Volume 35 Number 4
April 2015

Light learn learn Report
ACTA OPTICA

Vol. 35, No. 4
April, 2015

Uncertainty analysis of underwater hyperspectral attenuation measurement

Zhao Liancheng [1] Mao Zhihua [1] Tao Bangyi [1] Chen Peng [1,2] Zhu Qiankun [1]

[1] State Key Laboratory of Satellite Marine Environmental Dynamics, Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, Zhejiang, China

[2] Wuhan University, Wuhan 430072, Hubei, China

The uncertainty of the underwater hyperspectral attenuation measuring instrument (ACS) is studied. Through the Mie scattering theory of standard particles of different sizes (2, 5, 10, 20 μm)

On the comparison between the calculated value and the measured value of the ultraviolet-visible spectrophotometer (PE35), it is concluded that the maximum measurement error of the attenuation of PE35 does not exceed 8%. Against c

In the turbid water environment, ACS and PE35 were used to measure the attenuation of turbid seawater samples in the East China Sea. The results show that: ACS measurement under turbid water

The results are underestimated, and the uncertainty is negatively correlated with the wavelength; the turbidity of the water body has a great influence on the uncertainty of the ACS attenuation measurement, and it is positively correlated.

The measured value of ACS (10 cm) is underestimated by 17.2% ~ 19.04% under high water, and the measured value of ACS (25 cm) is underestimated by 7.84% ~ 15.36% under high turbidity
The underestimation of ACS (10 cm) increased to 26.4% ~ 28.24%.

Keywords marine optics; attenuation coefficient; Mie scattering calculation; uncertainty

CLC number P715.5 Document Identification Code A

doi: 10.3788 / AOS201535.0401004

Analysis of Uncertainties Associated to Underwater Hyperspectral Attenuation Measurements

Zhao Liancheng [1] Mao Zhihua [1] Tao Bangyi [1] Chen Peng [1,2] Zhu Qiankun [1]

[1] *State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, State Oceanic Administration, Hangzhou, Zhejiang* 310012, *China*

[2] *Wuhan University, Wuhan, Hubei* 430072, *China*

Abstract The uncertainty for the underwater hyperspectral measurement of attenuation (ACS) is studied. The attenuation measurements for standard particles of different diameters (2,5,10,20 μm) by ultra violet-visible (UV-Vis) spectrophotometer (PE35) are compared with model values by Mie scattering theory, and the attenuation measurement error of PE35 is found less than 8%. Subsequently, simultaneous atlenuation measurements by ACS and PE35 are carried out for samples from the high turbid water in the East China Sea. Comparative results show the attenuation measurements by ACS are underestimated in high turbid water, and the uncertainty of ACS measurements has a negative correlation with wavelength, conversely, with a strong positive correlation with turbidity of water. The attenuation measurements of ACS (10 cm) and ACS (25 cm) are underestimated within 17.2% ~ 19.04% and 7.84% ~ 15.36% in low turbid water, respectively, while ACS (10 cm) is within 26.4% ~ 28.24% in high turbid water.

Key words oceanic optics; attenuation coefficient; Mie scattering calculation; uncertainty

OCIS codes 010.4450; 120.4640; 280.4788

1 cited Say

The spectral attenuation coefficient $c(\lambda)$ of the water body refers to the attenuation rate of light per unit distance of each wave band in the water body. The light attenuation of natural water is main

The absorption and scattering compositions of dissolved organic matter and suspended particles have the following relationship with the absorption coefficient $a(\lambda)$ and the scattering coefficient $b(\lambda)$: c

In the measurement of the actual optical volume (IOP) of water, due to the lack of accurate experimental measurement methods for $b(\lambda)$ measurement, the direct measurement accuracy is low, which is u

Received date: 2014-09-09; Received revised date: 2014-11-06

Fund Project: National Natural Science Foundation of China (40576080, 41206170), National Major Scientific Research Instruments and Equipment Development Project (2013YQ1034303), Marine Public Welfare Science Technology Research Fund (2010050030), Open Research Fund of the Key Laboratory of State Oceanic Administration for Stereoscopic Monitoring Technology and Application of Ocean Red Lake Disaster (MATHAB201305)

About the author: Zhao Liancheng (1990—), male, master's degree, mainly engaged in the research of aquatic remote sensing. E-mail: zhaolianchengg@163.com

Tutor profile: Mao Zhihua (1966—), male, researcher, doctoral tutor, mainly engaged in the research of marine remote sensing.
E-mail: 1010827619@qq.com (communication contact)

The difference between $c(\lambda)$ and $a(\lambda)$ to estimate the total scattering coefficient $b(\lambda)$ of the water body . Therefore, in the actual research process, the attenuation coefficient $c(\lambda)$ and the absorption c

The radiation coefficient $b(\lambda)$ jointly becomes the radiance *L of the* water body $_{w}(\lambda)$ is the three most basic inherent optical quantities of this important water color remote sensing physical parameter [1-2]. by

Since $a(\lambda)$ and $b(\lambda)$ are both variable functions of the nature of natural water and the concentration of each component, so $c(\lambda)$ comprehensively reflects that light is suspended in water

The degree of influence of particles, soluble organic matter and plankton is a direct indicator of factors such as the transparency of water bodies and the concentration of suspended solids. Many scholars a

The correlation between the attenuation coefficient of natural water and organic particulates, inorganic particulates, chlorophyll and other parameters was studied.

There is a clear correlation between the near-shore turbid water body with high suspended solids concentration and the inland lake [1-8] . Phlips et al. [7] on the coast of Florida, USA

Linear regression analysis of the water attenuation coefficient of the water body and inorganic particles, chlorophyll a and water color found that the correlation between the attenuation coefficient and ino

Very good. Pak et al. [8] found that the particle beam attenuation coefficient c (660 nm) determined by the nature of suspended particles in water has a high correlation with the total particle volume concent

Relevant. Guan Wenjiang et al [9] found that the chlorophyll concentration data and the optical characteristics of pure seawater can be used to calculate the attenuation coefficient of the water body in the ne

Zhang Yunlin et al. [10] found that the increase of suspended solids concentration in Taihu Lake is the main reason for the decrease of the transparency of the water and the increase of the optical attenuation

And establish the power function relationship between the optical attenuation coefficient and the concentration of suspended matter.

At present , the measurement of $c(\lambda)$ can be obtained through laboratory measurement and on-site measurement. The commonly used measuring instrument in the laboratory is a spectrophotomete

After the sample is received by the spectrophotometer optical receiver, the attenuated light contains part of the forward scattered light, so the measurement error of the attenuation coefficient is mainly con

The measurement accuracy of forward scattering is on [11-12] . In order to reduce the measurement error, the receiving angle of the beam receiver should be smaller than the divergence angle of the light sourc

Etc. [13-14] When the attenuation coefficient measured using a spectrophotometer from the sample placed in a position closer to the source, and increasing the distance between the sample and the beam receiv

At the same time, a special slit baffle is placed between the sample and the light receiver to reduce the interference of forward scattering in the transmitted light and improve the measurement accuracy. Sh

Et al. [15] used Bricaud's method to verify the measurement method using standard particulate matter (center particle size 1.999 μm) when measuring the attenuation coefficient of algae

Reliability. Compared with the spectrophotometer, the hyperspectral attenuation measuring instrument (ACS) that can be applied on-site underwater needs to have rigidity with good airtightness

The collimated light path [16] to adapt to high-pressure underwater environment. Underwater 9-band and hyper-spectral absorption attenuation instrument (AC-9 and
ACS) is currently the most widely used underwater attenuation measurement instrument in the marine field. However, the previous analysis of the uncertainty of the instrument measurement is more

There are few studies. It has been considered that the measurement error of AC-9 attenuation is mainly due to the angle of view of the beam receiver (0.9), which is larger than the photon passing through

The distribution angle leads to an underestimation of $c(\lambda)$ [17-19] . Zaneveld et al. [20] proposed a “ratio method” to correct the error. Leymarie

Et al. [21] believed that the increase in the optical path of the photon caused by single and multiple scattering during the photon propagation and the tube wall is also the source of the $c(\lambda)$ measurement err

The Monte Carlo model is used to simulate and analyze the measurement accuracy of ACS. The results show that $c(\lambda)$ in complex water bodies is usually underestimated by 10% to 40%.

Most scholars use the method of numerical simulation to analyze the uncertainty of the measurement of the underwater hyperspectral attenuation instrument, and analyze it with the measured data

And the verification method has not been reported. In recent years, large amounts of underwater high

Spectral attenuation instrument, so it is very necessary to evaluate the uncertainty of ACS measurement in China's highly turbid water.

In order to simulate the influence of particles with different forward scattering intensities on the attenuation measurement of the spectrophotometer, this paper uses 4 different standard particle sizes 5, 10, 20 μm) Mie scattering theory calculated values and measured values to comprehensively evaluate the uncertainty of spectrophotometer measurement. Using ACS-based

A laboratory circulation measurement system and a spectrophotometer were built to simultaneously measure the water samples of the Yangtze River estuary in July 2012, and ACS actual measurements w

The more accurate uncertainty range under the conditions has important reference value for the accuracy evaluation of ACS attenuation measurement in high turbid waters in China.

2 Materials and methods

2.1 Selection of experimental samples

The experimental samples were selected from 4 different sizes of Thermo's Duke Standards ™ Microsphere Size Standards 4000 series, standard

The quasi-particulate matter is mainly composed of polystyrene, and the central particle diameters are 1.999, 4.993, 10.12, and 19.99 μm, respectively, and the central particle diameter distribution conforn

For cloth, the standard errors are 0.022, 0.05, 0.09, and 0.28 μm. Since polystyrene has no absorption characteristics, only the refractive index actual value is considered in the calculation

unit. Pass the particle size and distribution of particles, the number and concentration of particles in the suspension, the refractive index of water and standard particles

The Mie scattering theory can be calculated to calculate its attenuation coefficient at the same concentration (where the calculation code of Mie scattering uses Chiristian
Code published by Mätzler [23]). Comparing the calculated value of the standard particulate matter and the measured value of the spectrophotometer at the same concentration can determine the spectrophot

uncertainty.

The measured samples were selected from the July 2012 Yangtze River estuary seawater samples. After retrieval, they were evenly mixed using a magnetic stirrer. Different turbidity and total suspe

There are 8 groups of samples (number: Sample_a ~ Sample_h) of float concentration (TSM), as shown in Table 1.

Table 1 Seawater samples from the Yangtze Estuary in July 2012

Table 1 Seawater samples of Changjiang River in July 2012

Sample	Sample_a	Sample_b	Sample_c	Sample_d	Sample_e	Sample_f	Sample_g	Sample_h
Turbidity / NTU	twenty three	104.5	265.1	381.3	551.2	662.8	705.4	886.4
TSM / (mg / L)	9.81	53.18	325.65	190.72	424.24	544.35	616.3	660.88

2.2 Measurement of attenuation coefficient by spectrophotometer

The spectrophotometer uses the UV-Vis spectrophotometer PE35 produced by Perkin Elmer, with a wavelength range of 190 ~ 1100 nm, and stray

The light is less than 0.01% T (T is the transmittance), the resolution is 0.1 nm, and the spectral bandwidth is 1 nm. There are many factors that can affect the process of laboratory attenuation measureme

The accuracy of the measurement results, such as the polarization and instability of the light source, stray light, photometric linearity, etc. [23-32] , place the sample close to the light source during measureme

Increase the distance between the sample and the beam detector, and add a special black round baffle to the detector to reduce the impact of forward scattering on the measurement results (connect

The closing angle is reduced to 0.3 °). The measurement uses a 1 cm cuvette, Milli-Q standard pure water as a reference, and the attenuation coefficient is

$$c(\lambda) = \frac{2.303}{l \cdot [D_s(\lambda) - D_t(\lambda)]}, \quad (1)$$

Where l = 1cm is the optical path of the cuvette, $D_s(\lambda)$ is the absorbance of the sample, $D_t(\lambda)$ is the absorbance of Milli-Q standard pure water and blank cuvette. sea

Water samples also use this method to measure their attenuation coefficient.

2.3 ACS measurement of water attenuation coefficient

The underwater hyperspectral absorption attenuation measuring instrument produced by the Wetlab company in the United States is divided into two models according to the length of the measurem
ACS (10 cm) and 25 cm optical path ACS (25 cm). There are 85 spectral channels in the visible band, with a spectral resolution of 4 nm and a measurement accuracy of
0.01 m -1 . Before measuring the sample, the instrument performs pure water correction and temperature and salt correction in sequence, and finally obtains the attenuation coefficient of the water body con

$$c_{\mathrm{m}}(\lambda) = c_{\mathrm{mraw}}(\lambda) - c_{\mathrm{off}}(\lambda), \tag{2}$$

$$c_{\mathrm{m}TS} = c_{\mathrm{m}}[\psi_T(T - T_r) + \psi_S(S - S_r)], \tag{3}$$

Where c is the attenuation coefficient, λ is the wavelength, the subscript mraw represents the original measurement data, m represents the measurement data, off represents the offset of the pure water corre
The reference value is shown, and the subscript m TS indicates the temperature and salt corrected data, T is the temperature, S is the salinity, and ψ_T and ψ_S are the temperature and salinity correction coef
Since the attenuation coefficient of pure water is a constant, this article only compares and analyzes the attenuation coefficients of water components except pure water.

However, the traditional method of using ACS is on-site underwater measurement, and a large number of seawater samples are required in the laboratory according to the underwater measurement r
To increase the difficulty and cost of the measurement experiment, in order to solve this problem, an ACS flow cell measurement system that can be used for laboratory measurement was built.
As shown in Figure 1. Connect the cleaned Teflon water pipes to the ACS (25 cm) and ACS (10 cm) attenuation measurement tubes (hereinafter referred to as the c tube, in order to avoid
The black rubber tube is used at the optical interface), the water pipe on the left side of the ACS instrument is connected to the three-way valve, and the interface is connected to the calibration cylinder, w
Flat surface, used for calibration, the other interface is connected to the peristaltic pump, used for circulating system circulation power, the third interface is connected to the buffer pool, and finally connec
The c tubes of ACS (10 cm) and ACS (25 cm) form a closed loop measurement system. In order to solve the internal influence of the existence of bubbles in the circulation system

Figure 1 ACS laboratory circulation measurement system
Fig.1 ACS laboratory cycle measurement system

The problem of the measurement result shall be sealed at all interfaces. Adjust the peristaltic pump to the proper pressure to make the water in the water pipe flow slowly before the formal measurement
The bubbles in the water are flushed into the buffer tank. If the fluctuation of the curve measured by the ACS is stable within 0.005 m -1 , it is considered that the bubbles in the system have been eliminate
When using, you need to use the Milli-Q water that has been left in the calibration cylinder for one day to remove bubbles. The entire measurement system is slowly filled. After the bubbles are removed, t
The temperature of the water in the pool. After the calibration is completed, turn off the water flow switch of the calibration cylinder to make Milli-Q water flow slowly in the system. When measuring sar
Slowly add seawater samples into the pool and turn on the switch on the side of the buffer pool to allow the pure water to flow out slowly until the seawater samples completely replace the pure water
Ring system (subject to the stability of the curve value within 0.005 m -1), at this time close the buffer tank switch and stop the injection of seawater samples into the buffer tank, record the ACS
The measurement curve and the temperature and salt value at this time are used for data processing, and then take a sample of seawater mixed in the middle of the buffer tank and add it to a 1 cm cuvette.
PE35 is measured. After the measurement of a group of samples is completed, turn on the calibration cylinder switch, use Milli-Q water to flush the system, and start to measure the next group of seawater
sample. In order to ensure the stability of ACS measurement, remove the c tube of ACS for cleaning every 5 sets of data and continue to measure seawater samples after calibration with pure water.

3 Results and analysis

3.1 Evaluation of attenuation measurement accuracy of spectrophotometer

In this paper, the uncertainty of PE35 measurement is analyzed using standard particles with different particle sizes, and the uncertainty is defined as

$$E(\lambda) = \left[\frac{c_{\mathrm{m}}(\lambda) - c_{\mathrm{t}}(\lambda)}{c_{\mathrm{t}}(\lambda)}\right] \times 100\%, \tag{4}$$

Where $c_{\mathrm{m}}(\lambda)$ is the measured attenuation coefficient of PE35, $c_{\mathrm{t}}(\lambda)$ is the calculated value of the sample Mie scattering theory. $E(\lambda)$ is a positive value means that the measured value of PE35 is
Overestimated, negative value means underestimated.

Figure 2 is the comparison curve between the measured value of standard particles with different particle sizes and the calculated value of Mie scattering theory and the uncertainty analysis result of
The line is obtained by normalizing the theoretical calculated value of the standard particulate matter to the measured particle number concentration. In the 400-800 nm band, the PE35 measurement result
The theoretical value of Mie scattering is consistent in the spectral shape, but due to the influence of forward scattering cannot be completely eliminated, the measurement results of PE35 are generally low
The blue error line in the figure shows that the spectral shape of the measurement error fluctuating with the wavelength is consistent with the spectral shape of the calculated value of the standard particula
The difference between the measured value and the calculated value of the standard particulate matter in the peak range is much larger than the range of the valley (when the particle size D = 2 μm, the pea
The fixed degree is about -2%; when the particle size D = 5 μm, the uncertainty of the peak and trough is about -3%; when the particle size D = 10 μm, the uncertainty of the peak and trough is about
-4%; when the particle size D = 10 μm, the uncertainty of peaks and troughs is about -6%). According to the Mie scattering theory, with the increase of the measured spherical particle size

Figure 2 Comparison of the measured value of the attenuation coefficient of the standard particles with different particle sizes and the theoretically calculated value (normalized by the number concentration of the standard particles, t
Fig.2 Comparison of the attenuation coefficient measurements and theoretical calculations of the standard particles with different sizes

(normalized by particle concentration with unit of g / m ⁻¹)

In addition, the forward scattering of the suspension accounts for a larger proportion of the total scattering. Strong forward scattering causes the energy received by the beam receiver of the PE35 to increa
The attenuation value of is reduced, and as the particle size increases, the measurement uncertainty of the spectrophotometer increases, which are about -5%, -6%,
-8%, -10%.

Take the characteristic bands 412, 420, 443, 490, 531, 550, 555, 660, 670, and 678 nm for the calculated and measured values of 4 standard particles
Ratio analysis. The result is shown in Figure 3 (a), the diagonal line is 1: 1, the measured value of PE35 is relatively low relative to the calculated value (approximately true value), and the measured value
The size of the error has no obvious relationship with the band. From the point of view of the attenuation coefficient, the band fitting effect is better at the lower value of the actual measured attenuation co
At the measured high value of the attenuation coefficient.

Figure 3 (b) shows the measurement uncertainty distribution, most of which are within -1% ~ -10%, and some bands are located at -10% ~ -15% (412, 670, 678 nm
Office). Since the particle size distribution and refractive index parameters of spherical standard particles vary by an average of ± 1.1%, the effect on the results can be known from the calculation
The average is ± 0.2%, assuming that the system error caused by humans during the measurement of the instrument has an impact of ± 2% on the results, indicating the uncertainty of PE35
About -8% (when the measured particle size is 20 μm), when the measured particle size is as small as 2 μm, it is about -3%.

Figure 3 Analysis of standard particulate matter in different characteristic bands. (a) Distribution of measured and calculated values of PE35; (b) Uncertainty distribution of measured values of PE35
Fig.3 Analysis of the standard particles with different characteristic bands. (A) Distribution of measurement from PE35 and simulation;

(b) uncertainty distribution of measurement from PE35

3.2 Uncertainty analysis of ACS attenuation measurement

Due to the large sample size required by the ACS laboratory cycle measurement system, it is not suitable to use standard particulate suspensions to analyze its uncertainty. by
The accuracy of PE35 in section 3.1 is known, so the seawater sample is used as the measured sample for synchronous comparison of ACS and spectrophotometer.

Figure 4 shows the comparison results. ACS (25 cm) attenuation coefficient range is 0 ~ 32 m ⁻¹ , ACS (10 cm) range is 0 ~ 80 m ⁻¹ , the part that exceeds the range
Not shown in the figure. It can be seen from Figure 4 that the measured value of ACS in the 400-800 nm band is lower than that of PE35. Possible reasons for analysis are:
Errors caused by human operation during the measurement process; although the c-tube wall of ACS is composed of black light-absorbing material, the tube wall cannot fully absorb the measured sample
Scattered photons; the field of view of the optical path receiver of the ACS is 0.9 °, which causes part of the forward scattered light to be received by the optical receiver.
underestimate.

In low-turbidity water bodies, the measured values of ACS (25 cm) and ACS (10 cm) are slightly different. The measured values of ACS (25 cm) are higher than those of ACS (10 cm)
Slightly higher, closer to the measured value of PE35 (approximately true value), this is because when the divergence angle of the light source is fixed, increasing the optical path can not only make the ph
During the sample propagation, the scattered part is fully absorbed by the black tube wall, and at the same time, the photon receiver receives less forward scattered photons,
Thereby improving the measurement accuracy of c value.

From the analysis of the wave band, the uncertainty of ACS measurement is generally higher than that of the long wave band in the short wave band, which is positively correlated with the wavelen
There is no obvious relationship between the degree of certainty and the wavelength. The turbidity of the water body has a greater influence on the measurement accuracy of ACS. Under low turbidity wat
The value is 10% (± 2%) lower, and as low as 20% (± 2%) under high turbidity water bodies.

Taking 420,443,531,550,660,678 nm characteristic bands to analyze the measured values of ACS and PE35, as can be seen from Figure 5, the low turbidity
Under the water body, the measured value of ACS is closer to the measured value of PE35, but as the value of c increases, the difference between the measured value of ACS and PE35 gradually
Increase. The more turbid the water, the more drastically the accuracy of the ACS measurement will drop. This is mainly due to the strong forward scattering of the particles in the highly turbid water, and

Page 6

Figure 4 Comparison of ACS and PE35 measurement results

Fig.4 Comparison of measurements between ACS and PE35

The receiver received too much energy, and the value of *c* was seriously underestimated. Among them, ACS (25 cm) is saturated when measuring high turbidity, so it appears as shown in Figure 5 (a) at *c* 50 m ⁻¹) The error suddenly increases at 4 points.

From the uncertainty distribution of ACS, the comparison results of ACS (10 cm), ACS (25 cm) and PE35 are shown in Figure 5 (b). The measurement error of ACS varies with the turbidity.

The increase shows a significant increase trend, and its uncertainty is mainly concentrated at -1% ~ -15%, and a small part is at -15% ~ -20% (420 nm and 678 nm).

Tables 2 and 3 give the average relative error of each band of ACS (optical path 25 cm) and ACS (optical path 10 cm), / · indicates that ACS (25 cm) is out of range,
The average relative error of ACS (25 cm) is 4.145%, and the average relative error of ACS (10 cm) is 9.046%. Indicate the measurement of ACS and spectrophotometer

Page 7

The accuracy is within acceptable limits.

Figure 5 (a) Distribution of measured values of ACS and PE35 in different characteristic bands; (b) Comparison of ACS uncertainty and measured values of PE35

Fig. 5 (a) Distribution of measurements from ACS and PE35 with different characteristic bands; (b) comparison between ACS uncertainty and measurements from PE35

Table 2 Relative deviation of the measured value of ACS (25 cm) in the characteristic band

Table 2 Relative deviation of the measurements from ACS (25 cm) on the characteristic bands

Wavelength / nm	Sample_a /%	Sample_b /%	Sample_c /%	Sample_d /%	Sample_e /%	Sample_f /%	Sample_g /%	Sample_h /%
420	10.404	8.637	8.101	/ .	/ .	/ .	/ .	/ .
443	10.011	9.073	6.509	/ .	/ .	/ .	/ .	/ .
531	9.514	8.251	4.094	/ .	/ .	/ .	/ .	/ .
550	9.147	8.074	3.929	/ .	/ .	/ .	/ .	/ .
660	6.526	7.489	2.015	4.184	/ .	/ .	/ .	/ .
678	6.630	7.479	2.018	3.729	/ .	/ .	/ .	/ .
Mean	8.705	8.167	4.455	3.957				
Total mean /%					4.145			

Table 3 Relative deviation of ACS (10 cm) measured value in characteristic band

Table 3 Relative deviation of the measurements from ACS (10 cm) on the characteristic bands

Wavelength / nm	Sample_a /%	Sample_b /%	Sample_c /%	Sample_d /%	Sample_e /%	Sample_f /%	Sample_g /%	Sample_h /%
420	10.204	9.018	8.102	9.843	7.842	12.738	16.427	18.991
443	10.420	8.823	7.742	9.451	7.442	11.844	16.956	16.550
531	10.506	7.555	5.482	7.411	6.172	10.086	14.894	11.445
550	10.271	7.507	5.260	6.979	5.917	9.735	14.554	10.736
660	8.061	6.986	3.567	4.567	4.360	7.374	12.413	6.6840
678	8.261	7.122	3.663	4.428	4.302	7.075	12.170	6.3180
Mean	9.620	7.835	5.636	7.113	6.005	9.808	14.569	11.787
Total mean /%					9.046			

4 knots s

In order to analyze the uncertainty of the underwater hyperspectral attenuation measurement, the measurement value of PE35 is used as a reference, and the measurement system of PE35 and ACS f

The comparative analysis of the step measurement results gives the uncertainty of ACS. Passes 4 standard particles with different particle sizes (center particle size D = 2, 5, 10, 20 m)

The accuracy of the PE35 measurement is verified, and the results show that the PE35 measurement results and the theoretical values calculated by Mie scattering have a better spectral shape.

Consistent, but the measured value of PE 35 is generally low in amplitude. As the particle size increases, the underestimation of PE35 relative to its theoretical value

The increase is about -5%, -6%, -8%, -10%, and the average uncertainty is about -7%. Then through the ACS laboratory flow measurement system and spectrometer

The photometer performed a synchronous comparative measurement of the seawater samples obtained in the East China Sea voyage in July 2012. The measurement of ACS was based on the measured va

The analysis was carried out with certainty, and the results showed that the measured value of ACS at low turbidity was 10% (± 2%) lower than that measured by the spectrophotometer, and it was 20% (± 2%). It was found that in low turbidity water bodies, the measured value of ACS (25cm) is closer to the measured value of PE35 than ACS (10cm) (approximately true

Value), indicating that ACS (25 cm) is more suitable for measurement in low turbidity water bodies than ACS (10 cm), while ACS (10 cm) is suitable for turbid water bodies such as long

Measured in Eguchi.

The uncertainty of ACS can be roughly estimated: the measurement uncertainty of PE35 is about -8%. Under low turbidity water bodies, the measurement of ACS (25 cm) relative to PE35

The relative uncertainty of the quantity is about -6% (± 2%), so the measurement uncertainty of ACS (25 cm) is about -7.84% ~ -15.36%, ACS (10 cm) is relative to PE35

The relative uncertainty of the measurement is about -10% (± 2%), so the measurement uncertainty of ACS (10 cm) is about -17.2% ~ -19.04%; under high turbidity water body ACS
The measurement uncertainty of (10 cm) relative to PE35 is about -20% (± 2%), then the uncertainty of ACS (10 cm) is about -26.4% ~ -28.24%.

references

1 Bricaud A, Morel A. Light attenuation and scattering by phytoplanktonic cells: a theoretical modeling [J]. Applied Optics, 1986, 25 (4): 571-580.

2 Dana DR, Maffione R A. Determining the backward scattering coefficient with fixed- angle backscattering sensors- revisited [J]. Ocean Optics XVI, Santa Fe, New Mexico, 2002, 22 (6): 18-22.

3 Hao Yanling, Cao Wenxi, Ma Yi, *et al* .. Analysis of inherent optical properties in the occurrence and declination of a red tide [J]. Acta Optica Sinica, 2011, 31 (11): 1101004.

Hao Yanling, Cao Wenxi, Ma Yi, et al. Analysis of inherent optical properties of water bodies during the process of red tide generation and dissipation [J]. Acta Optics Sinica, 2011, 31 (11): 1101004.

4 Hao Yanling, Cao Wenxi, Cui Tingwei, *et al* .. The retrieval of oceanic inherent optical properties based on semianalytical algorithm during the red ride [J]. Acta Oceanologica Sinica, 2011, 33 (1): 52-65.

Hao Yanling, Cao Wenxi, Cui Tingwei, et al. Inversion of inherent optical properties of red tide water body based on semi-analytical algorithm [J]. Journal of Oceanography, 2011, 33 (1): 52-65.

5 Mu Bing, Cui Tingwei, Cao Wenxi, *et al* .. A semi-analytical monitoring method during the process of red tide based on optical buoy [J]. Acta Optica Sinica, 2012, 32 (2): 0201001.

Mu Bing, Cui Tingwei, Cao Wenxi, et al. Semi-analytical monitoring method of red tide generation and dissipation process based on optical buoy [J]. Acta Optics Sinica, 2012, 32 (2): 0201001.

6 Wu Tingting, Qiu Zhongfeng, He Yijun, *et al* .. Retrieval algorithms of diffuse attenuation coefficient in the yellow sea, the east China sea and the pearl river estuary [J]. Acta Optica Sinica, 2013, 33 (7): 0701001.

Wu Tingting, Qiu Zhongfeng, He Yijun, et al. Inversion of diffuse attenuation coefficients of water bodies near the Huangdonghai and Pearl River Estuary [J]. Acta Optics Sinica, 2013, 33 (7): 0701001.

7 Phlips E J. Chlorophyll a tripton, color, and light availability in Florida Bay, USA [J]. Mar Ecol Prog Ser, 1995, 12 (7): 223-234.

8 Pak H, Kiefer DA, Kitchen J C. Meridional variations in the concentration of chlorophyll and microparticles in the North Pacific Ocean [J]. Deep Sea Research Part A Oceanographic Research Papers, 1988, 35 (7): 1151-1171.

9 Guan Wenjiang, Qian Weiguo, Chen Xinjun. Computing underwater downward irradiance of fish aggregation lamps in class I ocean water based on Monte Carlo method [J]. Journal of Fisheries of China, 2010, (10): 1595-1604.

Guan Wenjiang, Qian Weiguo, Chen Xinjun. Application of Monte Carlo method to calculate the distribution of downward irradiance of aquatic fish catchers in a class of seawater [J]. Journal of Fisheries, 2010, (10): 1595-1604.

10 Zhang Yunlin, Qin Boqiang, Chen Weimin, *et al* .. Experimental study on underwater light intensity and primary productivity caused by variation of total suspended matter [J]. Advances In Water Science, 2004, 15 (5): 615-620.

Zhang Yunlin, Qin Boqiang, Chen Weimin, et al. Effects of suspended matter concentration on underwater light and primary productivity [J]. Advances in Water Science, 2004, 15 (5): 615-620.

11 Ronald J, Zaneveld V, Bartz R. Beam attenuation and absorption meters [C]. Ocean Optics VII. International Society for Optics and Photonics, 1984: 318-324.

12 Voss KJ, Austin R W. Beam-attenuation measurement error due to small-angle scattering acceptance [J]. Journal of Atmospheric and Oceanic Technology, 1993, 10 (1): 113-121.

13 Bricaud A, Morel A. Light attenuation and scattering by phytoplanktonic cells: a theoretical modeling [J]. Applied Optics, 1986, 25 (4): 571-580.

14 Bradner H. Attenuation of light in clear deep ocean water [C]. Proceedings of the 2nd NESTOR International Workshop, 1992: 247.

15 Shen Yuzhang, Mao Zhihua, Tao Bangyi. Scattering properties of two blooming algae: Skeletonema costatum and Prorocentrum donghaiense [J]. Journal of Marine Sciences, 2013, 31 (1): 45-52.

Shen Yuzhang, Mao Zhihua, Tao Bangyi. Scattering characteristics of Sclerotinia striata and Prorocentrum donghaiensis [J]. Oceanographic Research, 2013, 31 (1): 45-52.

16 Bartz R, Ronald J, Zaneveld V, *et al* .. A transmissometer for profiling and moored observations in water [C]. 22nd Annual Technical Symposium. International Society for Optics and Photonics, 1978: 102-109.

17 Otremba Z, Piskozub J. Modelling the bidirectional reflectance distribution function (BRDF) of seawater polluted by an oil film [J]. Optics Express, 2004, 12 (8): 1671-1676.

18 Jeyendran RS, Vander Ven HH, Perez-Pelaez M, *et al* .. Development of an assay to assess the functional integrity of the human sperm membrane and its relationship to other semen characteristics [J]. Journal of Reproduction and Fertility, 1984, 70 (1): 219-228.

19 Voss KJ, Austin R W. Beam-attenuation measurement error due to small-angle scattering acceptance [J]. Journal of Atmospheric and Oceanic Technology, 1993, 10 (1): 113-121.

20 Zaneveld JRV, Kitchen JC, Moore C C. Scattering error correction of reflecting-tube absorption meters [C]. Ocean Optics XII. International Society for Optics and Photonics, 1994: 44-55.

21 Leymarie E, Doxaran D, Babin M. Uncertainties associated to measurements of inherent optical properties in natural waters [J]. Applied optics, 2010, 49 (28): 5415-5436.

22 Mätzler C. MATLAB Functions for Mie Scattering and Absorption, version 2 [R]. Bern: IAP, 2002.

23 Wegmuller U, Matzler C, Huppi R, *et al* .. Active and passive microwave signature catalog on bare soil (2 ~ 12 GHz) [J]. IEEE Transactions on Geoscience and Remote Sensing, 1994, 32 (3): 698-702.

24 Ni Yi, Huang Meizhen, Yuan Bo, *et al* .. Development and current status of UV- VIS spectrophotometer [J]. Modern Scientific Instruments, 2004, 3: 1-11.

25 Zhu Ying, He Huipeng, Wu Xiaobo, *et al* .. UV-vis spectrophotometer and its application [J]. Chemical Intermediates, 2012, (11): 34-37.

Zhu Ying, He Huipeng, Wu Xiaobo, et al. Ultraviolet-visible spectrophotometer and its application [J]. Chemical Intermediates, 2012, (11): 34-37.

26 Wang Haijun, Ning Xinxia. Recent progress of application of UV- Vis spectrophotometric technique [J]. Physical Testing and Chemical Analysis (Part B: Chemical Analysis), 2012, 48 (6): 740-745.

Wang Haijun, Ning Xinxia. Application progress of ultraviolet-visible spectrophotometry technology [J]. Physical and Chemical Inspection-Chemistry Volume, 2012, 48 (6): 740-745

27 Zhang Zhihong. Error analysis and adjustment of the wavelength of spectrophotometer [J]. Industrial Measurement, 2003, 13 (2): 39-40.

Zhang Zhihong. Analysis of wavelength error and wavelength adjustment of spectrophotometer [J]. Industrial Metrology, 2003, 13 (2): 39-40.

28 Zhong Lexuan. Analysis of the reasons for the error caused by spectrophotometer [J]. Shanghai Coustruction Science and Technology, 2006, (5): 41-42.

Zhong Lexuan. Analysis of the cause of spectrophotometer error [J]. Shanghai Construction Science and Technology, 2006, (5): 41-42.

29 Chen Yunfang. Analysis of spectrophotometer measurement accuracy ofzero error affected by atomic absorption [J]. Hydrology, 2004, 24 (3): 56-57.

Chen Yunfang. Analysis of the Influence of the Zeroing Error of Atomic Absorption Spectrophotometer on Measurement Accuracy [J]. Hydrology, 2004, 24 (3): 56-57.

30 Hong Yinxia. Spectrophotometer [M]. Beijing: Machinery Industry Press, 1982.

Hong Yinxia. Spectrophotometer [M]. Beijing: Machinery Industry Press, 1982.

31 Tang Bin, Wei Biao, Mao Benjiang, *et al* .. Noise analysis and denoising research on the UV-visible absorption spectroscopy water quality detection system [J]. Laser & Optoelectronics Progress, 2014, 51 (4): 043002.

Tang Bin, Wei Biao, Mao Benjiang, et al. Noise analysis and treatment of water quality detection system by ultraviolet-visible absorption spectroscopy [J]. Progress in Laser and Optoelectronics, 2014, 51 (4): 043002.

32 Liu Jia, Huang Haiqing, Bai Yan, *et al* .. Influences of liner polarization light on the measurement of water absorption coefficient [J].

Acta Optica Sinica, 2014, 34 (6): 0601003.

Liu Jia, Huang Haiqing, Bai Yan, et al. Effects of different linearly polarized light on the measurement of water absorption coefficient [J]. Acta Optics Sinica, 2014, 34 (6): 0601003.

33 Moore C, Bruce EJ, Pegau WS, *et al* .. WET labs ac- 9: field calibration protocol, deployment techniques, data processing, and

design improvements [C]. SPIE, 1997, 2963: 725-730.

Column edit: Shi Min