ALGAL ACCESSORY PIGMENT DETECTION USING AVIRIS IMAGE-DERIVED SPECTRAL RADIANCE DATA

Laurie L. Richardson, Florida International University, Miami, Florida,
and Vincent G. Ambrosia, JCWS, Inc., NASA Ames Research Center, Moffett Field, California.

1. INTRODUCTION

Visual and derivative analyses of AVIRIS spectral data can be used to detect algal accessory pigments in aquatic communities (Richardson et al. 1994). This capability extends the use of remote sensing for the study of aquatic ecosystems by allowing detection of taxonomically significant pigment signatures which yield information about the type of algae present. Such information allows remote sensing-based assessment of aquatic ecosystem health, as in the detection of nuisance blooms of cyanobacteria (Dekker et al., 1992) or toxic blooms of dinoflagellates (Carder and Steward, 1985).

Remote sensing of aquatic systems has traditionally focused on quantification of chlorophyll *a*, a photoreactive (and light-harvesting) pigment which is common to all algae as well as cyanobacteria (bluegreen algae). Due to the ubiquitousness of this pigment within algae, chl *a* is routinely measured to estimate algal biomass both during ground-truthing and using various airborne or satellite based sensors (Clark, 1981; Smith and Baker, 1982; Galat and Verdin, 1989; Mittenzwey et al., 1992), including AVIRIS (Hamilton et al., 1993).

Within the remote sensing and aquatic sciences communities, ongoing research has been performed to detect algal accessory pigments for assessment of algal population composition (Gieskes, 1991; Millie et al., 1993; Richardson, 1996). This research is based on the fact that many algal accessory pigments are taxonomically significant, and all are spectrally unique (Foppen, 1971; Morton, 1975; Bjφrnland and Liaaen-Jensen, 1989; Rowan, 1989). Aquatic scientists have been refining pigment analysis techniques, primarily high performance liquid chromatography, or HPLC, (e.g. Mantoura and Llewellyn, 1983 and Wright and Shearer, 1984) to detect specific pigments as a time-saving alternative to individual algal cell identifications and counts (Gieskes and Kraay, 1983; Leavitt et al., 1989; Lizotte and Priscu, 1993; Soma et al., 1993; Wilhelm et al., 1991). Remote sensing scientists (Dekker et al., 1992; Richardson et al., 1991, 1994) are investigating the use of pigment signatures to construct pigment libraries analogous to mineral spectral libraries used in geological remote sensing applications (Farrand and Harsanyi, 1995).

The accessory pigment approach has been used successfully in remote sensing using data from the Thematic Mapper (Richardson et al., 1991), low-altitude, multiple channel scanners (Dekker et al., 1992), field spectroradiometers (Dekker et al, 1992; Richardson, 1991, 1995) and the AVIRIS hyperspectral scanner (Richardson et al., 1994). Due to spectral and spatial resolution capabilities, AVIRIS is the sensor of choice for such studies. We present here our results on detection of algal accessory pigments using AVIRIS data.

2. METHODS

AVIRIS data were collected 13 April 1989 over leveed salt ponds in the vicinity of Moffett Field, California. The AVIRIS sensor was flown at an altitude of 19.8 km on NASA Ames Research Center's ER-2 high-altitude aircraft. Spectral profiles in the visible/near IR wavelengths (channels 1-94) for the various ponds were derived from the data using the ERDAS IMAGINE (version 8.2) image processing software system, residing on a SUN SPARC-Station 2 at the Ecosystems Science and Technology Branch (Code SGE) at NASA Ames Research Center. No atmospheric corrections were made to the AVIRIS data. Profiles for specific ponds were derived by averaging the radiance values over the full extent of the pond, excluding any surface vegetation or levee surfaces. Spectral signatures were derived for all ponds containing various concentrations of algae and photosynthetic bacteria.

The AVIRIS derived spectra were further processed at Florida International University on a 386 Zenith personal computer using MATLAB (The MathWorks, Inc.), a high-performance computation oriented interactive software package. Processing included location and identification of accessory pigment absorbance features. Fourth order derivative spectra were generated by computing the cubic polynomial differentiations according to the simplified least squares procedure described in Savitzky and Golay, 1964, and previously used in processing both AVIRIS and spectroradiometer data (Richardson et al., 1994). Prior to the convolution procedure it was necessary to convert the spectral data to a fixed, uniform wavelength interval. Thus the AVIRIS derived spectra (band widths ranged from 8.30 to 11.22 nm) were fixed at 2 nm intervals. After the derivative spectra were computed, they were plotted and absorbance features identified by comparison with known pigment characteristics (Morton, 1975; Rowan, 1989) as well as our in-house algal spectral signature data base. Because the fourth derivative was used, absorption in the AVIRIS derived spectra could be directly compared with absorption in the derivative spectra.

3. RESULTS AND DISCUSSION

As discussed above, remote sensing of aquatic ecosystems has focused on mapping the distribution of chlorophyll *a*. Figure 1 is a one-band (band 30) AVIRIS image of the ponds that shows radiance data from 675.7-684.9 nm, which covers the chlorophyll red absorbance feature. Many of the ponds in the image appear the same. All ponds had dense, mixed populations of algae and cyanobacteria, and exhibit fairly uniform chlorophyll associated radiance.

Figure 2 is AVIRIS radiance data for band 23 (extracted from the same AVIRIS data set). Band 23 covers 606.8-616.0 nm, a spectral region specifically absorbed by the algal accessory pigment phycocyanin. In contrast to Figure 1, spectral variability is readily apparent among the individual ponds. In particular, ponds A and B are annotated for comparison. Ponds A and B appear virtually identical in Figure 1, but are distinctly different in Figure 2. This is due to varying amounts of cyanobacteria, which possess phycocyanin as a major light-harvesting accessory pigment, within the mixed populations of the two ponds. Thus pond B, which has a higher concentration of phycocyanin containing cyanobacteria, exhibits greater absorbance in band 23.

These differences are even more visible when analysing the AVIRIS derived spectra. Figure 3 shows spectra from both ponds. Each spectrum exhibits a typical cyanobacterial-dominated spectral radiance signature (Richardson et al., 1991, 1994) in which a green reflectance peak (due to red and blue absorbance by chlorophyll *a* as well as carotenoid absorbance in the blue) is accompanied by two absorbance features near 590 and 620 nm (due to the cyanobacterial accessory pigments phycoerythrin and phycocyanin respectively). The stronger absorbance due to the higher concentration of cyanobacteria in pond B is apparent when comparing the two spectra.

Accessory pigment estimates within spectral data can be enhanced using derivative analysis of spectra (Demetriades-Shah et al, 1990). Figure 4 shows the fourth derivatives of (smoothed) spectra from ponds A and B. In the derivative analysis, changes in the slope of a curve which are caused by absorbance features are represented as negative peaks, and reflectance features are seen as positive peaks. It can be seen that the chlorophyll *a* signal near 686, as well as atmospheric absorption features (e.g. at 760 nm) are virtually the same for each derivative spectrum. However, the phycoerythrin (near 590) and phycocyanin (near 620) peaks are different. As the areas under the peaks are directly proportional to the quantity of substances present which contain absorbance/reflectance qualities (Demetriades-Shah et al., 1990), this approach can be used to quantitate pigments (e.g. Bidigare et al., 1989; Goodin et al., 1993). When absorbance/reflectance features are very close

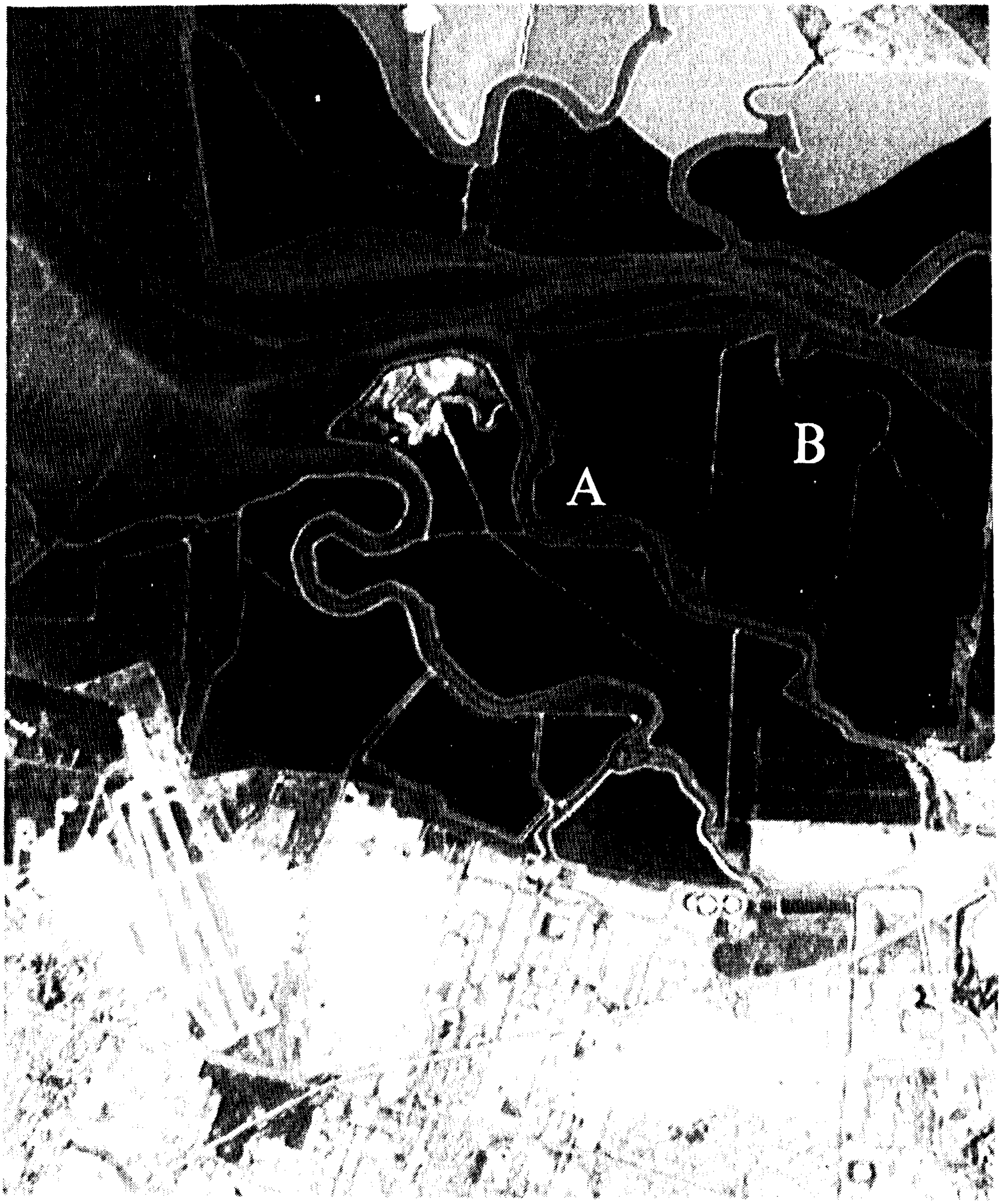

Figure 1. AVIRIS image (single band) of salt ponds near NASA Ames Research Center. Radiance data are from 675.7-684.9 nm (band 30) which covers the red absorbance feature of chlorophyll *a*.

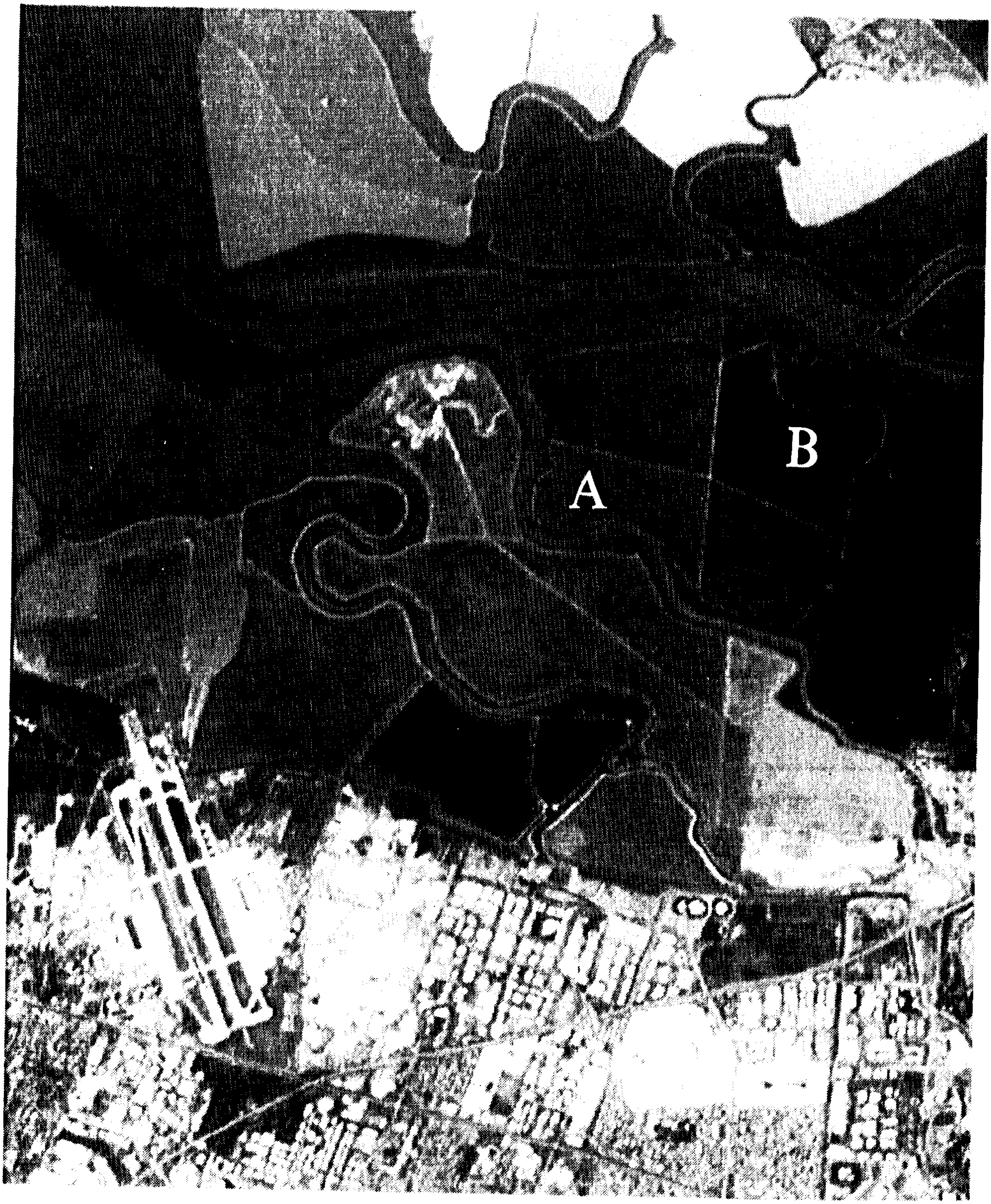

Figure 2. AVIRIS image (single band) of salt ponds near NASA Ames Research Center. Radiance data are from 606.8-616.0 nm (band 23), wavelengths specifically absorbed by phycocyanin.

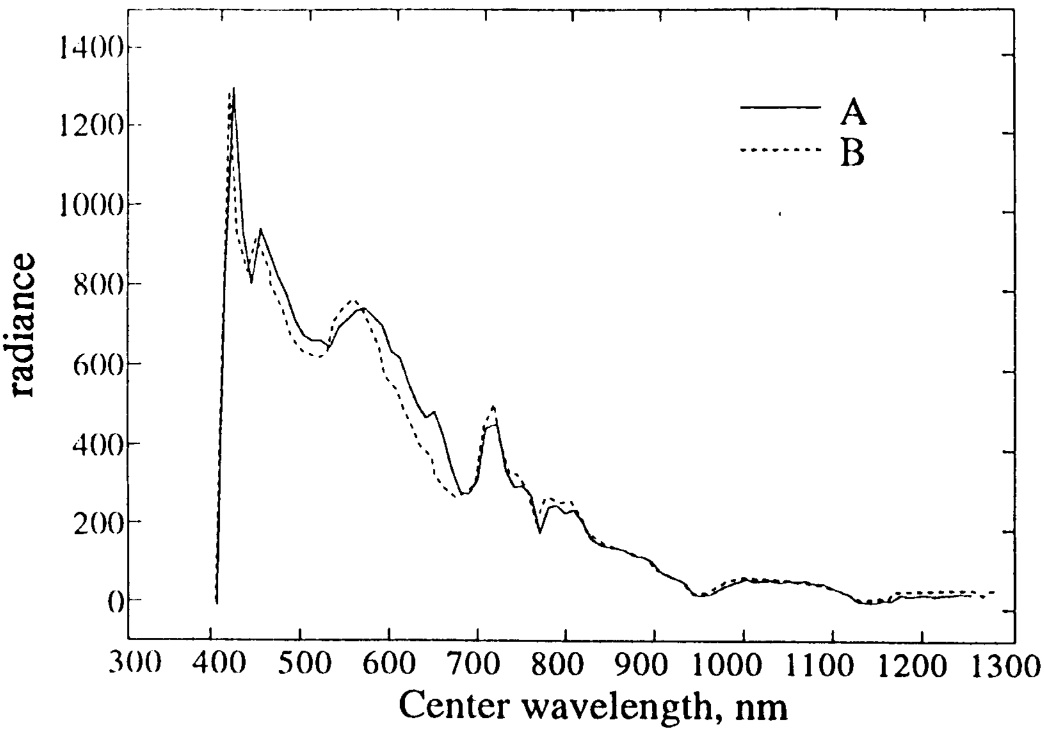

Figure 3. AVIRIS image-derived spectra of ponds A and B shown in Figures 1 and 2.

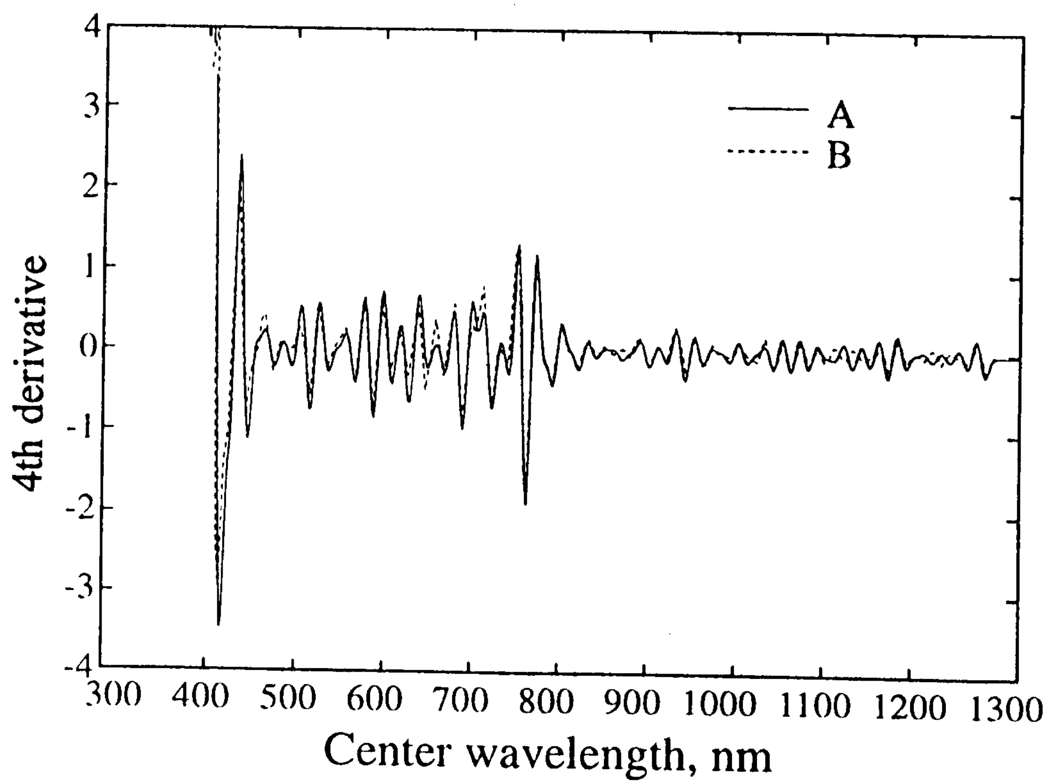

Figure 4. Fourth derivative of AVIRIS spectra shown in Figure 3.

together (spectrally), the fourth derivative must be used (Demetriades-Shah et al., 1990).

The detection of algal accessory pigments to study community structure and population dynamics of algae in aquatic ecosystems by remote sensing has been utilized by a number of investigators (Carder et al, 1993; Dekker, 1992; Richardson et al. 1991, 1994, 1995). These studies have all focused on detection of major groups of algae. Recently, investigators have used a similar approach to investigate algal dynamics at a species level (Bebout and Garcia-Pichel, 1995). In this study, measurements of surface reflectance at wavelengths corresponding to a species specific cyanobacterial accessory pigment (phycoerythrocyanin, λ max at 577 nm) were conducted to document vertical migrations of a population of one cyanobacterial species (*Microcoleus chthonoplastes*) within a mixed population cyanobacterial mat.

The increased signal to noise ratio which has been achieved for AVIRIS in recent years will enhance the capability of this sensor to detect accessory pigments. This will be especially important in less productive waters (as compared to the densely populated salt ponds), but should be possible in aquatic ecosystems such as lakes and shallow water coastal areas with high concentrations of phytoplankton. Research efforts in these areas will require atmospheric correction procedures, which are currently under development by other investigators (see, for example, Carder et al, 1993).

4.0 ACKNOWLEDGEMENTS

We thank Jeff Myers for collaboration, Cheng Jen Liu for spectral processing, and Daniel Buisson for pigment analysis. This research is supported by NASA grant #NAG5-3124.

5.0 REFERENCES

Bebout, B.M. and F. Garcia-Pichel, 1995, "UV B-Induced Vertical Migrations of Cyanobacteria in a Microbial Mat," *Appl. Env. Microbiol.*, vol. 61, pp. 4215-4222.

Bidigare, R.R., J.H. Morrow, and D.A. Kiefer, 1989, "Derivative Analysis of Spectral Absorption by Photosynthetic Pigments in the Western Sargasso Sea," *J. Mar. Res.*, vol. 47, pp. 323-341.

Bjørnland, T., and S. Liaaen-Jensen, 1989, "Distribution Patterns of Carotenoids in Relation to Chromophyte Phylogeny and Systematics," pages 37-60 in J.C. Green, B.S.C. Leadbeater, and W.L. Diver, eds. *The Chromophyte Algae: Problems and Perspectives*, Clarendon Press, Oxford.

Carder, K.L., P. Reinersman, R.F. Chen, F. Muller-Karger, C.O. Davis, and M. Hamilton, 1993, "AVIRIS Calibration and Application in Coastal Oceanic Environments," *Rem. Sens. Env.*, vol. 44, pp. 205-216.

Carder, K.L. and R.G. Steward, 1985, "A Remote-Sensing Reflectance Model of a Red Tide Dinoflagellate off West Florida," *Limnol. Oceanogr.*, vol. 30, pp. 286-298.

Clark, D., 1981, "Phytoplankton Pigment Algorithms for the Nimbus-7 CZCS", pages 227-237, in J.F.R. Gower, ed. *Oceanography from Space*, Plenum, New York.

Dekker, A.G., T.J. Malthus, M.M. Wijnen, and E. Seyhan, 1992, "Remote Sensing as a Tool for Assessing Water Quality in Loosdrecht Lakes," *Hydrobiologia*, vol. 233, pp. 137-159.

Demetriades-Shah, T.H., Steven, M.D., and J.A. Clark, 1990, "High Resolution Derivative Spectra in Remote Sensing," *Rem. Sens. Env.*, vol. 33, pp. 55-64.

Farrand, W.H., and J.C. Harsanyi, 1995, "Discrimination of Poorly Exposed Lithologies in Imaging

Spectrometer Data," *J. Geophys. Res.*, vol. 100, pp. 1565-1578.

Foppen, J.H., 1971, "Tables for the Identification of Carotenoid Pigments," Chromatogr. Rev., vol. 14, pp. 133-298.

Galat, D.L. and J.P. Verdin, 1989, "Patchiness, Collapse and Succession of a Cyanobacterial Bloom Evaluated by Synoptic Sampling and Remote Sensing", *J. Plankt. Res.*, vol. 11, pp. 925-948.

Gieskes, W.W., 1991, "Algal Pigment Fingerprints: Clue to Taxon Specific Abundance, Productivity, and Degradation of Phytoplankton in Seas and Oceans," pages 61-99 in S. Demers, ed. *Particle Analysis in Oceanography*, NATO ASI Series. Vol. G27, Springer-Verlag, Berlin.

Gieskes, W.W. and G.W. Kraay, 1983, "Dominance of Cryptophyceae During the Phytoplankton Spring Bloom in the Central North Sea Detected by HPLC Analysis of Pigments," *Mar. Biol.* vol. 75, pp. 179-185.

Goodin, D.G., L. Han, R.N. Fraser, D.C. Rundquist, W.A. Stebbins, and J.F. Schalles, 1993, "Analysis of Suspended Solids in Water Using Remotely Sensed High Resolution Derivative Spectra," *Photogramm. Eng. and Rem. Sens.*, vol. 59, pp. 505-510.

Hamilton, M.K., C.O. Davis, W.J. Rhea, S.H. Pilorz, and K.L. Carder, 1993, "Estimating Chlorophyll Content and Bathymetry of Lake Tahoe Using AVIRIS Data," *Remote Sensing of Environment*, vol. 44, pp. 217-230.

Leavitt, P.R., S.R. Carpenter, and J.F. Kitchell, 1989, "Whole Lake Experiments: The Annual Record of Fossil Pigments and Zooplankton, *Limnol. Oceanogr.* vol. 34, pp. 700- 717.

Lizotte, M.P. and J.C. Priscu, 1993, "Algal Pigments as Markers for Stratified Phytoplankton Populations in Lake Bonney (Dry Valleys)," *Antarctic J. of the U.S.*, vol. 27, pp. 259-260.

Mantoura, R.F.C., and C.A. Llewellyn, 1983, "The Rapid Determination of Algal Chlorophyll and Carotenoid Pigments and their Breakdown Products in Natural Waters by Reverse-phase High Performance Liquid Chromatography, *Anal. Chim. Acta*, vol. 151, pp. 297-314.

Millie, D.F., H.W. Paerl, and J.P. Hurley, 1993, "Microalgal Pigment Assessments Using High-performance Liquid Chromatography: A Synopsis of Organismal and Ecological Applications," *Can. J. Fish. Aquat. Sci.*, vol. 50, pp. 2513-2527.

Mittenzwey, K.-H., S. Ullrich, A.A. Gitelson, and K.Y. Kondratiev, 1992, "Determination of Chlorophyll *a* of Inland Waters on the Basis of Spectral Reflectance," *Limnol. Oceanogr.*, vol. 37, pp. 147-149.

Morton, A.M., 1975, *Biochemical Spectroscopy*, Wiley and Sons, New York, vol. 1.

Richardson, L.L., 1996, "Remote Sensing of Algal Bloom Dynamics by Detecting Algal Accessory Pigments," *Bioscience*, (in press)

Richardson, L.L., D. Bachoon, V. Ingram-Willey, C. Chee Chow, and K. Weinstock, 1991, "Remote Sensing of the Biological Dynamics of Large-scale Salt Evaporation Ponds," *Proc. Intl. Symp. Rem. Sens. Env.*, pp. 511-623.

Richardson, L.L., D. Buisson and V. Ambrosia, 1995, "Use of Remote Sensing Coupled with Algal Accessory Pigment Data to Study Phytoplankton Bloom Dynamics in Florida Bay," *Proc. Third Them. Conf. Rem. Sens. Mar. and Coast. Env.*, vol. 1, pp. 183-192.

Richardson, L.L., D. Buisson, C.J. Liu, and V. Ambrosia, 1994, "The Detection of Algal Photosynthetic Accessory Pigments Using Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) Spectral Data," *Mar. Tech. Soc. J.*, vol. 28, pp. 10-21.

Rowan, K.S., 1989, *Photosynthetic Pigments of Algae*, Cambridge University Press, Cambridge.

Savitzky, A., and M.J.E. Golay, 1964, "Smoothing and Differentiation of Data by Simplified Least Squares Procedures", *Anal. Chem.*, vol. 36, pp. 1627-1639.

Smith, R.C., and K.S. Baker, 1982, "Oceanic Chlorophyll Concentrations as Determined by Satellite (Nimbus-7 Coastal Zone Color Scanner), *Mar. Biol.*, vol. 66, pp. 269-279.

Soma, Y., T. Imaizumi, K-I. Yagi, and S-I. Kasuga, 1993, "Estimation of Algal Succession in Lake Water using HPLC Analysis of Pigments," *Can. J. Fish. Aquat. Sci.*, vol. 50, pp. 1142-1146.

Wilhelm, C., I. Rudolph, and W. Renner, 1991, "A Quantitative Method Based on HPLC-aided Pigment Analysis to Monitor Structure and Dynamics of the Phytoplankton Assemblage - A Study from Lake Meerfelder (Eifel, Germany)," *Arch. fur Hydrobiol.*, vol. 123, pp. 21-35.

Wright, S.W. and J.D. Shearer, 1984, "Rapid Extraction and High Performance Liquid Chromatography of Chlorophylls and Carotenoids from Marine Phytoplankton," *J. Chromatog.*, vol. 294, pp. 281-295.