Field of View Determination and Spatial Calibration of Night Airglow All-Sky Images

P.T. Patil[1] R. P. Patil[2] R. N. Ghodpage[3] S. B. Patil[4] D. P. Nade[5]
[1,3]Department of Electronic & Telecommunication Engineering [3]Department of Physics [4]Basic Sciences & Humanities
[1]Indian Institute of Geomagnetism, Shivaji University Campus, Kolhapur [2,4]D.Y.Patil College of Engineering and Technology Kolhapur [5]Sanjay Ghodawat Group of Institutions, Atigre, Kolhapur- 416 011

Abstract— the various phenomenon and structures observed in night airglow all-sky imager (ASI) images (such as, drift motions of gravity waves and plasma bubbles) these are accurately measured only after the spatial calibration of the images. While spatial calibration is a process of computing pixel to real-world unit transformations although accounting for many errors inherent to the imaging setup. Calibration of image is important when accurate measurements required in real-world units. In this paper spatial calibration includes the alignment to true north and measurement of field of view (FOV) of captured ASI images. For the spatial calibration the stars in the (ASI) image are used as a reference points which is then compared and calibrated with star catalogue image to find true north and FOV of ASI image. The spatial calibration and FOV measurement of an image is useful when the imaging setup is not stationary. This paper presents developed simple but accurate methodology for spatial calibration and FOV measurement of ASI image. The software is developed for the FOV measurement and spatial calibration by using Mat Lab 7.0.

Key words: Night Airglow, Star Map, Field Of View, True North

I. Introduction

An optical observation is one of the best techniques to observe nighttime phenomenon in F region. The equatorial ionosphere observations have been conducted from various low latitude sites over the past three decades to study plasma irregularities associated with equatorial spread F (ESF). These irregularities originate at or near the magnetic equator in the post sunset bottom side ionosphere and trigger the vertical development of plasma bubbles. There are two main categories of optical emissions from the upper atmosphere: airglow, generally resulting from chemical reactions leaving product species in excited states which then emit photons, and aurora, or photon excitation generally resulting from particle impact on ambient atmospheric gasses [1]. Recombination of the F region plasma at ionospheric altitudes of several hundred km proceeds through several mechanisms, and results in detectable optical emissions from atomic oxygen at wavelengths of OI 630.0, OI 557.7, and OI 777.4 nm [2]. Typical airglow intensities are on the order of a few hundred Rayleighs (R=106 photons/s/cm2 integrated along a line of sight) [1] and are well below the detection threshold of the human eye. Ground-based all-sky imagers (ASI) can provide high-quality images of depletion structures over fields of view in excess of 1000 km diameter from a single instrument. The system details about the ASI are given in [3]. The basic methods required for the image processing of ASI images is discussed by Garcia [4]. For the large-field information present in the all-sky data, accurate field of view (FOV) measurement and spatial calibration is essential. We can achieve this by using the stars in each image as known reference points in the sky [5]. While taking the all-sky observation from remote location it is desirable to have the correct knowledge about the directional orientation and field of view of the ASI is being operated from limited exposure. Hence, in this paper we report a simple but useful methodology developed implemented by using program developed in Mat Lab to do the special calibration of the all-sky image and field of view determination.

II. Determination of Field-of-View

A. *Using Geometric Method:*

Airglow emissions exhibit considerable temporal fluctuations over large geographic regions. Thus, one requirement of atmospheric imaging is to capture large areas in each image with high quality. A fisheye lens is a special type of ultra-wide angle lens used for capturing large geographic area (i.e. large FOV) with losing the straight lines of perspective as seen in rectilinear images.

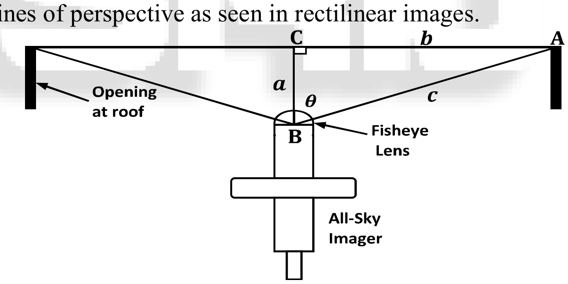


Fig. 1: Geometry Showing Determination of the Field Of View of All Sky Imager

To avoid the effect of city light, the all-sky camera operated for the limited field of view from the observing room which have circular opening in its roof/slab then the FOV of the image can be measured by measuring the diameter of the circular opening and the spacing between top of opening in the roof and base of fish eye lens. Figure 1 shows the geometry of FOV estimation, where ΔACB is considered for the determination of angle θ where simple trigonometry is applied, twice of the angle θ gives the value of FOV of the imager. The measurements and the estimation of FOV are given in the Table 1. Refer to the Figure 1 and Table 1 the estimated field of view of the image is ~146o.

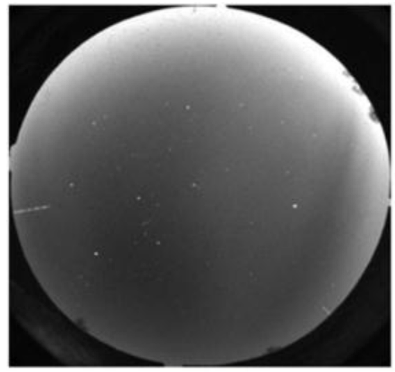
Sr. No.	a (mm)	b (mm)	$c = \sqrt{a^2+b^2}$ (mm)	$\frac{b}{a}$	$\theta = tan^{-1}(b/a)$ (deg.)	FOV = (2θ) (deg.)
1	160	521	545	3.2562	72.9281	145.8563

Table. 1: Estimation of the FOV of All Sky Imager

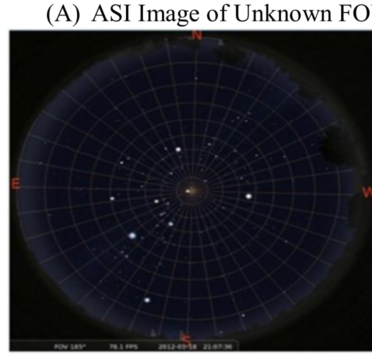
B. Using Star Map:

Star map is a general map or image of a region of the sky which is software generated with high accuracy, star map may comprise a set of many images or variety of sky objects which produces star catalogue. One of the best star catalogues is Stellarium (0.12.4) software which is freely available on internet, and it is easy-to-use, sky map software that provides an excellent way to learn about astronomy and explore the sky visible in the distant past, the present, and the far-off future. It can display and print attractive, highly-customizable maps of the sky as seen from the observing station or any other location on the Earth. So this star map is used as reference in this paper work to calibrate ASI image.

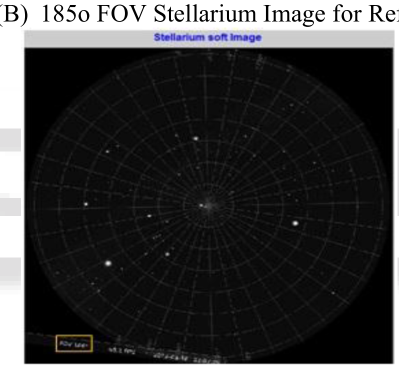
The FOV for each campaign is determined with the help of elevations of star positions on raw images. Elevation angles are noted for few stars around the edges of an all-sky image and the FOV for a given operating condition is computed from these angles. This condition is useful when the sky is clear and dark but due to growth of city around the observing site illuminate the circular edges of the all-sky image hence, it is difficult to find out the stars around the edges. The stars observable around the zenith area of the image can be considered for the FOV determination. The circular image generated by the Stellarium software by giving proper location, date and time parameters and the image is circularly reduced to match with the ASI image. The ASI and Stellarium images are added or overlapped and adjusted to see the best matching between the stars observable in the middle portion of the images. When this is done the field of view given by the Stellarium software is equal to the field of view of the ASI image. The method is illustrated in figure 2 where figure 2(a) shows the ASI image of OI 630 nm line recorded on 18 January 2012 at 2107 from low latitude station Kolhapur (Lat. 16.40o N, Long. 74.15oE) with unknown FOV. Figure 2(b) is the Stellarium image for the same location, date and time with 185o FOV. For determination of the correct FOV of ASI image a program developed in Mat Lab tries to make matching between the ASI and Stellarium images. To do so the program rotates and adjusts the FOV of Stellarium image and checks the best match by superimposing the two images on each other. This process is repeated until the best match between the ASI and Stellarium image and it is shown in figure 2(c) where the Stellarium image is rotated by 8o in clock wise direction and its FOV is reduced to 146o which is marked by a rectangle around the FOV values. Figure 2(d) shows the best matched i.e. superimposed image of ASI and Stellarium images where six bright circles around stars shows the best matching of the two images. After this best matching between the two images the FOV of ASI image is equal to the FOV of Stellarium image and here it is 146o. In this way the FOV of ASI image determined by geometry method and comparison with star map is same, hence both methods will be equally correct and useful.



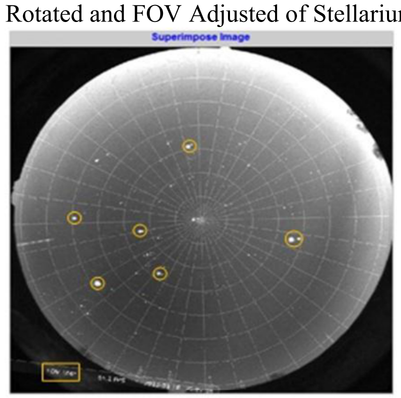
(A) ASI Image of Unknown FOV



(B) 185o FOV Stellarium Image for Reference



(C) Rotated and FOV Adjusted of Stellarium Image



(D) Superimpose Of ASI And Stellarium Images

Fig. 2: Determination of FOV of ASI Image By Using Reference Image

III. SPATIAL CALIBRATION OF ASI IMAGE

Spatial calibration of ASI image is one of the most important steps of image processing. The purpose of performing spatial calibration is to align image to true north with the top of the image, to project the image top-down. In ASI image with FOV less than 150o the location of North

Star is not visible. For spatial calibration 4 to 8 stars around the zenith in the ASI image are aligned with the Stellarium image. The Stellarium image is always aligned to true north direction, hence when the ASI image is matched with Stellarium software image then it automatically get aligned with true north direction. For 180o FOV of ASI image the North Star is visible then it is easy to find out it with the standard methods as discussed in next section.

A. Determination of True North:

In fact finding direction using the stars is much quicker and easier than using a compass. Fortunately there is one star in the Northern Hemisphere of the night sky that does not appear to move. It is called Polaris, or the North Star. The North Star is the last star in the handle of the Ursa Minor constellation. If we have trouble to find it then find the Ursa Major, it is the easiest method for finding the North Star. The 'Ursa Major constellation is the group of seven stars. As shown in figure 3, locate the two stars that form the outer edge of the Ursa Major. Draw an imaginary line straight through the two stars of the Ursa Major edge and toward the Ursa Minor. The line will point very close to the handle of the Ursa Minor. The brightest star in the Ursa Minor is at the end of its handle. This is the North Star and is at approximately 5 times the distance between the two stars in the outer edge of the Ursa Major.

True north lies directly under this North Star. The Ursa Major rotates anti-clockwise about the North Star, so it will sometimes appear on its side or even upside down. However its relationship with the North Star never changes and it will always dependably point the way to it.

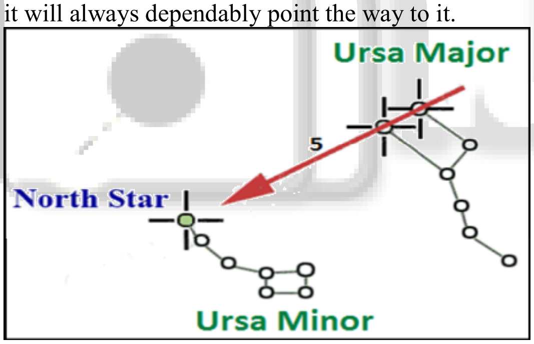
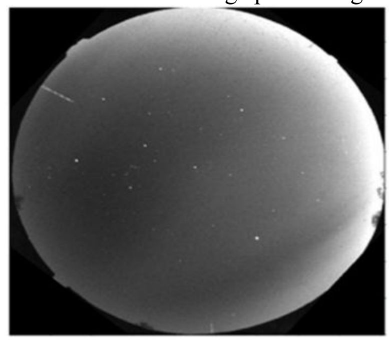


Fig. 3: Identification of North Star in the Night Sky

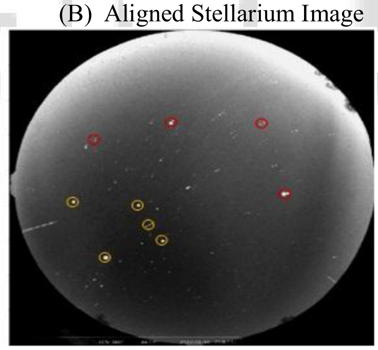
B. Spatial Calibration of ASI image for FOV < 150^o

The method is illustrated in figure 4 where figure 4(a) shows the raw ASI image of OI 630 nm line recorded on 18 January 2012 at 2107 from low latitude station Kolhapur (Lat. 16.40o N, Long. 74.15oE) with 146o FOV. Figure 4(b) is the Stellarium image for the same location, date, time and FOV. For spatial calibration i.e. alignment with true north of the ASI image a program developed in Mat Lab tries to make matching between the ASI and Stellarium images. To do so the program rotates the ASI image and checks the best match by superimposing the two images on each other. This process is repeated until the best match of stars around the zenith in both the ASI and Stellarium image and it is shown in figure 4(c) where the ASI image is rotated in anti clock wise direction. The dark and bright circles are marked around the best matched stars in both the ASI and Stellarium image. From figure 4(c) it can be observed that the stars in the lower half circular portion are well aliened than the starts in the upper half circular region of the ASI image. This effect is due to improper horizontal and vertical alignment of the ASI camera at the observing location. Figure 4(d) shows the best matched i.e. spatially calibrated ASI image with FOV < 150o and the true directions are marked on the image. From the calibrated image it can be noted that the image has been projected top-down. [6] As a result, in figure 4(d) the developed program performs the spatial calibration task of the image processing.

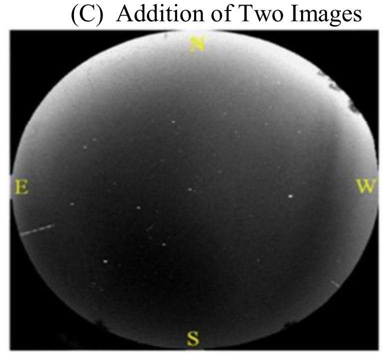


(A) Unaligned ASI Image

(B) Aligned Stellarium Image



(C) Addition of Two Images



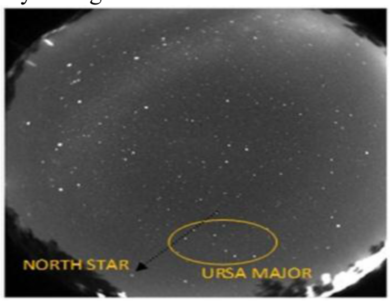
(D) Spatial Calibrated Image

Fig. 4: Spatial calibration for FOV < 150o

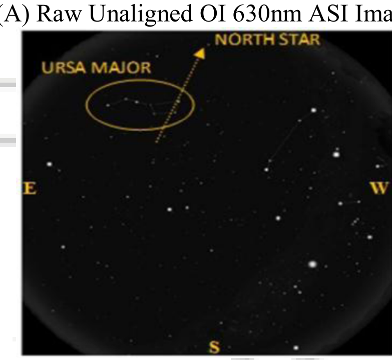
C. Spatial calibration of ASI image for FOV = 180^O

The method is illustrated in figure 5 where figure 5(a) shows the raw ASI image of OI 630 nm line recorded on 1

February 2008 at 0130 am from Panhala Hill Station at Kolhapur (Lat. 16.48o N, Long. 74.6oE) with 180o FOV. The ASI image in figure 5(a) is the raw full sky image where position of Ursa Major star constellation is marked by an enclosed oval shape circle and the North Star is pointed by a black dotted arrow. Figure 5(b) is the Stellarium image for same location, time and date of raw ASI image, similar to raw ASI image the position of Ursa Major star constellation and the North Star are marked accordingly. The image in figure 5(b) is the correct image hence it is necessary to adjust the raw ASI with it. Hence, the ASI image in figure 5(a) is flipped vertically and horizontally and rotated by -8 degree in anti clockwise direction.



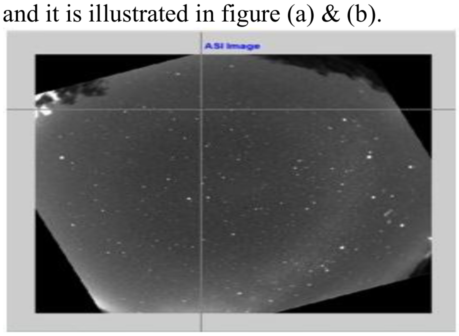
(A) Raw Unaligned OI 630nm ASI Image

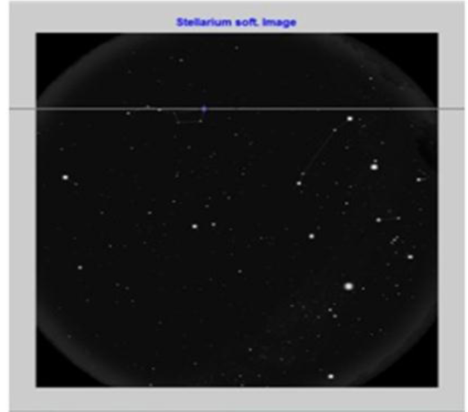


(B) Aligned Sterallium Software Image

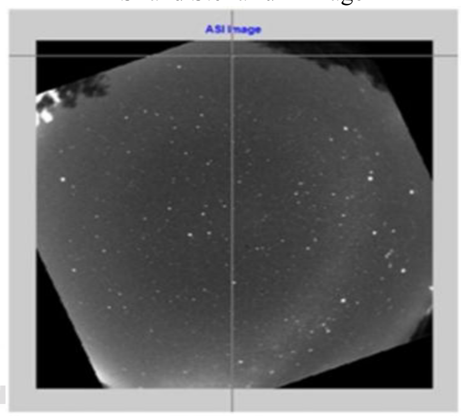
Fig. 5: Full FOV (180o) All-Sky Images On 1 February 2008**,** (a) Raw unaligned OI 630nm ASI image. (b) Aligned Sterallium Software image.

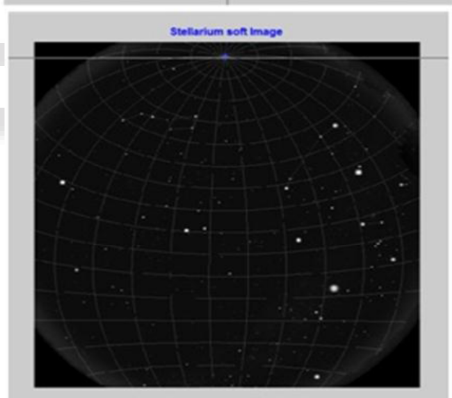
To see the best matching between ASI and Stellarium image the program utilizes different approach in which instead of superimpose of the images the matching is examined by using a shooting crosswire marker. First the dimensions of the ASI and Stellarium images are made equal then as mentioned in previous paragraph the ASI image adjusted. After this to check the best matching between the images the user has to click on one of the star in Ursa Major star constellation and the North Star in ASI image then the corresponding stars in Stellarium image get highlighted which shows the matching between the two images and it is illustrated in figure (a) & (b).





(A)Matching Between a Star of Ursa Major In ASI and Stellarium Image

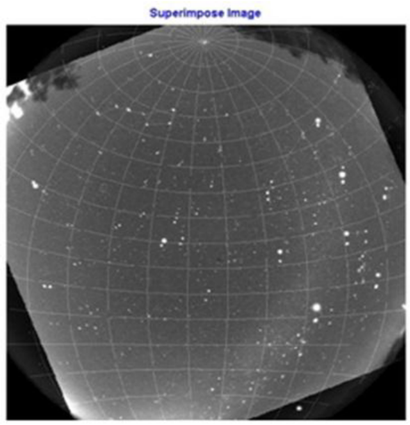




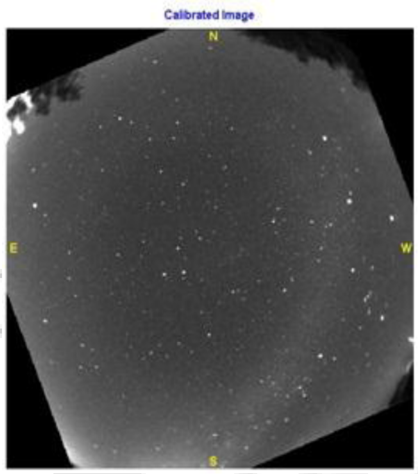
(B)Matching Between the North Star in ASI And Stellarium Image

Fig. 6: Testing of Matching Between the ASI and Stellaruim Image (a)Matching between a Star of Ursa Major in ASI and Stellarium image. (b)Matching between the North Star in ASI and Stellarium image.

After this the program superimpose or add both the ASI and Stellarium image with latitudinal and longitudinal grid to test the correct orientation of the ASI image and it is shown in figure 7(a). The program creates final spatially calibrated image with proper direction marking on it and is shown in figure 7(b). In this way by using shooting crosswire and super impose the perfect matching between the ASI and Stellaruim image are tested which further results in correct spatial calibration of the full FOV all-sky image.



(A) Super Impose Between The Perfectly Aligned OI 630 Nm ASI Image And Aligned Sterellium Software Image



(B)Final Calibrated ASI Image

Fig. 7: All-sky images on 1 February 2008 on 0130 IST from Panhala, Kolhapur
(a) Super impose between the perfectly aligned OI 630 nm ASI image and aligned Sterellium Software image.
(b) Final calibrated ASI image.

IV. SOFTWARE PROGRAM FOR SPATIAL CALIBRATION OF ASI IMAGE

The flow chart given in figure 8 is self-explanatory and shows programming steps to determine the FOV and the spatial calibration of ASI image. Before running the program the user has to generate a Stellarium image in png format by giving the parameters of the ASI image. The program first reads both the Stellarium and ASI images then are cropped and made of equal in dimensions. As per star positions in the Stellarium image the ASI image flipped and rotated to match with it. Then the program adds both the images then the user has to see the matching between 4 to 8 stars around the zenith portions of the superimposed image. If there is some difference then the ASI image rotated accordingly and again the matching in the stars are examined this process repeated until the stars gets perfectly matched. After the perfect matching in the stars the degree of rotation of the ASI image along with the direction of rotation is noted and it further applied to all the ASI images recorded from the same location without disturbing the ASI camera.

The matching in the stars in the ASI and Sterallium image can also be tested by using star selection in the ASI image by using cross wire. When a star in ASI image is selected then the corresponding star in the Stellarium image get highlighted similarly other stars in different locations can be tested for best matching in the both images. If there is mismatch between the stars in both the images then the ASI image rotated in clockwise or anticlockwise direction by some degree and again the procedure repeated until the some 4 to 8 stars around the zenith get matched.

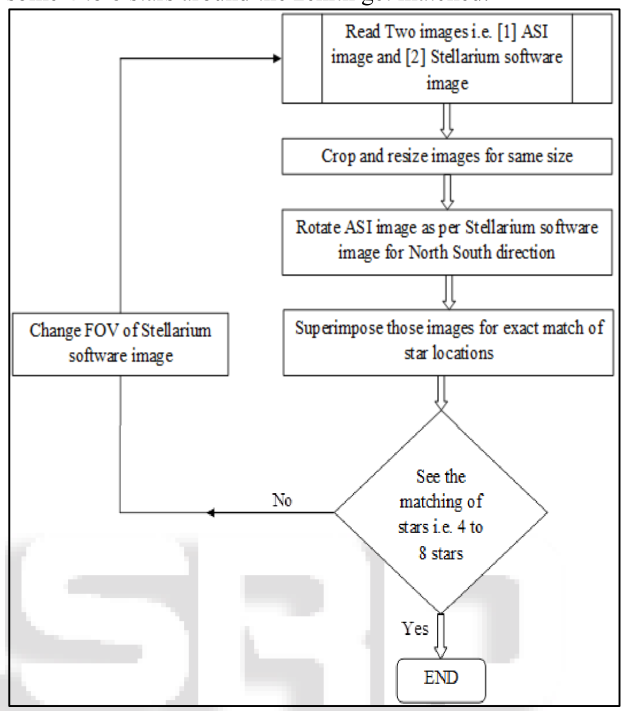


Fig. 8: Flow Chart of FOV Determination and Spatial Calibration of Image

V. CONCLUSIONS

We have proposed a novel method for the FOV determination and spatial calibration of ASI image. Determination of true north direction by locating north poles is worked successfully which is very useful for the spatial calibration of the ASI image. The algorithms described in this paper perform the basic function of matching of stars within the FOV of the stellarium software. The developed software algorithms are very useful to determine the FOV of the ASI image in limited exposure as well as in open sky. The spatial calibration performed with this new method is very easy and quick; once we find the correct rotation angle of one ASI image to match it with true north then it can be easily applied for all other images of the same location. Once the correct FOV and true spatial alignment for the ASI image is performed then the estimation of atmospheric parameters will have minimum errors.

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