponds to the surface reflectance over a determined spectral range, with the number of bands extending from few as in the Systeme Probatoire d'Observation de la Terre (SPOT) and Landsat Thematic Mapper (TM) images to hundreds, as is the case for Airborne Visible Infrared Imaging Spectrometry (AVIRIS) images. While each of these optical sensors has been used to classify wetlands, differences in number of bands and wavelength intervals have not been shown to improve classifications. Typically multi-spectral bands have been used to separate vegetated from non-vegetated regions based on well-known reflectance characteristics of vegetation, soil and water.

Mixed results have resulted when using optical sensors to classify boreal wetlands. For most classifications there is confusion between the upland forest, and innundated cover types. This confusion is mainly due to the similarity of the spectral signature of these classes and to the fact that much of the boreal landscape is covered by shallow depressions of surface water which do not express the low reflectance across the solar spectrum that is typical of deeper water bodies. While land cover classifications with four or five classes of wetlands have been reported, the confusion among classes is very high and the classification results are problematic [1]. Employing different methods of classification have not produced better estimates of wetlands; unsupervised classifications have proved to be as accurate as hybrid supervised classifications or hybrid geographic information systems (GIS) rule-based classifications [2]. Therefore, additional information needs to be considered to obtain more consistent results in wetland classification schemes.

Recently, new methods and sensors have been used to classify inundated and non-inundated regions [3], [4]. Their new approach used the bi-directional reflectance differences to discriminate between inundated and non-inundated land cover types. Specifically they used the sunglint observed in POLDER images as a basic characteristic to discriminate among land covers types. POLDER (POLarization and Directionality of Earth Reflectance) is a new satellite sensor with five spectral bands, two of them polarized. This sensor has the capability of acquiring multiple view angle images for a region that allows characterization of the bi-directional radiance for all classes. This type of image opens a new range of unexplored and feasible possibilities for classification of wetlands. Multiple view angle images allow confirmation of inundated features that clearly differentiate them from non-inundated vegetation and soil. These physically based spectral characteristics predominant in the principal plane of the image and give a unique way to map wetlands [3], [5].

This study takes advantage of the POLDER data to produce nadir looking multi-spectral band and multiple view-angle imagery. We evaluated the potential for using multiple view angle images to map non-inundated boreal regions. First, we present the classification of the study region using only the spectral-band imagery. Second, we present the classification for the same region but using multiple view-angle images. Third, the classification using a new image composite of both multiple view-angle and multi-spectral images is presented. Finally, a comparison of the results of the three datasets used to classify wetland regions was performed.

## I. Objectives

Our objective was to compare the discrimination between inundated and non-inundated regions using three types of remotely sensed airborne POLDER images. The images used to classify inundated and non-inundated regions within our study area were nadir spectral-based imagery, multiple view angle imagery and hybrid imagery, a combination of spectral and multiple view angle images.

## II. Methods

The discrimination between non-inundated and inundated regions was performed for airborne POLDER imagery acquired over the southern NASA BOREAS study area (centered at 54° N, 105° W) southwest of Hudson Bay in central Saskatchewan, Canada. The imagery was taken between 9:00 am and 1:00 pm (local solar time)on July 21 1994. Because the methodology to discriminate among inundated and non-inundated areas using multiple view angle images is based on specular reflection, just the principal plane of the imagery was used. Also we limit our study to flight line No. 05.

### *IMAGERY*

To perform the discrimination between inundated and non-inundated land cover areas we used three different types of imagery from the POLDER sensor that exactly covered the same spatial region of the flightline. The nadir looking multi-spectral based image had five spectral bands over the spectral region between 430 and 910 nm. The bands correspond to blue (430 nm), green (510 nm), red (665 nm), and near-infrared (865 nm and 910 nm). For this analysis just one view angle was considered, the nadir direction. This type of multi-spectral image represents the typical satellite and airborne multiple band datasets currently used to classify wetlands.

The second image type corresponds to a composite POLDER dataset that represents a multiple view-angle image where each pixel has 16 different view angles from one spectral wavelength band (red, 665 nm). In this way, each band of the dataset represents a different normalized view angle (NVA) that ranges from the backscatter direction (NVA = 0), through nadir direction (NVA = 0.5) to the forward scatter direction (NVA = 1.0).

$$\text{Normalized View Angle (NVA)} = (\phi_s + \phi_v) / 2\,\phi \qquad (1)$$

Where

$\phi_s$ Solar Zenith Angle

$\phi_v$ View Angle

Each view angle can be displayed as a gray scale image. A complete description of the composite image dataset can be found in [4] and [3].

The third and last image data set used was a combination of the first two image types described above. This new data set has 21 bands in which the first five bands correspond to the nadir spectral bands and the last 16 bands correspond to each of view angle of the multiple view angle data set.

Due to the fact that sophisticated methods of classification do not produce significant improvements in the accuracy of wetland classifications [2] a simple unsupervised classification method was performed over the three datasets. The unsupervised methodology employed was the ISODATA algorithm as provided in the ENVI software package (RSI, Boulder, CO.). This methodology provides a base line to compare the results of the three different types of image datasets.

For each of the image datasets 20 classes were initially separated which were afterward combined into fewer classes which expressed clear spectral differences. Following merging of similar classes from the unsupervised classification, we discriminated five classes: non-inundated vegetation (two types of upland vegetation), non-inundated soils, open water and inundated vegetation. However our primary goal was to determine which dataset produced the best discrimination between only two classes: inundated and non-inundated areas. To determine the accuracy of the classification, we performed a standard photointerpretation of the study area using high spatial resolution infrared photography. NASA acquired photos concurrently with the POLDER images. The analysis was performed on a Zeiss Zoom Transfer scope using standard photogrammetry procedures. The analysis was performed five times in separate sessions to provide confidence in the results and any classification differences were resolved by reevaluation of the sub-areas. Because of the spatial resolution of the photography, it was possible to easily identify open water, inundated vegetation and upland vegetation cover. This photointerpetation provided the baseline cover percentage for each class, which was used to compare the results of each image classification. The effectiveness of the discrimination between different types of inundated and upland vegetation covers was based on the distinctive spectral patterns shown by the classes in each image rather than on the results of the photointerpretation.

## III. RESULTS AND DISCUSSIONS

The descriptive statistics for each of the datasets allow us to identify the bands that represent specific spectral characteristics for use in the classification procedure. Figure 1 presents the basic statistics for the nadir multi-spectral band dataset (a), and for the composite multiple view-angle dataset (b). From this Figure we see that the nadir multi-spectral images of band 3 (665nm) and band 4 (865nm) produce the minimum and maximum radiance values. These minimum and maximum values correspond to the well-known patterns of reflectance for vegetation, with low values in red and high values for the near-infrared radiance, thus the mean condition is representative of vegetation for the study area. For the multiple view-angle image a bi-modal peak in radiance corresponds to the backscatter and the forwardscatter directions. These peaks are due to hot spot and to specular reflection, respectively. These patterns serve as the basis for the discrimination.

### *A. Nadir-spectral based image*

Figure 2a presents the mean spectrum for each class for the nadir looking multi-spectral image. From this Figure only two groups can be identified: open water and vegetation. These are separable because water has high absorption of energy across the near-infrared region in contrast to vegetation, which has high absorption in the red band and high reflectance over the near infrared. These opposite radiance characteristics allow consistent discrimination between vegetation and open water. Based on the fact that water reflectance characteristics are present in both open water or water in vegetation or soils [6] and that most vegetation produces low reflectance in the red we could try to discriminate between non-inundated and inundated vegetation. For non-inundated vegetation the spectra should appear as a mixture of the pure spectra for water and upland vegetation. However in the Figure presented here there is no specific spectrum that could be considered as characteristic of inundated regions. While there is variation in the range of reflectance between four of the five classes none appears as a clear indicator of inundation vegetation.

Figure 3a presents the classification results of the nadir analysis for the study area. From this Figure we see how open water was easily identified but there was no separation of inundated regions, which from the photointerpretation corresponds to 26% of the area of the image. Even when a more careful classification was performed over the nadir multi-spectral based image we found difficulty defining a threshold that would consistently differentiate inundated from non-inundated vegetation. All classifications attempted produced confusion with non-inundated regions.

***B. Multiple view angle POLDER image***

Figure 2b presents the mean spectra for the classes resulting from the classification of the multiple view angle image. The view dependent characteristic that water produces in the normalized view angle spectrum is clear. In this case, not only open water but also inundated areas produce a distinctive pattern that is easily discriminated. Between inundated and non-inundated regions, a high value of radiance over the last normalized view angle is the key to the classification. For this classification, pixels having a low percentage of inundated area could still be confused with vegetation that has specular reflection [7]. However the fractional contribution of different cover classes could be addressed using an unmixing technique that predicts the percentage of the pixel covered by water, thereby reducing this confusion. Using the composite view angle POLDER image we discriminated the non-inundated regions into two types of vegetation and a soil class. This was done by evaluating the slopes of the normalized view angle spectra over the view angles in the hot spot direction. For one type of vegetation the radiance had minimum values at normalized view angles >0.80, but for the other, minimum values of radiance were detected at normalized view angles >0.70. For soils the radiance of the normalized view angle spectra appears more constant throughout the range of normalized view angles.

Figure 3 presents the land cover classification for the composite POLDER image. Here, blue represents open water, aquamarine represents inundated regions and vegetation is represented by green (two scales of green for some classifications). Maroon represents soils. As can be seen the nadir spectral classification (Figure 3a) does not discriminate inundated regions. Instead these are confused with the upland vegetation patterns and the Figure appears almost entirely green. In contrast Figure 3b and 3c show the localized inundated regions throughout the principal plane of this flight line.

***C. Hybrid Image***

To try to improve the resolution of the beyond discrimination of inundated and non-inundated cover classes a hybrid image was created. The results of the classification over this image are presented in Figure 2c and Figure 3c. The mean class spectra (Figure 2c) can be seen as a combination of the multi-band nadir view angle and the multiple view angle images. This classification takes advantage of both multi-spectral and bi-directional characteristics of the land cover features. Using the spectral part of the image it is possible to more easily separate the upland vegetation types present in the image, while the bi-directional data contributes to clearly discriminating inundated features.

A close look at Figure 2c demonstrates the advantage of using bi-directional data for the classification. For example, looking at just the spectral bands, band 1 to band 5, we see how the inundated features have overlapping radiance. With the exception of the open water there are no particular features that separate vegetation and inundated vegetation types. Using nadir images for classification these pixels will not be consistently separated from non-inundated vegetation or soil. However, multiple view-angle bands (bands 6 to 21) provide remarkable separation, particularly at band 21, that guarantees a positive discrimination between inundated and non-inundated regions. Notice how using only the spectral data, the areas classified as Inundated 1 can be merged with the class Non-inundated vegetation 1. The Inundated 1 class represents the 27 % of the area, a significant part of the total inundated region in the image. Therefore incorrect separation of these classes causes a large overestimation of wetlands if the merging of the two classes is assigned as wetlands, or an underestimate if it is discriminated as upland vegetation.

Also, from the Figure 2c we can discriminate between different inundated types by using the multiple view angle bands. Comparing again band 1 through 5 for Inundated 1 and Inundated 2 classes we see that there is little difference in radiance among these spectral bands. In a classification using the nadir looking image, the pixels that represent these spectral curves will be combined into just one class. However by looking at the combined spectra we obtain a key for separating each of these inundated vegetation classes. A difference in bi-directional radiance is found in the specular direction and in the hot spot direction, permitting a direct separation of these classes. Figure 3c presents the final classification of the region using this hybrid image set showing the greatest number of classes that can be discriminated using this data.

## IV. ACCURACY ASSESSMENT

After the classification of the three sets of images we performed a comparison between their results and the photointerpretation results. Table 1 summarized percentages of the areal cover for each class predicted by each image type.

From the table, one can notice that the classification using nadir-spectral based data under represents the total percentage of areal cover by inundated regions. The classification of these data identified just 1% out of a total of 20% of inundated vegetated pixels that were identified by the photointerpretation technique. In contrast, multiple view angle imagery closely estimates the correct percentage. Although multiple view angle imagery over estimated the percentage of inundated area compared with the photointerpretation estimates we think that this number is more nearly to correct due to the uniqueness of the normalized view angle spectral characteristics for inundated regions that can identify regions with surface water.

While the non-inundated types of vegetation could be separated with the combined data into additional cover types, validation data are unavailabe to verify the vegetation assessment. By combing the two types of images for the study site we obtain the best classification of the image segment segment. Also the greatest number of vegetation types were identified with the best accuracy.

## V. CONCLUSIONS

After comparing the results of the three classifications we found that employing multiple view angle imagery with nadir viewing multiple spectral bands accurately identified inundated and non-inundated regions. While the nadir spectral band image generally correctly separated open water from other classes it could not consistently separate the various inundated regions that define wetlands. Because these regions are important in the estimation of trace gasses like $CO_2$, $CH_4$ that are released from the wetlands to the atmosphere the correct areal extent of these land cover types is needed to close the trace gas budget. The methodology using multi-spectral bands combined with multiple view-angle data will improve classifications for these land cover types.

## REFERENCES


[1] J. E. Jacabson, R. A. Ritter, and G. T. Koel, "Accuracy of Thematic Mapper Derived Wetlands as Based on National Wetlands Inventory Data," presented at ASPRS / ACSM / WFPLS, Reno, NV, USA, 1987.

[2] A. S. Steven, A. Douglas, and L. Wen-Shu, "Accuracy of Landsat-TM and GIS Rule-Based Methods for Forest Wetland Classification in Maine," *Remote Sensing of Environment*, vol. 53, pp. 133-144, 1995.

[3] V. C. Vanderbilt, G. L. Perry, J. A. Stern, S. L. Ustin, M. C. Diaz Barrios, S. Zedler, J. Syder, L. A. Morrisey, G. P. Livingston, F. M. Breon, S. Bouffies, M. Lerroy, M. Herman, and J. Y. Balois, "Sunglint Allows Boreal Wetland Discrimination," *Submited to IEEE transactions on Geoscience and Remote Sensing.*, 1997b.

[4] M. C. Diaz Barrios, S. Ustin, J. Pinzon, V. Vanderbilt, and G. Perry, "Discrimination of Inundated and Non-Inundated Community Types Wiht Multi-spectral Multi-angle POLDER data.," *In preparation*, 1997.

[5] V. C. Vanderbilt, G. L. Perry, J. A. Stern, S. L. Ustin, M. C. Diaz Barrios, S. Zedler, J. Syder, L. A. Morrisey, G. P. Livingstons, F. M. Breon, S. Bouffies, M. Leroy, M. Herman, and J. Y. Balois, "Discrimination of wetland and not wetland community types with multi-spectral, multi-angle, polarized data.," presented at 7th Int. Symp. Physical Measurements & Signatures in Remote Sensing, Courchevel, France, 1997 a.

[6] T. Lillesand and R. Kiefer, *Remote Sensing and Image Interpretation*: John Willey & Sons, Inc, 1987.

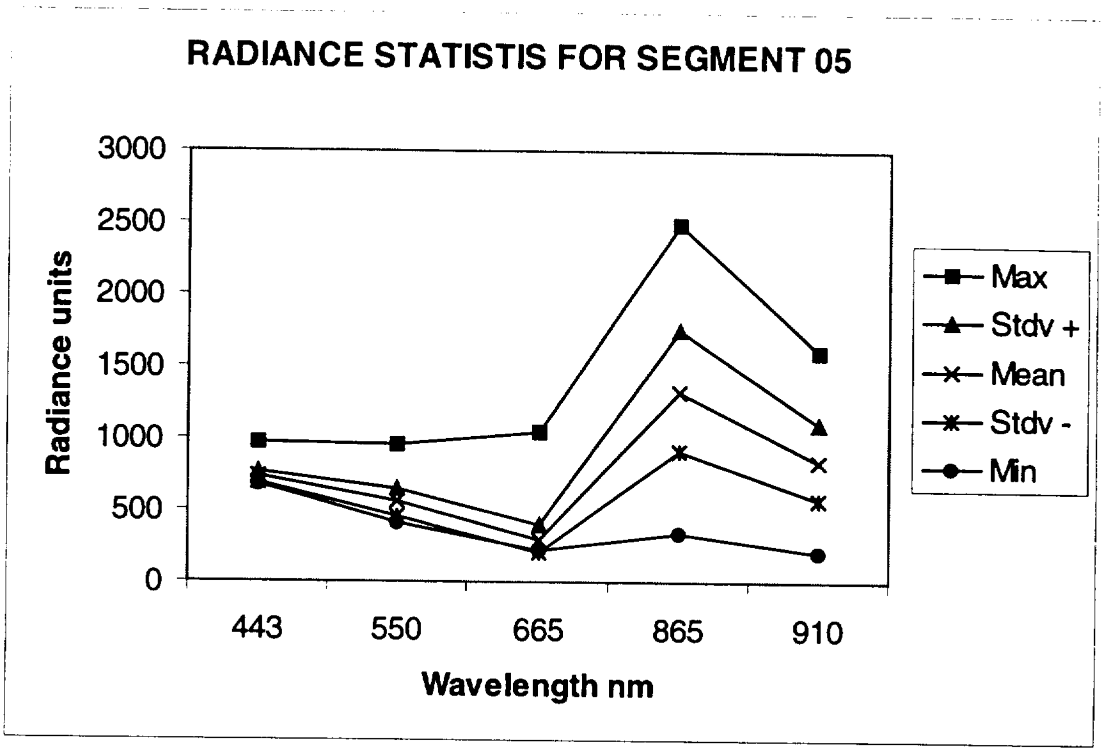
[7] V. Vanderbilt and G. L., "Plant Canopy Specular Reflectance Model," *IEEE Transactions on Geoscience and RemoteSensing*, vol. GE-23, pp. 722-730, 1985.

Table 1 Classifications results using three different images set for Segment 05

| IMAGE TYPE | PERCENTAGES OF AREA COVER | | | | |
|---|---|---|---|---|---|
| | Open Water | Inundated | Non-Inundated Soils | Non-Inundated Vegetation type | |
| | | | | 1 | 2 |
| Nadir-Spectral based image | 10.54 | 0.92 | 2.63 | 83.85 | 2.06 |
| | | | | 85.91 | |
| Multiple view angle image | 11.45 | 27.49 | 1.49 | 47.72 | 12.14 |
| | | | | 59.86 | |
| Hybrid Image | 11.80 | 28.87 0.57 | 1.26 | 49.60 | 7.90 |
| | | 29.44 | | 58.77 | |
| Photointerpretation | 9.7 | 20 | 70.30 | | |

## List of Figures

(1a)




(1b)

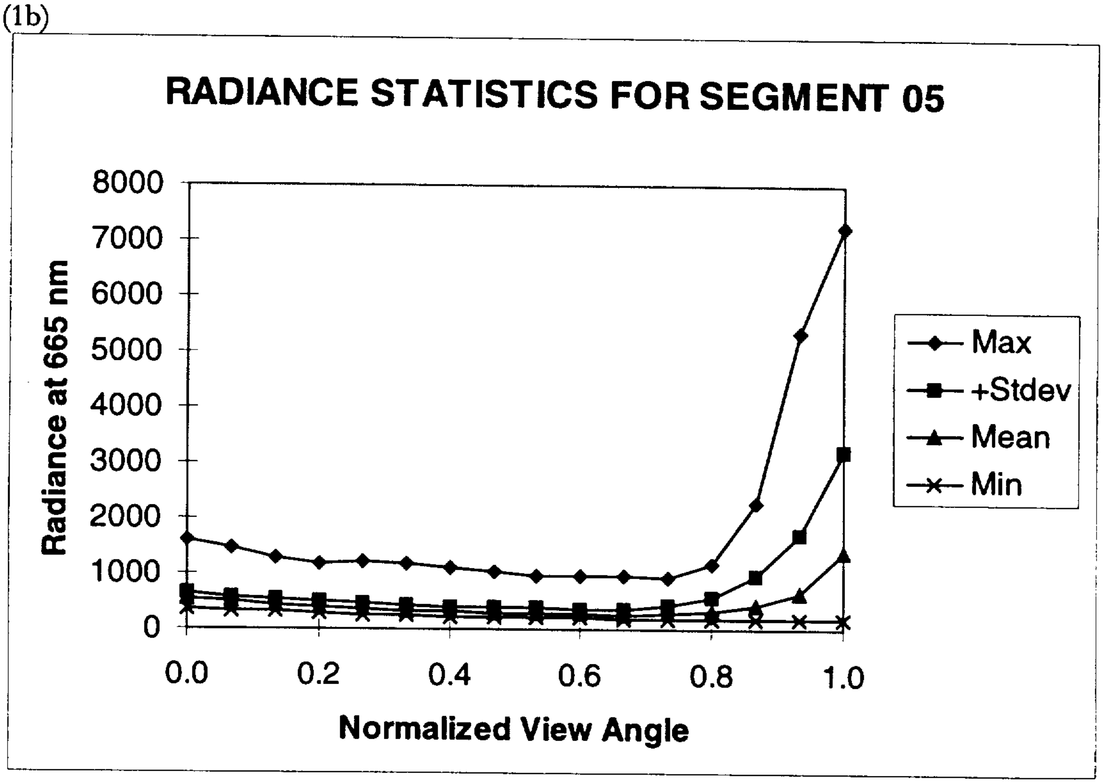
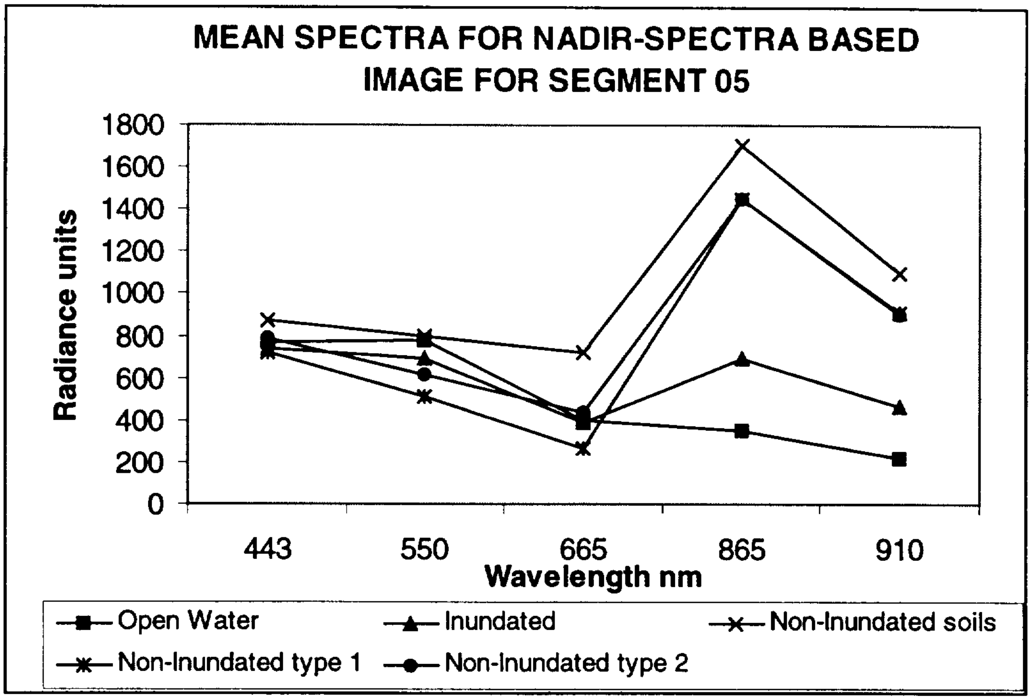



Figure 1 Diaz Barrios M. C., Ustin S., Perry G., et al.

(a)




b)

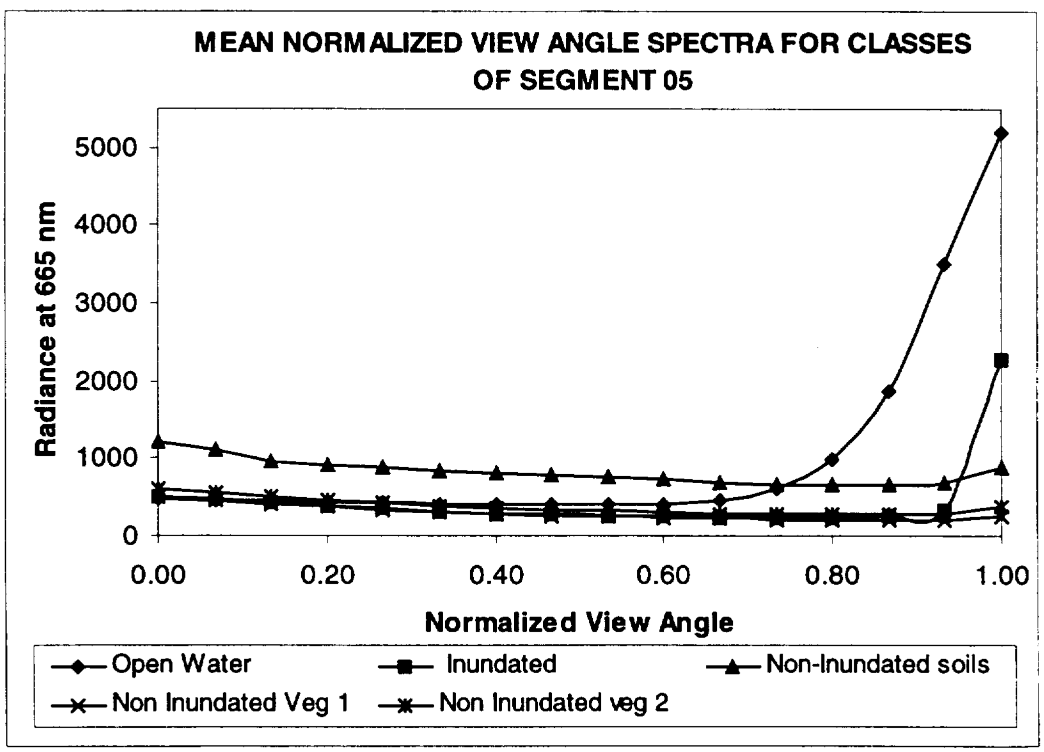



Figure 2 Diaz Barrios M. C., Ustin S., Perry G., et al.

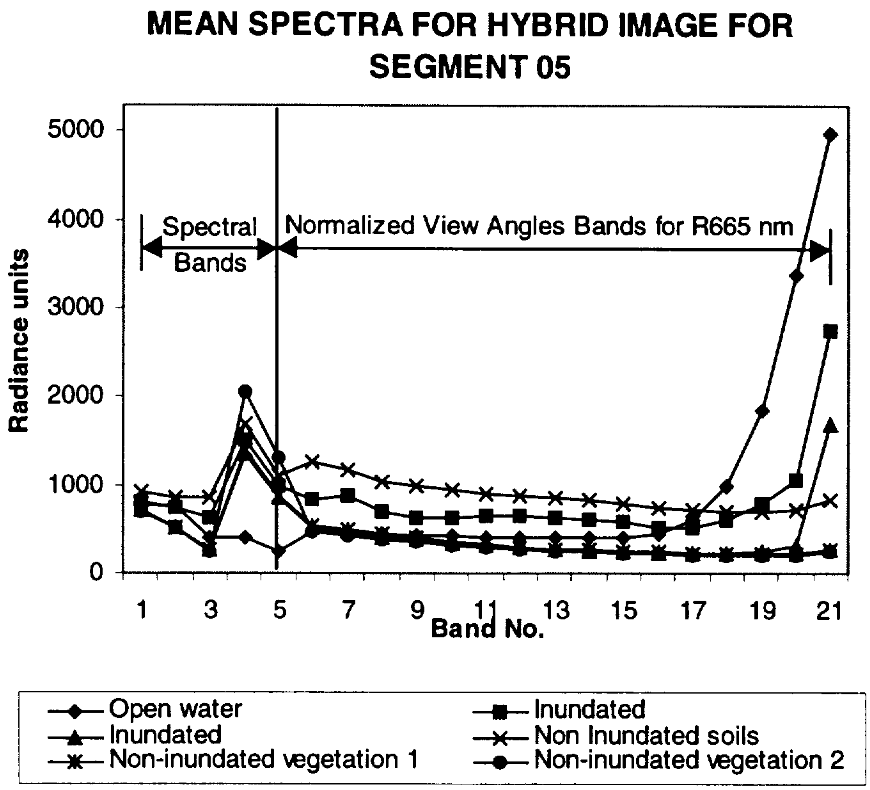



Figure 2c Diaz Barrios M. C., Ustin S., Perry G., et al.

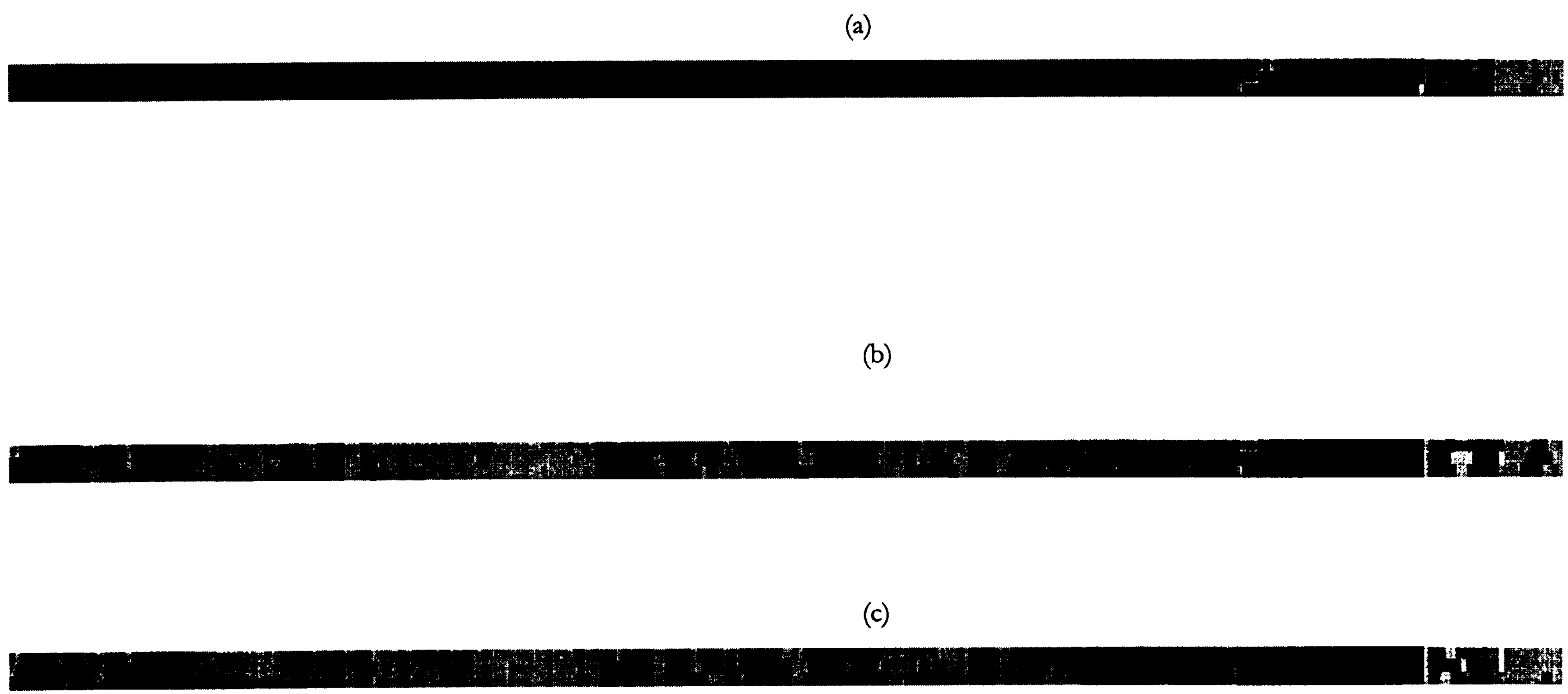



Figure 3  Diaz Barrios M. C., Ustin S., Perry G., et al.