Comparison of Cloud Cover from All-Sky Imager and Meteorological Observer

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ABSTRACT

Naked-eye observation of cloud cover has widely resisted automation. Replacement of human observation by instruments is an inexorable trend for the development of ground-based macroscopic cloud observation. In this paper, cloud covers from an all-sky imager (ASI) are compared with those from a meteorological observer (MO) through field experiments performed at three sites in China. The correlation coefficient between ASI and MO is 0.77 for all cases. The ASI cloud fractions have great agreement with MO for clear sky, overcast sky, and sky loaded with low- and middle-level clouds. About 78% of the ASI cases had deviations between ±1 tenth compared to MO cloud cover. High-level cloud (or aerosol) is the main reason causing this difference. It is partially due to MO, who takes aerosol as high, thin cloud. Another reason might be that ASI made a wrong estimation for high-level cloud (or aerosol) because of its detector and the cloud-determination algorithm. Distinguishing high, thin cloud from aerosol is a challenge, and is the main problem that needs to be resolved for future developments of ASI. A new, improved method is discussed at the end of this paper.

1. Introduction

Observation of cloud cover by humans has a long history (Barrett and Grant 1979; McGuffie and Henderson-Sellers 1989; Min et al. 2008). At present, there are many advanced technologies and instruments applied for cloud detection, such as lidar and satellites. However, ground-based macroscopic cloud observations are now still mainly dependent on meteorological observers (MOs) at worldwide normal meteorological observation stations. MO cloud covers are often regarded as standards for examining the accuracy of other cloud covers, for instance, cloud measured by satellites (Dürr and Philipona 2004; Rossow et al. 1993). However, cloud covers reported by humans are somewhat subjective because they are estimated by the eyes and brain. They are also very costly in terms of human resources and even are unavailable for sparsely populated locations. Development of an automatic observing instrument is necessary and urgent for ground-based macroscopic cloud observation. The all-sky (whole, total, or hemispheric) imager is just such a potential instrument that can replace MO for ground-based macroscopic cloud observation.

Currently, several different types of all-sky imagers, for example, the whole-sky imager (WSI), developed by the University of California, as well as the total-sky imager (TSI), produced by Yankee Co., have been made (Pfister et al. 2003; Long et al. 2006; Heinle et al. 2010). Both WSI and TSI have been applied in the Atmospheric Radiation Measurement (ARM) Program for cloud observation (http://www.arm.org). Other countries, including Japan, Spain, and China, have also developed similar types of imagers. These imagers all have nearly the same working principles that a digital camera has to capture images of the hemispheric sky, and the retrieval algorithm for cloud cover estimation and type classification (Kubota et al. 2003; Kassianov et al. 2005; Calbó and Sabburg 2008; Huo and Lu 2009).

Human observations have collected lots of cloud cover data. These cloud covers are still applied into meteorological research and cannot be tested entirely due to a lack of absolutely exactly comparable data. From a climatological point of view, for the continuation of cloud cover observation and the link between all-sky imager (ASI; or other imagers) and MO, comparison between ASI and MO is a necessary step for the development of ground-based macroscopic cloud observation. This paper investigates differences between ASI
and MO through field experiments at three different climate characteristics sites. This paper presents the current working level of the ASI and MO, as well as suggestions for future improvements of ASI.

2. Data

a. All-sky imager

ASI (see Fig. 1) is developed by the Institute of Atmospheric Physics, Chinese Academy of Sciences (Lu et al. 2001). It uses a digital camera equipped with a fisheye lens to capture all-sky images (JPEG format and 2272 × 1704 resolution). ASI also has a device to obscure direct solar incidence in order to protect its charge-coupled device (CCD) sensor from damage. ASI observes from sunrise to sunset every 3 min daily.

Cloud cover (also known as cloud fraction or cloud amount) refers to the fraction of the sky obscured by clouds. ASI determines each cloudy pixel by comparing the gray ratio of red to blue channels with a predefined threshold, which is achieved by analyzing the features based on Fourier transform and the symmetrical features (Huo and Lu 2009). Then, the ratio of numbers of pixels labeled as cloudiness (Nc) versus the numbers of all-sky pixels (Na) is the ASI cloud cover, rounded off to the hundredths place. The final ASI cloud cover is recorded as the value of that ratio multiplied by 10 to be consistent with the observer’s record; for instance, a ratio of 0.10 is recorded as 1.0 tenth cloud cover (0.25 is recorded as 2.5 tenths). To remove pixels containing buildings, trees, and clutter etc. from different locations, the algorithm selects pixels with evaluation angles > 5° and angles relative to the solar center > 10° to obtain the number of whole sky pixels (Na). The cloud cover estimation algorithms used for the three sites are the same.

b. Meteorological observer

In this paper, all MO cloud covers are recorded by professional meteorological observers on duty who are employees of each observatory. These observers, who are experienced and skilled, have worked on cloud observation for more than 5 yr. The cloud covers they reported are the same data sent to their superior departments for restoration and filling. Therefore, MO cloud covers used in this paper are of guaranteed quality and they represent the average measurement level of China. MO cloud cover is defined as the proportion of cloudiness obstructing the sky excluding obstacles at the surface, such as buildings, trees, etc. For clear skies, cloud cover is 0. When the proportion is <5%, cloud cover is also set as 0. For overcast skies, cloud cover is 10 tenths (100%); for a value of (5–10)%, cloud cover is given a value of 1 tenth; for a value of (15–20)%, cloud cover is equal to 2 tenths, etc. (China Meteorological Administration 2003).
c. Other cloud instruments

1) SIRIS

The Scanning Infrared Imaging System (SIRIS), also developed by the Institute of Atmospheric Physics, measures thermal brightness temperatures of all sky in the infrared wave band (8–12 μm) by scanning (Zhang et al. 2007). It extracts cloud characteristics (like cloud cover and cloud-base height) by analyzing the difference of thermal infrared brightness temperature between cloudy and cloudless sky. Theoretically, an instrument working on the thermal infrared channel will show better ability than that using the visible channel in discriminating cloud from heavy aerosol and fog because scattering radiation by cloud, aerosol, and fog is somewhat independent of wavelength while they have different brightness temperatures. At Beijing Observatory, ASI worked together with SIRIS simultaneously. Cloud cover retrieved from SIRIS can be used to validate and test cloud covers from ASI and MO.

2) WACR

The W-band ARM Cloud Radar (WACR) systems are zenith-pointing Doppler radars that probe the extent and composition of clouds at 95.04 GHz. It works by transmitting a pulse of millimeter-wave energy and receiving the return signals (reflected by objects, i.e., cloud). It operates in co-polarization and cross-polarization modes and can estimate cloud boundaries (e.g., cloud bottoms and tops). WACR can penetrate into cloud and is relatively powerful for detecting most clouds, including several layers of cloud and high-level clouds (Clothiaux et al. 1995).

3) MPL

The physical principle of the ARM micropulse lidar (MPL; at 523-nm wavelength) is somewhat similar to radar (Campbell et al. 2002). Energy transmitted into the atmosphere is scattered back (by cloud) to the transceiver, and then is collected and measured as a time-resolved signal. From the time delay between each outgoing transmitted pulse and the backscattered signal, the distance to the scatterer (i.e., the altitude of clouds overhead) is inferred. MPL is mainly used to detect cloud-base height. The accuracy will be affected by aerosol below cloud because the signal wavelength is 523 nm.

Though WACR and MPL cannot estimate cloud cover directly, they help to identify whether there is cloudiness overhead. At Shouxian Observatory, WACR and MPL worked simultaneously during our comparison experiment. The data from both are used as reference for cloud identification when MO and ASI have conflicts.

3. Field experiment

Our comparison experiments were performed at the following three stations: Shouxian National Climatic Observatory of Anhui Province, Beijing Observatory of Beijing, and Yangjiang Observatory of Guangdong Province (see Fig. 1). The three sites have obvious different cloud, aerosol, and climate characteristics and show typical climate characteristics of China.

ASI has a nearly the same working principles as that of MO on cloud cover estimation, but their data are not completely identical for their different working manner. ASI captures all-sky images in a very short time by using a fish-eye lens, whereas MO will take more times to browse the whole sky by scanning and estimating cloud cover with eyesight. Thus, their working time and the observing objects (cloud) are not entirely identical. Moreover, ASI cannot simulate all psychological and physiological features of MO; for instance, mapping and processing modes are different between fish-eye lenses and human eyes. Therefore, it is a complicated problem to make a complete comparison between ASI and MO because these factors are hard to quantify, and they are also random and related to cloud types, cloud distributions, and sky conditions. The paper will just use MO and ASI cloud cover data directly to analyze and understand their differences under current conditions, and will not consider these factors, namely, we will regard them as the same.

According to national meteorological observing standards (China Meteorological Administration 2003), an observer should finish recording cloud cover, cloud type, visibility, and weather phenomena in 15 min before every hour on the hour. In practice, most MO cloud cover is not reported right on the hour but somewhat ahead of it. As a result, ASI cloud cover monitored on the hour or somewhat before is chosen for comparison.

In this paper, the following seven quantities are counted: 1) the number of all time-matched cases of each site from MO and ASI, 2) the number of cases whose ratio of the absolute error versus MO cloud cover are ≤20% (in this paper, “error” is defined as ASI cloud cover minus MO cloud cover), 3) the number of cases whose errors are between ±1 tenth, 4) the number of cases whose errors are within ±2 tenths, 5) the mean error (ME), 6) the standard deviation (std), and 7) the Pearson correlation coefficients between ASI and MO (CC). Additionally, four different conditions are classified for comparison: 1) all time-matched cases from MO and ASI; 2) the cases where the ratio of low- plus middle-level MO cloud cover versus total MO cloud cover is ≥70% (described as the “low group”), 3) the cases where the ratio of low- plus middle-level MO
cloud cover versus total MO cloud cover is \(\leq 30\%\) (including cases that ASI cloud cover is zero, described as the “high group”), and 4) cases where visibility is \(> 10\) km (from MO reports).

a. Site 1: Shouxian National Climate Observatory

Shouxian National Climate Observatory (32.57°N, 116.78°E) has a subtropical monsoon climate and is located in Anhui Province, a south–north climate transition zone of China. An ASI was installed at this site and worked from 1 December 2008 to 31 December 2008 (31 days), with more Ac and Ci clouds. The CIMEL aerosol data showed that the mean aerosol optical depth is 0.51 during the experiment. During this “winter” period, the ARM Mobile Facility (AMF) was performing observations at the same time at this station. The WACR and MPL supported third-party cloudiness data, allowing for a more detailed comparison between ASI and MO.

The 299 available ASI cloud covers were matched individually to MO data for the same date and times at this station (299 pairs). Table 1 showed comparison results of this site. On the whole, ASI showed good agreement with MO. The CC between ASI and MO was 0.854. Error for 79.9% of the cases was within \(0.1\) tenth and for 85.3% of the cases was between \(0.2\) tenths. Quantities including ME, standard deviation, and CC showed a better agreement for low-group cases, while they got worse for high-group cases. High-level cloud might be an important source generating differences. In addition, for cases whose visibility was greater than 10 km, the CC was 0.843, which was even less than the CC of all cases, and meant that lower visibility might not be the main cause of the difference.

b. Site 2: Beijing Observatory

Beijing Observatory (39.8°N, 116.47°E) is located in south of Beijing and has a temperate subhumid continental monsoon climate. The comparison experiments were performed from 1 May 2009 to 31 October 2009 (from summer to autumn). According to the observer’s report, frequency of occurrence of dense Ci, Sc, Ac, and Cu clouds is the greatest. There were 1918 pairs of cases matched for comparison during 6 months. The CC between ASI and MO for all cases, which was lower than that at the Shouxian site, was 0.762 (see Table 2). However, comparison results also showed good agreement for low groups.

At this site, more high-level clouds were reported by MO and they likely bring more differences. Figure 2 showed the shape of the difference distribution of all cases (solid) and cases excluding high-level clouds (dashed). For all cases, there was a large population of near-zero difference in cloud cover. Around 61.6% of the cases had errors that were within \(0.5\) tenth and around 70.7% had errors that were within \(1\) tenth in cloud covers. However, for cases excluding high-level clouds (about 47.7% of all cases), error obviously decreased. CC was 0.9 and an error of around 83.8% of the cases was between \(0.5\) tenth and about 87.5% of the cases was within \(1\) tenth. Thus, different cloud cover estimation between MO and ASI mostly occurred on high-level clouds; conversely, these high-level clouds might be aerosol.

It is well-known that aerosol suspended in the atmosphere will scatter and absorb incident radiation and change the spectral distribution of radiance. Aerosol helps to decide how white tinted the “blue” of the sky will appear, and the cloudless sky will look whiter when there are more aerosols in the atmosphere. Therefore, skies with more aerosols and the skies containing high, thin clouds (high-level cloud) are somewhat difficult to distinguish clearly both for MO and ASI. With development and expansion of Beijing, the Beijing Observatory is now very near the south fifth circular road.

### Table 1. Comparison of cloud cover between ASI and MO at Shouxian National Climate Observatory (proportion of cases suitable for conditions vs all matched cases is shown in parentheses).

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>≤(20%)</th>
<th>≥(1)</th>
<th>≥(2)</th>
<th>ME</th>
<th>Std</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>299 (100)</td>
<td>243 (81.3)</td>
<td>239 (79.9)</td>
<td>255 (85.3)</td>
<td>−0.32</td>
<td>2.52</td>
<td>0.854</td>
</tr>
<tr>
<td>Low group</td>
<td>165 (55.2)</td>
<td>149 (90.3)</td>
<td>149 (90.9)</td>
<td>150 (91.5)</td>
<td>0.6</td>
<td>1.98</td>
<td>0.892</td>
</tr>
<tr>
<td>High group</td>
<td>127 (42.5)</td>
<td>88 (69.3)</td>
<td>83 (65.4)</td>
<td>98 (77.2)</td>
<td>−1.46</td>
<td>2.63</td>
<td>0.571</td>
</tr>
<tr>
<td>Vis ≥ 10 km</td>
<td>232 (77.6)</td>
<td>188 (81.0)</td>
<td>185 (79.7)</td>
<td>198 (85.3)</td>
<td>−0.45</td>
<td>2.49</td>
<td>0.843</td>
</tr>
</tbody>
</table>

### Table 2. As in Table 1, but for Beijing Observatory.

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>≤(20%)</th>
<th>≥(1)</th>
<th>≥(2)</th>
<th>ME</th>
<th>Std</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>1918 (100)</td>
<td>1289 (67.2)</td>
<td>1279 (66.7)</td>
<td>1460 (76.1)</td>
<td>−0.13</td>
<td>2.90</td>
<td>0.762</td>
</tr>
<tr>
<td>Low group</td>
<td>732 (38.2)</td>
<td>570 (77.9)</td>
<td>593 (81.1)</td>
<td>617 (84.3)</td>
<td>0.90</td>
<td>2.47</td>
<td>0.863</td>
</tr>
<tr>
<td>High group</td>
<td>1025 (53.4)</td>
<td>578 (56.4)</td>
<td>551 (53.8)</td>
<td>699 (68.2)</td>
<td>−0.87</td>
<td>3.1</td>
<td>0.645</td>
</tr>
<tr>
<td>Vis ≥ 10 km</td>
<td>1389 (72.4)</td>
<td>851 (61.3)</td>
<td>852 (61.3)</td>
<td>1008 (72.6)</td>
<td>−0.33</td>
<td>3.06</td>
<td>0.748</td>
</tr>
</tbody>
</table>
with great traffic, where a large volume of aerosol from car exhaust is released into the atmosphere. The average aerosol optical depth of this site is larger than 0.6 during the experiment period (Yan and Liu 2009; Guan and Li 2010). Aerosol will increase errors on cloud cover estimation, which can be seen from the comparison between the Beijing Station and Shouxian Observatory.

c. Site 3: Yangjiang Observatory

Yangjiang Observatory (21.83°N, 111.97°E) is a coastal site with a subtropical climate. The comparison experiment was from 6 July 2010 to 15 August 2010 (41 days) in wet summer with higher rainfall. During the experiment, skies containing several layers of cloud were frequent. Table 3 showed comparison results of this site. The correlation coefficient between ASI and MO was 0.698. An error of about 65.2% of the cases was within ±2 tenths. Similarly to other two sites, CC increased while ME and standard deviation decreased for low-group cases. If high, thin cloud and low, thick cloud exist in the sky simultaneously and part of them overlapped, then we found that the ASI cloud-determination algorithm was hard to distinguish entirely because the cloud-determination threshold was based on the image itself and the algorithm normally regarded very thin cloud as clear sky. Distinguishing high-level cloud from clear sky with complicated cloud distribution is a challenge for the ASI algorithm. New approaches, for example, point-to-point contrast with a real clear-sky image, might be helpful for future improvement.

4. Further comparison of high-level cloud cover

Comparisons above showed that high-level clouds were likely to be treated differently by MO and ASI. Results of Yangjiang Observatory indicated that ASI would underestimate cloud cover for skies with complicated cloud distribution because of the algorithm. However, ASI was not always wrong when differences emerge. We made a further analysis for high-level clouds using data from the Beijing Observatory. One-hundred and ninety-one cases were chosen to be compared with thermal infrared SIRIS data (high-level clouds were reported by MO, while ASI “thought” no cloud existed). These cloud covers from MO and SIRIS were shown in Fig. 3. The number of cases in which cloud cover was greater than 3 tenths as reported by MO was 147, but most SIRIS cloud covers (about 66.5%) were equal to zero, and most cases (about 170) were less than 2 tenths. Though SIRIS has the limitation of detecting very thin cloud, some MO cloud covers might be suspicious because neither ASI nor SIRIS find these high-level clouds. MOs overestimated cloud cover likely because the aerosol suspended in the sky at Beijing Observatory will affect the judgments on high-level clouds (another proof case is discussed in the next paragraph), especially for areas near the sun. The current ASI algorithm also showed limits in high-level cloud detection. One reason might be that the sensor was not sensitive enough to capture and record very thin clouds, because sometimes our naked eyes were unable to find them from the images (the high, thin clouds that “existed” were observed by MO). Another reason was that the cloud-determination algorithm omitted some high-level clouds pixels existed in images, especially pixels surrounding the sun and near the horizon.

At the Shouxian site, data from MPL and WACR showed us other information on whether high-level clouds existed. Figure 4 illustrated the evolution of cloud cover from 0800 to 1700 local time (LT) on 7 December, a no-fog day with a mean of 12-km visibility. The upper panel in Fig. 4 showed the altitude level of cloud overhead from WACR, the middle panel was obtained from MPL, and

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**Table 3.** As in Table 1, but for Yangjiang Observatory.

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>≤20%</th>
<th>≤1</th>
<th>≤2</th>
<th>ME</th>
<th>Std</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>417 (100)</td>
<td>225 (53.9)</td>
<td>187 (44.8)</td>
<td>272 (65.2)</td>
<td>-1.71</td>
<td>2.18</td>
<td>0.698</td>
</tr>
<tr>
<td>Low group</td>
<td>186 (44.6)</td>
<td>130 (69.9)</td>
<td>117 (62.9)</td>
<td>163 (87.6)</td>
<td>-0.73</td>
<td>1.27</td>
<td>0.89</td>
</tr>
<tr>
<td>High group</td>
<td>60 (14.4)</td>
<td>17 (28.3)</td>
<td>15 (25)</td>
<td>20 (33.3)</td>
<td>-3.42</td>
<td>3.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Vis ≥ 10 km</td>
<td>410 (98.3)</td>
<td>221 (53.9)</td>
<td>183 (44.6)</td>
<td>268 (65.4)</td>
<td>-1.69</td>
<td>2.16</td>
<td>0.692</td>
</tr>
</tbody>
</table>
the lower panel showed cloud cover plots reported by MO (red dot) and ASI (black square). The lower panel also included several all-sky images that were taken at every hour on the hour. According to MO records shown in the lower panel, cloud covers were all 10 tenths (overcast) during the 9 h from 0800 to 1700 LT. The reported cloud types were dense Ci and transparent Ac. However, WACR, MPL, and ASI showed different situations. From around 0930 LT, both MPL and WACR showed that there was no cloud overhead at this time, and it lasted over half an hour. ASI image at 1000 LT also showed that there was no cloud in the sky. It can be inferred that MO mistook sky as cloud, at least, at this moment. From temporal series of all-sky images (from 0800 to 1600 LT), we could see the distribution and evolution of cloud during this period. It was a part-time part-cloud covered day, and cloud cover during this period changed with time. However, MO’s records of this day showed that the sky was almost overcast all of the time. From Fig. 4, it can be seen that MO also overestimated cloud cover at other times (i.e., at 0900, 1100, and 1600 LT) by contrasting with MPL, WACR, and ASI. The case in Fig. 4 is a detailed example of this. In fact, several other cases like it also occurred at this site. Those comparison cases from sites 1 and 3 shown above reveal that MOs also will make mistakes in high-level cloud recognition, and will even sometimes show us incorrect information, especially in situations when more aerosol are present.

5. Improved method in determining high-level cloud

Light scattered by cloud and aerosol is not closely related with wavelength, so it is difficult to discriminate them only by the blue/red ratio threshold. Researches above have demonstrated this. Fortunately, in general, the distribution of cloud is uneven while aerosol is relatively uniform. Using the different distribution characteristics and the numerical simulation, we found two useful approaches for improving the capabilities of high cloud detection: the monotonically increasing method on the solar principal plane, as well as the square-symmetrical method.

a. Monotonically increasing method on the solar principal plane

Applying the Library for Radiative Transfer (LIBRADTRAN) model, we simulated the radiance on the solar principal plane under different aerosol optical depths with urban and rural aerosol types. Some typical simulation results are shown in Fig. 5. It can be seen that there is a common feature on the solar principal plane that radiance increases from the antisolar point to the solar center monotonically whatever the aerosol optical depth. The monotonically increasing feature will be upset when cloud existed on the main planes. Thus, using this monotonically increasing characteristic of the solar principal plane, we can predict whether cloud exists on the solar principal plane. This method supports the determination algorithm cloud information when choosing the best blue/red ratio threshold and helps to “find” high, thin clouds.

b. Square symmetrical method

The radiative transfer equation indicates that the radiation distribution of the sky is symmetric and the solar principal plane is on the axis of symmetry. And the square-symmetrical method is based on this. Assuming that distribution of aerosol in a cloudless sky is uniform,
then each pixel in the all-sky imager has a symmetrical pixel. Of course, a square containing $256 \times 256$ pixels is symmetrical square (see white and green square on Fig. 6c,f). Through comparing their gray and blue/red ratio distribution [by fast Fourier transform (FFT)] and calculating the correlation coefficient, it helps to identify whether cloudy pixels exist in the square and then choose the right threshold for this area.

Figure 6 shows two examples and their different appearance of solar principal plane and symmetry. Figure 6a is a cloudless image with heavy aerosol. Figure 6d is a high-level cloud image also loaded with heavy aerosol. The gray of the pixels on the solar principal plane of each image are also present (see Figs. 6b,e). The curve from cloudless image increased monotonically and smoothly while another (Fig. 6e) fluctuated and increased, which illustrates that cloud existed in the all-sky image. Figures 6c,f are gray-contoured images rearranged from an original image by zenith angle and azimuth. The symmetrical character can be seen clearly from Fig. 6c. However, for the cloudy sky image (Fig. 6f), the discrepancy between cloud and aerosol can be seen and calculated in the two symmetrical squares. Additionally, the gray and ratio of blue/red of real cloud pixels also can be found. Using the discrepancy and the gray and ratio values of real cloud pixels, a new cloud-determination method hopes to improve the ability in cloud discrimination. Relatively, this is a time-consuming
method because pixels on each square are point-to-point processed and analyzed.

Using the new, improved algorithm, we reanalyzed our high cloud data of three sites. From Table 4, the results are improved but some errors remain. In principle, because the cloud and aerosol has several certain common characteristics in the shortwave scattering radiation, detecting cloud will be inevitably vulnerable to the effects of aerosol if only the visible wave band is used. Cloud detection, especially high cloud detection, needs to be combined with other observations, such as radar observations, aerosol observations, and so on, to get comprehensive and accurate information of cloud.

6. Summary and conclusions

Automatic observing of macroscopic cloud is urgently needed for operational cloud observation. The all-sky imager simulates naked eyes and records cloud distributions and other information of the half-hemispheric sky. It is superior to human observers when working conditions are worse and observational frequency acquisition is high. The complicated sky conditions, filled with aerosol, fog, and cloud, challenges the accuracy of ASI and its inversion algorithm for cloud detection. For the objectives of improving ASI and supporting references for the future fusion and linkage of long-term cloud cover datasets between MO and ASI, three comparison experiments were performed and presented in this paper. Because MO cloud cover is easily affected by many factors, like psychology, etc., and there is no exact and accurate cloud cover data, it is difficult to estimate the exact accuracy of ASI and MO at present. We analyzed the current degree of discrepancy between ASI and MO quantitatively. The main conclusions are as follows:

1) As a whole, ASI cloud cover has a good agreement with MO. The mean CC was above 0.76 and error of more than 64% of the cases was within ±1 tenth at the three sites.

2) ASI and MO show better consistency in observing low- and middle-level cloud cover. The CC between

<table>
<thead>
<tr>
<th>High group</th>
<th>≤20%</th>
<th>±1</th>
<th>±2</th>
<th>ME</th>
<th>Std</th>
<th>CC</th>
</tr>
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<tr>
<td>Site 1</td>
<td>127</td>
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<td>88</td>
<td>107</td>
<td>−1.26</td>
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<tr>
<td>Site 2</td>
<td>1025</td>
<td>687</td>
<td>633</td>
<td>821</td>
<td>−0.81</td>
<td>2.91</td>
</tr>
<tr>
<td>Site 3</td>
<td>60</td>
<td>34</td>
<td>27</td>
<td>39</td>
<td>−2.92</td>
<td>3.01</td>
</tr>
</tbody>
</table>

Fig. 6. Differences in original cloudless image with (a) heavy aerosols and (d) high, thin cloud image with heavy aerosol. For (a),(d), panels (b),(e) gray variation of pixels on solar principal plane from original image (blue dashed line), and (c),(f) gray-contoured image rearranged by zenith angle and azimuth from original image, which can more clearly illustrate the symmetrical character.
MO and ASI was 0.89 and the error of about 78% cases was between ±1 tenth.

3) Discrepancy between MO and ASI mostly occurs on the judgments about high-level cloud (or aerosol). ASI cloud covers on average were lower than MO. One reason is that MOs sometimes mistake sky loaded with more aerosol for high-level cloud. On the other hand, ASI underestimated high-level cloud cover because of sensor sensitivity and algorithm. The ASI sensor is not sensitive enough to capture some very thin cloud, which was reported by MO (if it is true), because our naked eyes cannot find them from the image. Another reason is that the cloud cover estimation algorithm did not detect or distinguish high-level clouds from sky pixels with heavy aerosol or those near the sun and horizon, and then underestimated the cloud cover.

This paper shows that ASI has a good consistency with MO, especially for low- and middle-level clouds. MO records about high-level clouds are sometime doubtful, especially for sky with heavy aerosol. In contrast with MO, ASI shows more superiority in working frequency, objectivity, and lower cost, etc. However, high-level clouds (or aerosol) are main challenges for both ASI and MO, though the new method improves the accuracy of high cloud detection. In our next work, more comparisons and examinations will be performed at more locations using other cloud cover data, like satellites. For ASI, future works need to be focused on how to improve the ability of detecting high-level clouds from aerosol.

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