Remote Sensing Algorithms for Estimating *Enterococcus* Concentration in Coastal Louisiana Beaches

Zaihong Zhang**,** Zhi-Qiang Deng, Kelly A. Rusch, Maria Gutierrez Wing, and Kevin Chenier
(Louisiana State University**,** Baton Rouge, LA, USA)

ABSTRACT: Remote sensing algorithms are presented for retrieving enterococci concentrations in the Cameron Parish beaches with emphasis on Holly beach along the southwest Louisiana shoreline. Images containing NASA (National Aeronautics and Space Administration) MODIS (Moderate-resolution Imaging Spectroradiometer) data for the period 2005-2009 were collected and processed using ERDAS software and then reflectance values were obtained. Enterococcus data collected from 2005-2009 at the Holly beach by Louisiana Beach Monitoring Program was employed as the ground-truth data. The reflectance values and the bacteria concentration data were then utilized to develop the retrieval algorithms for rapid estimation of enterococcus concentration in beach waters. Results showed that enterococcus concentrations were linearly correlated with reflectance values of Terra band 1 ($R^2 = 0.629$). Enterococcus concentrations are also correlated with reflectance values of Aqua bands 1 and 2 ($R^2 = 0.5595$) and with Terra bands 1 and 2 ($R^2 = 0.5007$). Significance of the results is that a decision concerning beach water quality can be made daily by combining the new algorithms and daily Terra and Aqua data, greatly reducing the potential risk of contaminated beach waters to human health and improving beach management.

INTRODUCTION

The federal BEACH (Beaches Environmental Assessment and Coastal Health) Act requires beach managers to monitor bacterial water quality indicators and issue swimming advisories when water quality standards are exceeded. However, current bacteria-count methods require an incubation step of 24 – 48 hours to obtain results, preventing beach managers from taking action the day of exceedance. People swimming during the time between sample collection and test results may be unnecessarily exposed to microbial pollutants at peak contamination time. In addition, conventional grab sampling methods are unable to provide a synoptic view of bacterial movement and distribution in beach waters. A novel approach is necessary to address the deficiency in current beach water quality monitoring programs. Satellite remote sensing, especially MODIS Terra and Aqua data, has been widely used in monitoring water quality in coastal and estuarine waters (Kahru et al., 1993, 2000; Kahru, 1997; Esaias et

al., 1998; Kutser, 2004; Richard et al., 2004). Water quality monitoring using NASA EOS Terra/Aqua MODIS sensors is an emerging technology and is particularly suitable for near-real-time monitoring of coastal beaches in terms of cost-effectiveness and synoptic views of large spatial scale (length) (http://www.epa.gov/eerd/RemoteSensing.htm). This study is intended to develop a novel remote sensing-based approach to rapid determination of fecal-indicator bacteria concentration with ground-truth and MODIS data.

FIGURE 1. Holly beach, is located east of the Sabine River and west of the Calcasieu River Outlet in the Calcasieu River Basin within Cameron Parish, Louisiana.

The study area of this article is the Cameron Parish beaches with an emphasis on Holly Beach along the southwest Louisiana shoreline, as shown in Figure 1. Holly Beach is located along the Gulf of Mexico, east of the Sabine River and west of the Calcasieu River Outlet in the Calcasieu River Basin within Cameron Parish, Louisiana. Use of Holly beach is very high during the swimming season, with approximately 150 people using the beach on a typical weekday, 1,000 people on a typical weekend, and 6,000 people on a typical holiday. Peak use of it occurs during May through Labor Day.

MATERIALS AND METHODS

Enterococcus data for Holly beach collected by the Beach Monitoring Program of Louisiana Department of Health and Hospitals (LDHH) during January 2005- August 2009 was employed as the ground-truth data. Water samples were collected weekly by LDHH on Monday morning at the time when the NASA satellite Terra passed through the region. Samples were analyzed for fecal-indicator bacteria,

turbidity, and chlorophyll-a. EPA (Environmental Protection Agency) approved method ASTM #D6503-99 was utilized for enterococci analysis.

The MODIS sensors on NASA's Terra and Aqua spacecrafts began providing science data and subsequent operational products for the land, ocean, cryosphere, and atmosphere in February 2000 (Terra) and June 2002 (Aqua). The Terra overpass time is around 10:30am (local solar time) in its descending mode and 10:30pm in ascending mode. The Aqua overpass time is around 1:30pm in ascending mode and 1:30am in descending mode (Wan et al., 2004). They are multi-spectral sensors with several wavebands designed for the sensing of earth's environment including atmosphere, land, and ocean. Many studies has proved that MODIS band 1 (620-670 nm) and band 2 (841-876 nm) imagery with 250 m spatial resolution can provide data with sufficient spatial resolution for coastal waters regularly (up to 4 times per day) (Tiit et al., 2005). This study also uses these two bands to derive remote sensing algorithms for retrieving concentrations of enterococci.

Images containing NASA MODIS data from both the Terra and Aqua satellites during the same sampling dates were downloaded through one of NASA Internet servers: LAADS Web. The product selected at LAADS Web was MOD02QKM, which includes reflectance and radiance values of MODIS/Terra and Aqua bands 1 and 2. The images were processed using ERADAS software and MODIS satellite scene of study area was obtained (Figure 2) and then sample sites data were used to define sample sites' accurate location in MODIS satellite scene and then reflectance values were obtained. The reflectance values and the bacteria concentration data were then utilized to develop retrieval algorithms for rapid estimation of enterococcus concentration in beach waters.

RESULTS AND DISCUSSION

While several retrieval algorithms have been obtained in our study using reflectance values and the bacteria concentration data, the following three models with $R^2 > 0.5$ (R^2 = root mean square error) are recommended for estimation of enterococcus concentration in beach waters.

$$\text{Entero}cocci = -105.8R_{TB1} + 5632 \qquad R^2=0.629 \qquad (1)$$

$$Enterococci = 9.4254e^{0.1232(R_{AB1}-R_{AB2})} \qquad R^2=0.5595 \qquad (2)$$

$$\log(Enterococci) = -1.5724 \ln\left(\frac{R_{TB1} + R_{TB2}}{\frac{\log R_{TB1}}{\log R_{TB2}}}\right) + 8.4675 \qquad R^2=0.5007 \qquad (3)$$

where R_{TB1}= reflectance value of Terra band 1; R_{TB2}= reflectance value of Terra band 2; R_{AB1}= reflectance value of Aqua band 1; R_{AB2}= reflectance value of Aqua band 2.)

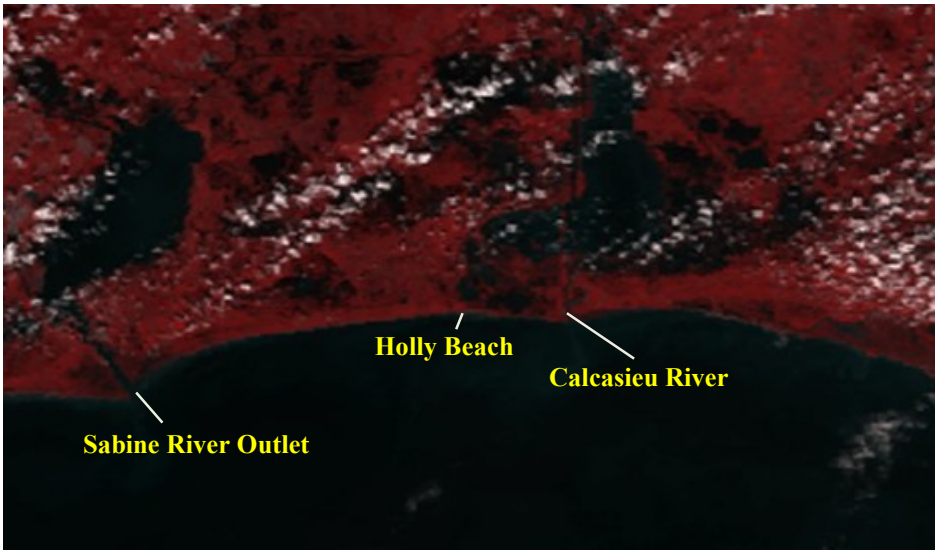

FIGURE 2. MODIS satellite scene of the study area (Aqua, Oct. 18, 2007)

Equation (1) indicates a robust linear relationship between band 1 (620–670 nm) MODIS Terra 250 m data and enterococci concentration with $R^2 = 0.629$, as shown in Fig. 3. The second equation shows that enterococcus concentrations is also exponentially correlated with reflectance values of Aqua bands 1 and 2 ($R^2 = 0.5595$) (Fig. 4). Equation establishes a relationship between enterococcus concentrations and Terra band 1 and band 2 data with a $R^2 = 0.5007$. The result of Equation (3) is shown in Fig. 5.

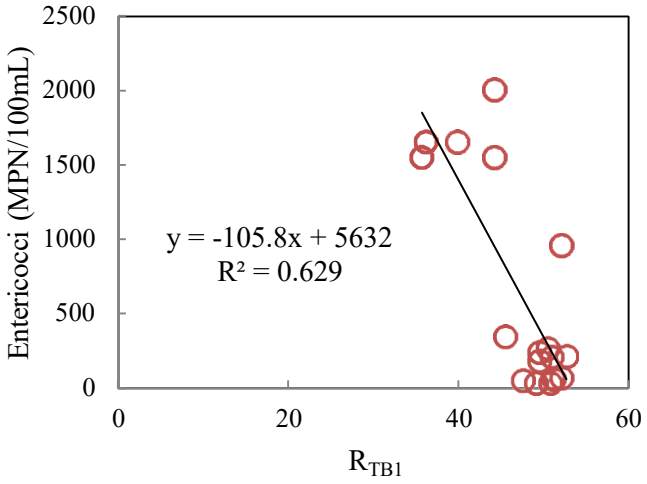

FIGURE 3. Entericocci concentration as a function of MODIS Terra 250 m band 1 reflectance value. All data were obtained from six sampling sites: Holly 1, Holly 2, Holly 3, Holly 4, Holly 5 and Holly 6 on 10/18/2007, 06/13/2008 and 5/21/2009.

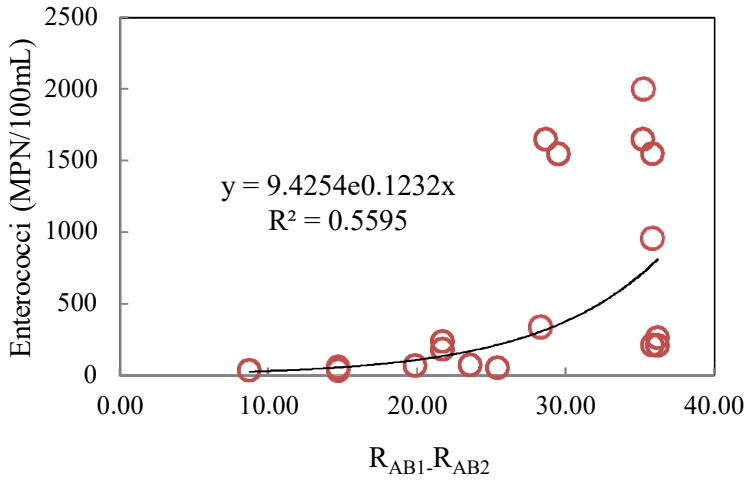

FIGURE 4. Entericocci concentration as a function of MODIS Aqua 250 m band 1and band 2 reflectance value.

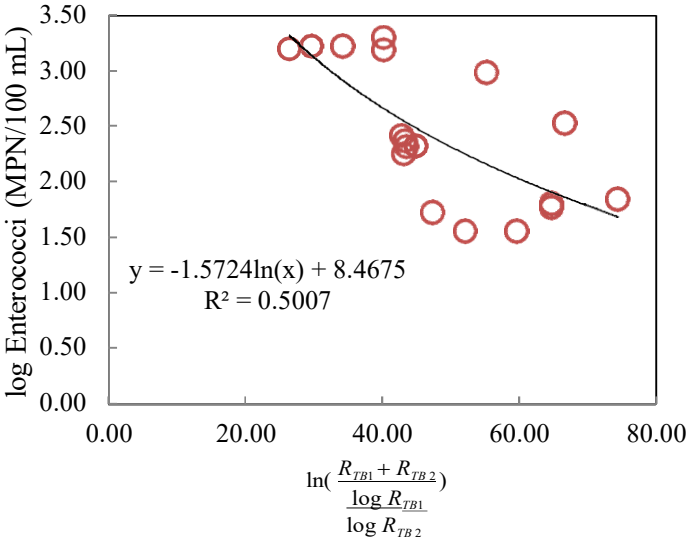

FIGURE 5. Entericocci concentration as a function of MODIS Terra 250 m band 1and band 2 reflectance value.

CONCLUSIONS

This study demonstrates that it is possible to use space-borne remote sensing data to monitor enteroccocus concentration in beach waters at near-real-time. Three useful remote sensing algorithms for retrieving concentrations of enterococci are presented. The algorithms may be used to nowcast and forecast enterocococi levels in beach waters. While the algorithms are specifically developed for Holly beach, they may be extended to other coastal beaches in the Gulf of Mexico Region. Applications of the

remote sensing algorithms will significantly improve beach management and greatly reduce the potential risk of contaminated beach waters to human health.

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REFERENCES

Esaias, W. E., M. R. Abbott, I. Barton, O. B. Brown,, J. W. Campbell and K. L. Carder. 1998. "An overview of MODIS capabilities for ocean science observations". *IEEE Transactions on Geoscience and Remote Sensing*, 36(4): 1250–1265.

Kahru, M., J.-M.Leppänen, and O Rud. 1993. "Cyanobacterial blooms cause heating of the sea surface". *Mar. Ecol. Prog. Ser.*, 101: 1-7.

Kahru, M. 1997. "Using satellites to monitor large-scale environmental change in the Baltic Sea". *In Monitoring Algal Blooms: New Techniques for Detecting Large-scale Environmental Change* (Kahru, M. & Brown, C. W., eds), pp. 43.61. Springer-Verlag, Berlin.

Kahru, M., J.M. Leppänen, O. Rud, and O. P. Savchuk, 2000. "Cyanobacteria blooms in the Gulf of Finland triggered by saltwater inflow into the Baltic Sea". *Mar. Ecol. Prog. Ser.*, 207: 13-18.

Kutser, T. 2004. "Quantitative detection of chlorophyll in cyanobacterial blooms by satellite remote sensing sensing". *Limnol. Oceanogr.* 49: 2179-2189.

Wong M. S., K. H. Lee, Y. J. Kim, J. E. Nichol, Z.Q. Li and N. Emerson, 2007. "Modeling of Suspended Solids and Sea Surface Salinity in Hong Kong using Aqua/MODIS Satellite Images". *Korean Journal of Remote Sensing*, 23(3):161-169.

Richard L. Millera and Brent A. McKeeb, 2004. "Using MODIS Terra 250 m imagery to map concentrations of total suspended matter in coastal waters". *Remote Sensing of Environment*, 93(1-2): 259–266.

Wan Z., Y. Zhang and Q. Zhang, 2004. "Quality assessment and validation of the MODIS global land surface temperature". *INT. J. REMOTE SENSING,* 25(1):261–274.

Vilmaliz Rodríguez-Guzmán and Fernando Gilbes-Santaella, 2009. "Using MODIS 250 m Imagery to Estimate Total Suspended Sediment in a Tropical Open Bay". *International Journal of System Applications, Engineer & Development*, 3(1):36-44.