WATER TURBIDITY PARAMETERS DERIVED FORM SATELLITE IMAGERY

Chi-Kuei Wang, Assistant Professor
Che-Chuan Kang, Student
Department of Geomatics
National Cheng Kung University
1 University Road, Tainan, Taiwan, R.O.C. 701
chikuei@mail.ncku.edu.tw
f646911013ncku@hotmail.com

ABSTRACT

Bathymetry lidar technology has proved to be cost-effective for mapping coastal waters if the system operated in a favorable situation. Water turbidity is one the most significant factors that affects the performance of the bathymetric system. However, it is rarely monitored regularly. Knowledge of water turbidity in coastal water, such as seasonal variations and spatial extend, would be beneficial for planning a bathymetric lidar mission. In this paper, Aqua MODIS imageries and in-situ inherent optical properties were used to derive water turbidity parameters of coastal water (water depth less than 30 m) in Taiwan with the secchi depth ranging from 5 m to 20 m.

INTRODUCTION

Bathymetric lidar is a cost effective tool for shallow water mapping in the coastal areas, where the ship-based sonar operation is limited by the hazardous environment or is unable to access due to its remote location. One of the keys for a successful bathymetric lidar project is “clear water”. The efficiency of bathymetric lidar is a function of water clarity (or, conversely, water turbidity). The clearer the water is the deeper depth the bathymetric systems can measure.

The current commercial bathymetric lidar systems, including Optech SHOALS3000 (LaRocque et al., 2004), Tenix LADS MkII (Sinclair, 2005), and Airborne Hydrography AB Hawk Eye II (Airborne Hydrography AB, 2008), have the capability to map water depth form approximately 20 cm to 75 m, depending on system configurations and water clarity. In addition, a research oriented system, NASA EAARL, is more suitable for extremely shallow water applications, such as coral reef area, can map water depth from 30 cm to 26 m (Wright and Brock, 2002). Note that all of the above systems are perfect for coastal bathymetric mapping when the weather and water clarity are preferable.

Weather forecast, although not as reliable as it should be, provides valuable data for the flight planning managers to decide whether or not to perform an aerial operation. There are rare continuous water optical property monitoring setup in coastal areas (Dickey et al., 2006), which can provide essential information for flight manager of bathymetric lidar operation, not to mention a water clarity forecast. This becomes a huge disadvantage for aerial bathymetric lidar system, because the uncertainty of the water clarity can jeopardize a project by requiring many reconnaissance flights and field crew members on the sea to ascertain good condition of water clarity, hence increasing the budget.

Remotely sensed images from satellites has the potential to provide crucial information for flight planning manager to better prepare the flights of when and where a flight should be planned. This is also crucial for the promotion the use of bathymetric lidar system. There are many places that need to be mapped without any optical property records.

In this research, the MODIS sensor onboard Aqua is used due to its spectral resolution. The MODIS image can be used along with the Quasi-Analytical Algorithm (QAA)(Lee, et al., 2002), a Remote Sensing inversion algorithm derived from radiative transfer relationship of different constituents in water, thus, eliminates the need for a regression model.

More importantly, by use of field measurements, the water optical properties are translated to a single turbid measuremtn, Secchi depth, which is more adopted by the bathymetric lidar community. A secchi disk a round disk of 20 cm of diameter with alternating black and white quadrants. At the depth where the secchi disk disappers as it is lowered in the water and reappears when it is raised, it is called secchi depth. Secchi depth is a more intuitive reading to correlate the condition of water clarity because of its easy access and requires essential no maintenance. For most of the commercial bathymetric lidar systems, they are capable of measuring up to 2 secchi depth in day and 3 secchi depth at night. It is our goal to produce water turbidity maps of coastal areas to assist hydrographic lidar operation.

METHOD

The conversion from satellite radiance value to water optical properties, absorption coefficient (a) and backscattering coefficient (b_b), is based on QAA (Lee et al., 2002), which is provide by NASA SeaDAS 5.1 software as a level 2 product.

The relationship between water optical properties and secchi depth can be described by underwater visibility equation (Hou et al., 2007). When the secchi depth is viewed from above, the relationship has the form $\left(c+K_d\right)Z_{SD}=\Gamma$, where c and K_d are water beam attenuation coefficient and diffuse attenuation coefficient, respectively, Z_{SD} is the secchi depth, and Γ is a constant, that is a function of water scattering properties (i.e., the scattering phase function).

K_d can be estimated by the use of Gershun's equation.

$$K_d\left(z\right)=\frac{a\left(z\right)}{\bar{\mu}\left(z\right)},$$

where $a\left(z\right)$ and $\bar{\mu}\left(z\right)$ are the water absorption coefficient and average cosine of the underwater light field at the depth of z .

The average cosine at different depth can determined by using the following equations adopted from Berwald et al. (1995):

$$\bar{\mu}\left(z\right)=\bar{\mu}_\infty+\left(\bar{\mu}_0-\bar{\mu}_\infty\right)\exp^{-P_\tau\tau},$$

where $\bar{\mu}_0=0.000421\left(\frac{\omega_0}{1-\omega_0}\right)^2-0.0274\left(\frac{\omega_0}{1-\omega_0}\right)+1$,

$$\bar{\mu}_\infty=-1.59\omega_0^4+1.71\omega_0^3-0.467\omega_0^2-0.347\omega+1,$$

$$P_\tau=-0.166\omega_0^2+0.341\omega_0+0.0305,$$

$$\tau=cz,$$

and, $\omega_0=b/c$.

By definition, $c=a+b=a+m\cdot b_b$, where m is the ratio of backscattering coefficient and scattering coefficient. For the representative particle, m is constant and approximately 50 (Mobley, 1994). The value of Γ and m will be determined and modified based on the field information.

DATA

In-Situ Data

The water absorption coefficient and beam attenuation coefficient are measured by using a WET Labs AC9. The backscattering coefficient is measured by using a HOBI Labs HydroScat-6. Two instruments performed the profiling tasks in sequence, not in any particular order. The profile was lowered down to the depth of 20 m or 2~3 m above sear floor to prevent collision with the sea floor. In addition, secchi depth readings are recorded. The field data are collected starting from May 2007 to December 2007, which includes summer, spring, and winter. And the sites cover north-east, east, and south tip of Taiwan Island and Peng-Hu Island (Figure 1).

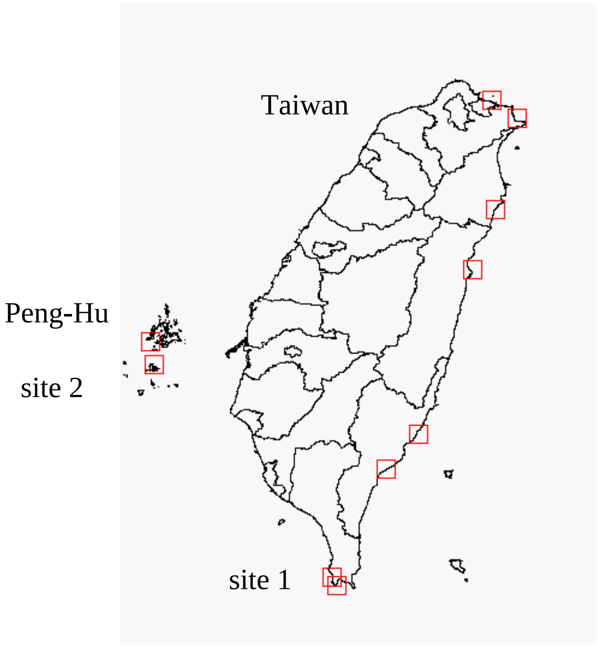

Figure 1. Map of Taiwan and Peng-Hu islands. The red rectangles denote the ten sites with in-situ data collection.

The profile data are processed by median filter to remove environmental noise. The m profile is calculated by $m = \frac{c_{AC9} - a_{AC9}}{b_{bH6}}$, where AC9 and H6 denote the source of instrument (H6: HydroScat-6).

In summer, the water at site 1 is clearer than site 2 (Figure 2AandFigure 2B). In fall, the water at two sites has similar turbidity (Figure 2C and Figure 2D). The dash line in Figure 2 indicate 2 optical depth (not the same as 2 secchi depth) based on the beam attenuation coefficient profile data. It is assumed that light originated form below this depth is undetectable by MODIS due to its minimal radiant energy. A dash line at deeper depth indicates a clearer water. Among the profiles, the m profile remain mostly constant in the proximity of 50.

The field data are used to determine the Γ values for all sites. For site 1 and 2, the average value are 2.7 and 3.5 for the summer of 2007; the average values are 5.75 and 4.0 for the fall of 2007.

Satellite Data

Level 1A Auqa MODIS images are obtained though NASA ocean color website (http://oceancolor.gsfc.nasa.gov/) and processed by SeaDAS 5.1, which is a suite of programs that is provide by NASA for Ocean Color studies. The spatial resolution of MODIS is 1 km and the MODIS has every day revisit at approximately 1 pm local time of the sites.

Three years of MODIS data, from 2004 to 2006, were processed. One pixel is extracted for site 1 and site 2, respectively. The temporal variation in Figure 3 shows that the absorption coefficient (A and C) is more stable than backscattering coefficient (B and D). The backscattering coefficient of site 2 (Figure 3B) shows distinctive seasonal change, which have a good correspond to field measurement. Site 2 is famous for its clean and crispy blue water during summer, and it notorious for its gusty wind in winter.

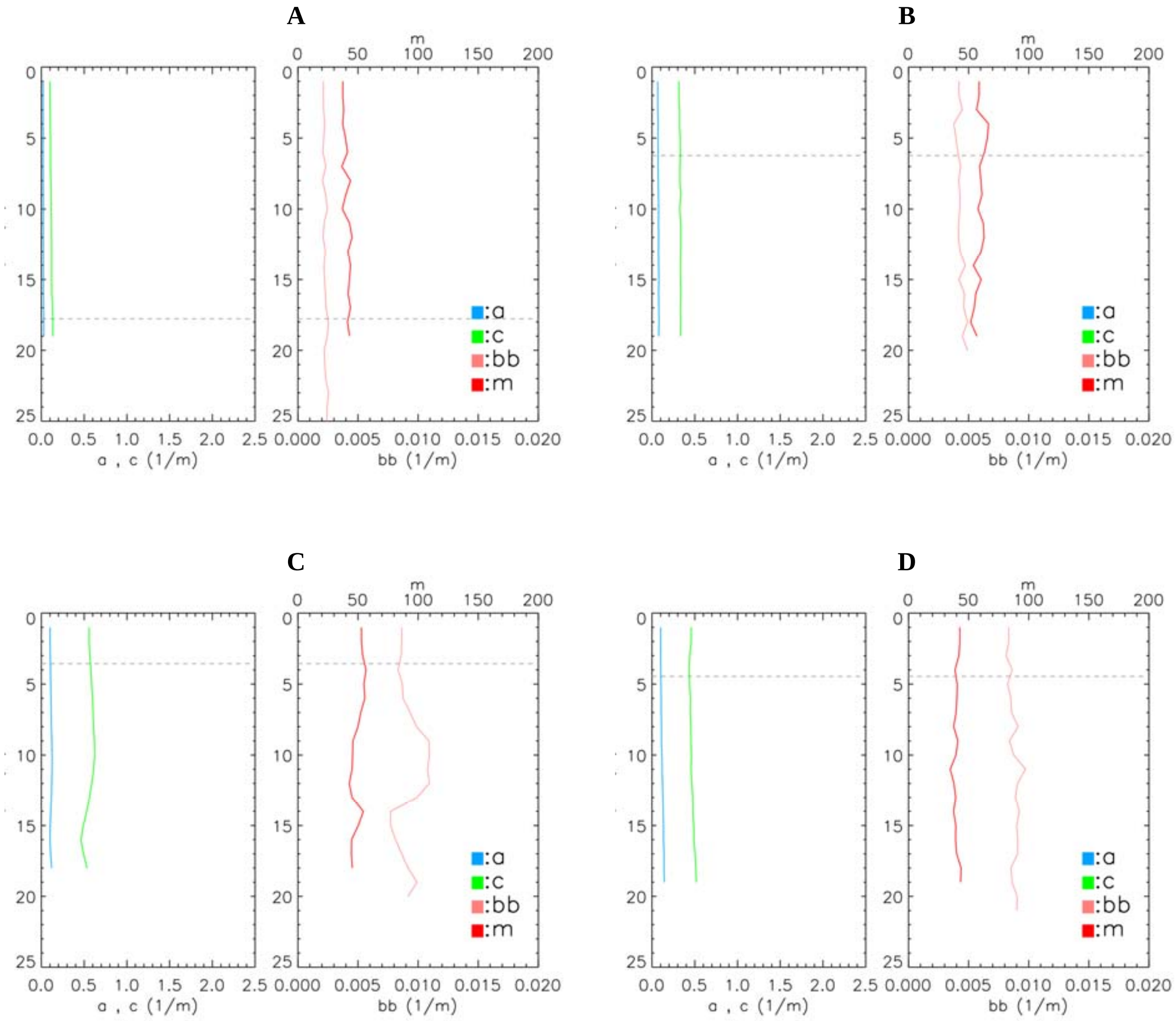

Figure 2. The water optical properties profiles measured at site 1 and site 2 for the summer and fall of 2007. A: site 1, summer; B: site 2, summer; C: site 1, fall; D: site 2, fall. The dash line marks the 2 optical depth, which is determined from the beam attenuation coefficient profile data. Note how much the water optical properties change for different time and location, while the m value remains to be in the proximity of 50.

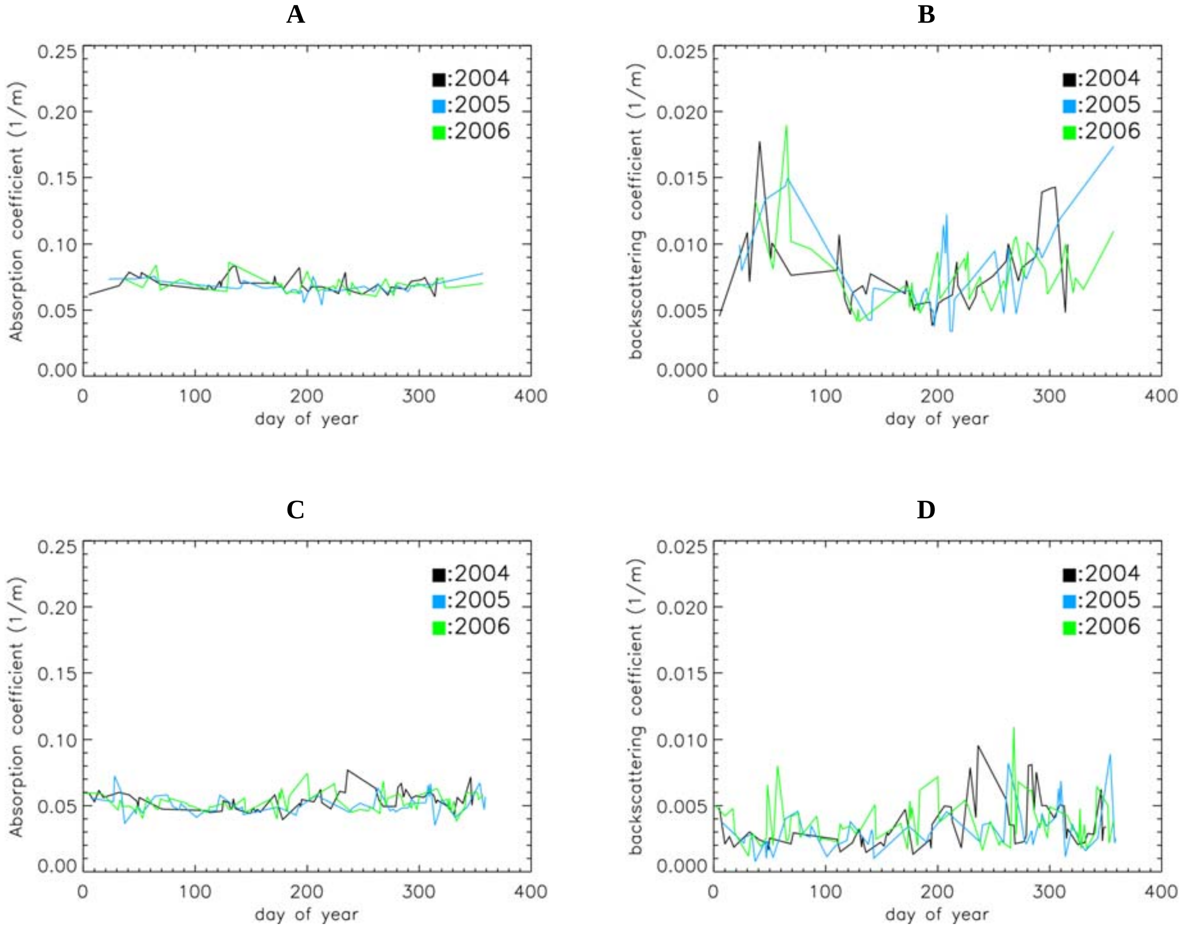

Figure 3. Annual variation of water optical properties at site 1 (A and B) and site 2 (C and D) from 2004 to 2007.

RESULTS

As suggested by the temporal MODIS data (Figure 3), we would expect clear coastal water in summer. Figure 4 and Figure 5 show the water optical properties derived from Aqua MODIS acquired on July 7, 2007 for site 1 and site 2, respectively. It includes the absorption and backscattering coefficients derived from QAA, scattering and downwelling attenuation coefficients, and the secchi depth derived by using the method proposed by this research. For site 1, the secchi depth near the coast line is great than 10 m, which would suggest 20 m of depth penetration of bathymetric lidar measurement. For site 2, the secchi around the coast lines is greater than 5 m, and been 10 m for most of the area, which would indicate a good bathymetric lidar penetration of up to 10 m for the coastal area and 20 m for the outer region.

We have developed a method to use Aqua MODIS image to assess water turbidity for coastal water of Taiwan. The turbidity parameter can be converted to a more intuitive reading of secchi depth. The results (Figure 4 and Figure 5) has good agreement with field experience.

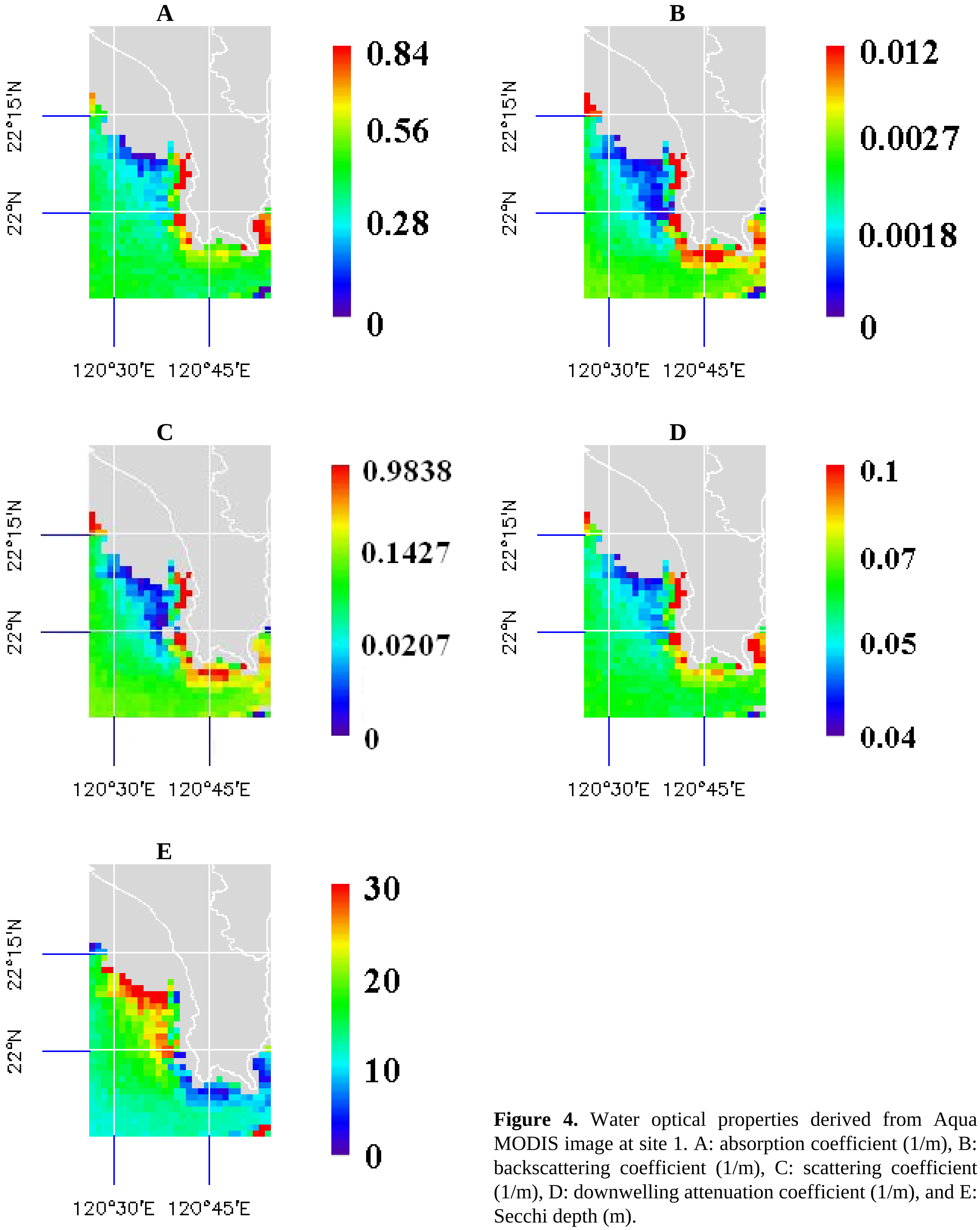

Figure 4. Water optical properties derived from Aqua MODIS image at site 1. A: absorption coefficient (1/m), B: backscattering coefficient (1/m), C: scattering coefficient (1/m), D: downwelling attenuation coefficient (1/m), and E: Secchi depth (m).

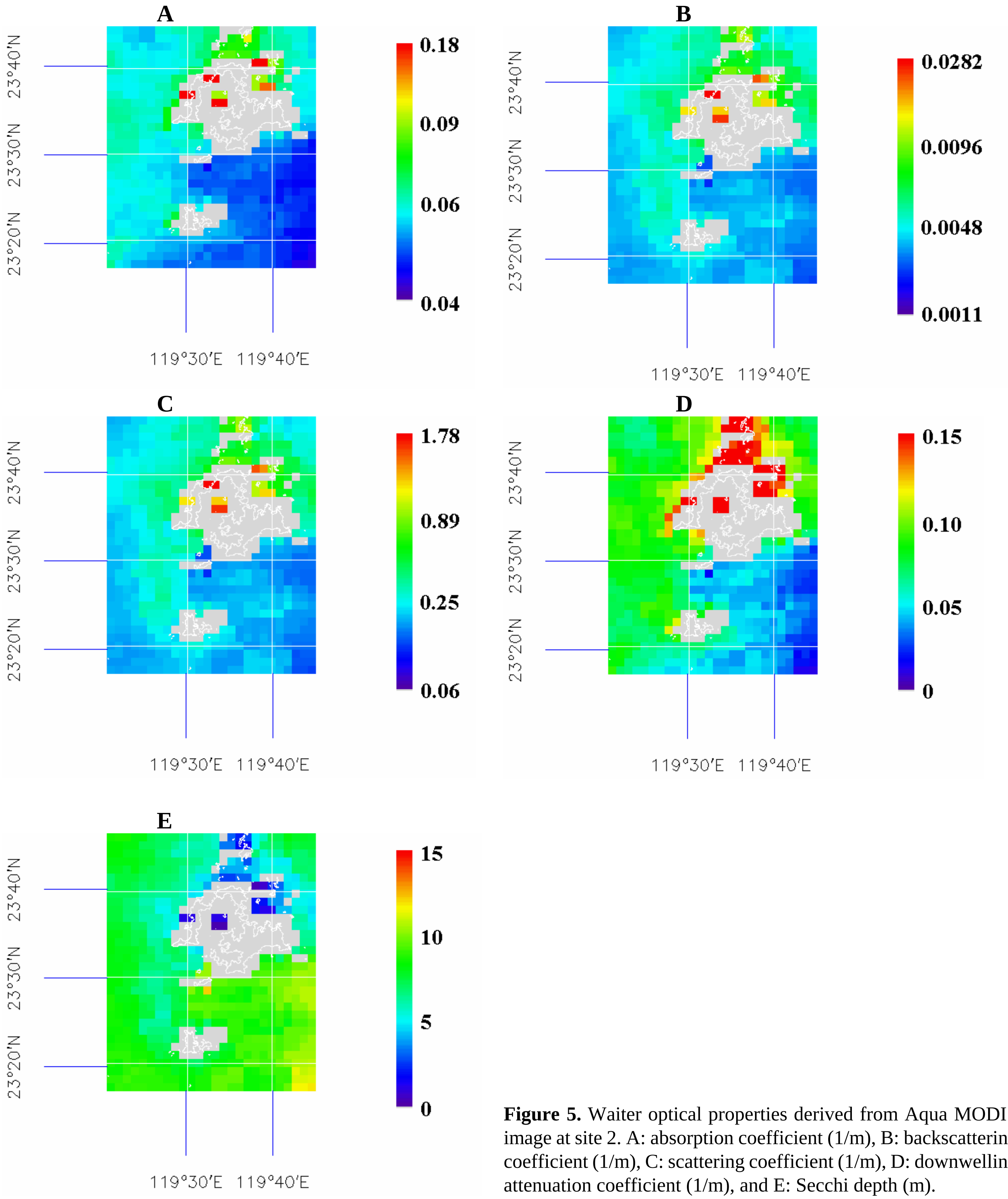

Figure 5. Waiter optical properties derived from Aqua MODIS image at site 2. A: absorption coefficient (1/m), B: backscattering coefficient (1/m), C: scattering coefficient (1/m), D: downwelling attenuation coefficient (1/m), and E: Secchi depth (m).

ACKNOWLEDGEMENT

The authors thank William D. Philpot of School of Civil and Environment Engineering, Cornell University for lending the AC9 and Hydroscat-6 instruments and the field crew of Chung-Hsing Surveying Co., Ltd. (Taiwan) for the support of field operation. The authors appreciate NASA's great effort for collecting, hosting, and disseminating MODIS data and the associated data processing software. The final support is provided by The Ministry of Interior of Republic of China under the contract no. of H950801.

REFERENCES

Hou, W., Z. Lee, A. D. Weidemann, 2007. Why does the Secchi disk disappear? An imaging perspective, *Optics Express*, *15*(6): 2791-2801.

Mobley, C.D., 1994. *Light and Water: Radiative Transfer in Natural Waters,* Academic Press, New York.

Berwald , J., D. Stramski, C. D. Mobley, D. A. Kiefer, 1995. Influences of absorption and scattering on vertical changes in the average cosine of the underwater light field, *Limnology and Oceanography*, *40*(8): 1347-1357.

Hou, W., Z. Lee, A. D. Weidemann, 2007. Why does the Secchi disk disappear? An imaging perspective, *Optics Express*, *15*(6): 2791-2801.

Lee, Z.P., K.L. Carder and R. Arnone, 2002. Deriving inherent optical properties from water color: A multi-band quasi-analytical algorithm for optically deep waters, *Applied Optics*, 41: 5755–5772.

Brock, J. C., Wright, C. W., Clayton, T. D., and A. Nayegandhi, 2004. LIDAR optical rugosity of coral reefs in Biscayne National Park, Florida, *Coral Reefs*, 23: 48-59.

LaRocque, P. E., J. R. Banic, A. G. Cunningham, 2004. Design description and field testing of the SHOALS-1000T airborne bathymeter, *Laser Radar Technology and Applications IX*. Ed. Kamerman, Gary W. Proceedings of the SPIE, Volume 5412, pp. 162-184.

Wright, C. W. and J. C. Brock, 2002. EAARL: A lidar for mapping shallow coral ree*fs and other coastal environments*, *In:* Proc 7th Int. Conf Remote Sensing Marine Coastal Environment, 20–22 May 2002, Miami, FL.

Airborne Hydrography AB, 2008. http://www.airbornehydro.com/.

Dickey, T., M. Lewis, G. Chang, 2006. Optical oceanography: recent advances and future directions using global remote sensing and in situ observations, *Reviews of Geophysics*, 44, RG1001.