OPTICAL POLARIZED EFFECTS FOR QUANTITATIVE REMOTE SENSING

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ABSTRACT:

Polarization is one of the four basic physical properties of solar radiation. After the solar radiation reaches the surface of these media, it reflects, scatters or refracts, and exhibits different degrees of polarization. We use Rayleigh scattering model to get the simulation results of the sky polarization field. We use polarized fisheye camera to collect the sky polarization image, and calculate the distribution pattern of DOLP (degree of linear polarization) and AOLP (azimuth of linear polarization) of the skylight. The stability and gradual change of the degree of polarization in the zenith direction are verified, and the distribution law and daily change law of the degree of polarization in the sky are obtained. With the increase of the solar altitude angle, the degree of polarization will decrease. We also observed the skylight polarization in different weather conditions.

1. INTRODUCTION

The atmosphere is an important environment element for human beings, and it is an indispensable natural resource. Earth's radiation balance is determined by the combination of aerosols, clouds, atmospheric gases, and surface reflections in the atmosphere (Levy et al., 2005; Kieffer, Stone, 2005). When the solar radiation passes through the atmosphere, it is scattered by the atmospheric particles, which will cause the polarization of light. In general, the primary scattering of atmospheric particles causes the sky polarization to produce a positive value, while the multiple scattering causes the sky polarization to produce a negative value. The intersection of positive and negative polarizations in the sky is zero polarization point. This point is called the atmospheric neutral point (Neutral point), which is the point of zero polarization in the sky (Berry et al., 2004; Yan, et al., 2009). Due to the scattering absorption of incident sunlight by air molecules and aerosol particles, the sky has a relatively stable polarization mode at some point in the day and at a certain position, which is the sky polarization field (Smith, 2007; Yan et al, 2020). In 1809, for the first time, Arago discovered the polarization phenomenon of sky light and found that there is a point in the sky where the degree of polarization is zero, that is, the atmospheric neutral point. In 1870, Strutt (1871) proposed Rayleigh scattering theory, which scientifically explained the polarization phenomenon of sky-scattered light and can more accurately describe the polarization state distribution of scattered light in clear sky.

The human eye can not directly perceive the polarization information of light, but we can create some fast and high-precision polarization measuring instruments (Swindle, Kuhn, 2015), which is one of the hotspots. Because polarization is one of the basic properties of light, which contains many characteristic information of the object under test, polarization detection is a basic measurement method that can not be ignored in the field of optical measurement. G. Horváth et al. proved that the skylight polarization field under cloud, fog and dust weather is similar to that in sunny weather (Pust, Shaw, 2012; Suhai, Horváth, 2004). Nathan J. Pust and Joseph A. Shaw (2008) proved that the degree of polarization of cloudy weather is significantly lower than that of sunny weather due to the influence of multiple scattering, but the distribution of polarization azimuth is almost unchanged. A fully automatic imaging all sky polarized light testing instrument is designed and manufactured. The actual distribution of sky polarization mode in cloudy weather is simulated, and the simulation results are consistent with the test results (Pust, Shaw, 2012). With the continuous development of polarization instruments, polarization measurement is playing an increasingly important role in many fields (Pomozi et al., 2001; Pust et al., 2011; Chu et al., 2017).

2. MATERIALS AND METHODS

In atmospheric polarization measurement, Stokes vector S is usually used to describe the polarization state of polarized beam. Stokes vector $S=[S_1,S_2,S_3,S_4]^T$ can be expressed as another form $S=[I,Q,U,V]^T$, where I is the total intensity of light, Q and U are linearly polarized light in two orthogonal directions, and V is circularly polarized light. In atmospheric polarization measurement, circular polarized light V is usually ignored because linear polarized light is the most common type of polarization in nature. Stokes vector represents the polarization state of the light, while Mueller matrix represents the process of the polarization device changing the Stokes vector of the incident light. If the Stokes vector of the

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incident light is S and the Mueller matrix of the linear polarization device is T, then the Stokes vector of the outgoing light $S^{'}=[I^{'},Q^{'},U^{'},V^{'}]^{T}$ can be obtained by linear transformation S'=T S:

$$S'=\begin{bmatrix} I' \\ Q' \\ U' \\ V' \end{bmatrix}=\begin{bmatrix} t_{00} & t_{01} & t_{02} & t_{03} \\ t_{10} & t_{11} & t_{12} & t_{13} \\ t_{20} & t_{21} & t_{22} & t_{23} \\ t_{30} & t_{31} & t_{32} & t_{33} \end{bmatrix} \tag{1}$$

The Mueller Matrix of the ideal optical detection system is as follows:

$$T=\frac{1}{2}\begin{bmatrix} 1 & \cos 2\alpha & \sin 2\alpha & 0 \\ \cos 2\alpha & \cos^2 2\alpha & \cos 2\alpha \sin 2\alpha & 0 \\ \sin 2\alpha & \cos 2\alpha \sin 2\alpha & \sin^2 2\alpha & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{2}$$

Where α is the angle between the preferred transmission plane and the reference plane of the linear polarizer.
In the new Stokes vector S', the first row is used to represent the intensity of the outgoing light passing through the optical system. If I' is expressed as a function of α, the intensity of the outgoing light is as follows:

$$I'(\alpha)=\frac{1}{2}(I+Q\cos 2\alpha+U\sin 2\alpha) \tag{3}$$

According to formulas (2) and (3), if the light intensity values at three different α positions are known, then the parameters of Stokes vector, DOLP and AOLP, can be calculated.

$$DOLP=\frac{\sqrt{Q^2+U^2}}{I} \tag{4}$$

$$AOLP=\frac{1}{2}\arctan(\frac{U}{Q}) \tag{5}$$

The experimental instruments are Nikon D200 digital camera, fish eye lens, optical polarizer, and tripod for photography. We use the digital compass and leveling instruments to find the north direction and adjust the tripod platform to the horizontal position. Install the digital camera on the tripod, install the fisheye lens on the digital camera, and then install the optical polarizer on the top of the fisheye lens. By using the scale around the polarizer, the rotation angle of the polarizer can be obtained, which can be marked as 0 degree, 60 degree and 120 degree. For each acquisition, the polarizer was rotated at 0 degree, 60 degree and 120 degree respectively, and three all-sky images with different polarizing angles at that time were obtained. Every 10 minutes or 30 minutes, we collected experimental data of whole sky, and observed the distribution of sky polarized light in Peking University, Haidian District, Beijing.

Figure 1. Fish eye camera for polarization observation

3. RESULTS

3.1 Skylight polarization in clear weather

The experimental site was the platform on the top floor of Remote Sensing Building, School of Earth and Space Science, Peking University , (116.2345°E,39.9953°N) . The experiment was from 9:00 a.m. to 16:00 p.m. on March 13, 2019. The sky was clear, and the air quality index is excellent. Because the lens was upward to the zenith, the top of the image corresponds to the south direction of the geography, the bottom of the image corresponding to the north direction, the left corresponding to the west direction, and the right corresponding to the east direction, which is slightly different from the ordinary map. We transformed the RGB information of color image into gray information, and calculate Stokes component I, Q, U, DOLP and AOLP according to the formulas.

Fig.2. shows the change of sky polarization information in the whole day. We can see the change rule of Stokes components I, Q and U. The light intensity I is largest at the solar spot, and sharply decreases towards the surrounding. Q component and U component are all zero at the position of the sun, which is an isolated point, and both components have the symmetrical axis with the minimum value. As shown in the blue strip in the figure, with the movement of the sun, the symmetrical axis rotates against the direction of the sun's motion, and the minimum value of the symmetrical axis of the two components is nearly perpendicular to each other, especially at 10:00-15:00, because Q and U are the line polarized light in two orthogonal directions.

Fig.3. shows the simulation results of the degree of polarization based on the Rayleigh scattering model and the results of the degree of polarization and the angle of polarization obtained from the actual observation experiment. The maximum zenith angle in Rayleigh model is 60 degrees because the field angle of fish eye camera is about 120 degrees. For the distribution of the degree of polarization, the simulation results are almost the same as the actual results, because the experimental conditions are ideal sunny, and the air scattering was mainly Rayleigh scattering.

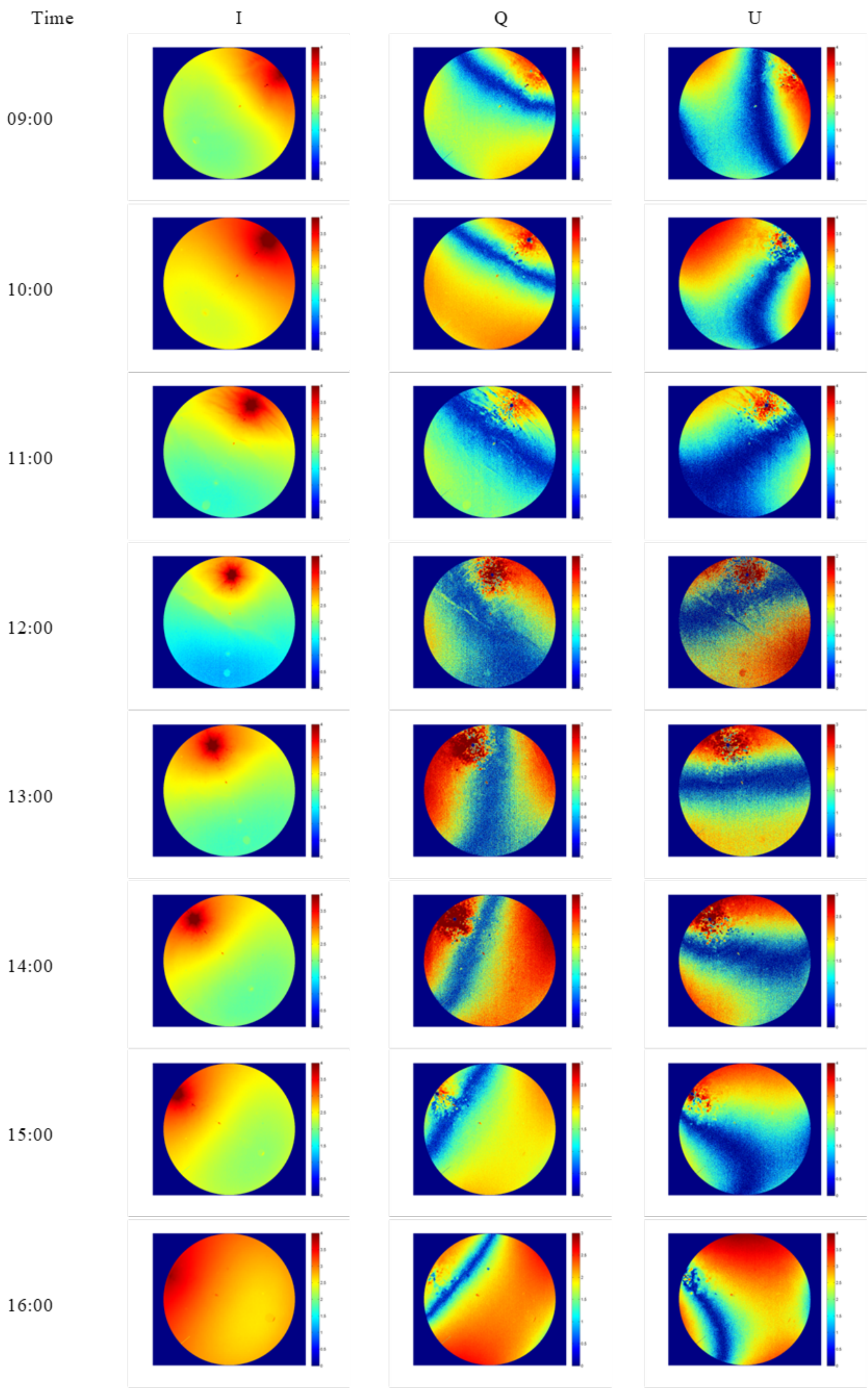


Figure 2. Daily variation of Stokes component of skylight (March 13, 2019, Peking University)

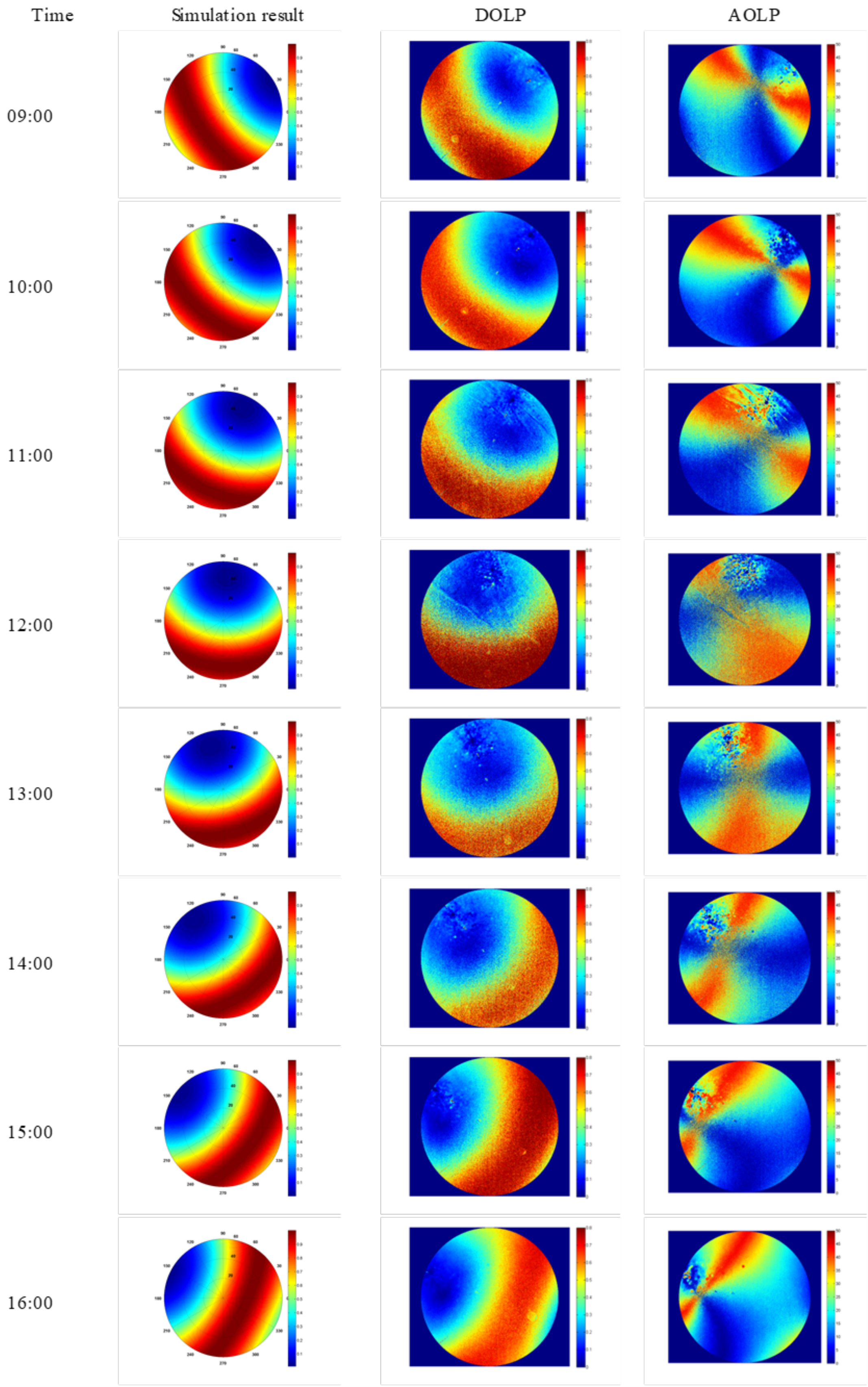


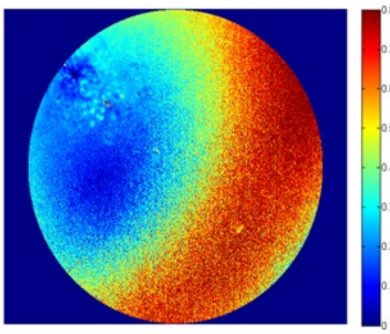
Figure 3. Daily variation of DOLP and AOLP of skylight (March 13, 2019, Peking University)

Rayleigh model can accurately represent the degree of polarization distribution in sunny days, which proves the accuracy of the sun position calculation method and the degree of polarization calculation method. It can be seen from the experimental results that the degree of linear polarization in the whole sky decreases with the increase of the solar altitude angle, and the position of the atmospheric neutral point is related to the position of the sun. The linear degree of polarization presents an obvious circular distribution, which is often called halo phenomenon.

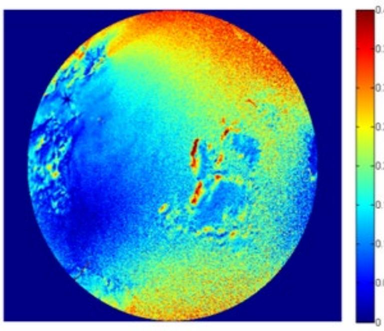
When the solar altitude angle is low, such as at 9:00 a.m. and 16:00 p.m., the double aperture effect is more obvious. The degree of polarization of the sun incident direction is the smallest, which is the neutral point of the atmosphere. The degree of polarization of the center to the surrounding area gradually increases, and the degree of polarization perpendicular to the sun incident direction reaches the maximum, and then begins to decrease. This is because there is a neutral point near the sun, and there is also a neutral point on the anti-sun side, that is, Babinet point and Arago point. The interaction of the two points results in a double aperture effect.

3.2 Skylight polarization in different weather conditions

Because the atmospheric particles will affect the scattering of skylight, they can affect the distribution of polarized light in the sky. In order to compare the skylight polarization field in different weather conditions, we used polarized fish eye camera to take two images on March 13 (sunny day, cloudless) and April 2 (with a small amount of clouds) in 2019 (Fig. 4).



a. Polarization field in clear sky (3.13, 14:00)



b. Polarization field in cloudy sky (4.2, 14:30)

Figure 4. Skylight polarization in different weather conditions

We can see that, compared with clear sky one, the presence of clouds reduce the DOLP of skylight significantly, which is due to the depolarization effect caused by multiple scattering of the atmosphere due to the presence of clouds. As far as the total light intensity is concerned, the presence of clouds has changed the distribution of the total light intensity in the sky, and the halo centered on the sun has become blurred and interlaced, or even completely disappeared.

4. CONCLUSION

From the image of polarization angle in a clear sky, it can be seen that the concentration point of polarization angle is the position of atmospheric polarization neutral point. The position and shape of the polarization angle distribution are different with different solar height angles. It can be found that with the change of the position of the sun, the convergence point of the polarization angle of the whole sky revolves around the zenith. When the solar altitude angle is high, we can only observe one convergence point of the sky polarization angle, and we can only see one convergence point for most of the day. Only when the solar altitude angle is low, such as the image at about 16:00 p.m., can we observe another convergence point.

In cloudy weather, the clouds cut off the complete polarization ring, however, the change trend of polarization can still be seen, and the neutral point area of the atmosphere in the sky is still obvious. In sunny days, the value of sky polarization is large, and the circular distribution is relatively complete; in cloudy conditions, the value of sky polarization is small, and the circular distribution is irregular.

The experimental results of the two weather conditions are in accordance with the theoretical law, and the experimental data are available. But clouds interfere with the sky's polarization pattern. In order to ensure the accuracy of navigation, the sky polarization mode should be measured in sunny and cloudless conditions.

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