Automatic detection of chromospheric plages in the Coimbra Observatory spectroheliograms

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Abstract
Full-disk spectroheliograms have been routinely taken in Coimbra since 1926 in the Ca II K3 line and in the K1v line from 1973 onwards. Additionally, in 1990 started regular observations in the Hα line. More, in 2007 the photographic plates were replaced by a CCD camera. This extensive collection acquired with the same instrumentation must be processed all together since its large temporal coverage can provide important inputs for the knowledge of the solar activity. In this study we applied the mathematical morfology approach to the CA II K3 series to detect automatically and analyse the chromospheric plages. To evaluate the performance of the method, the results were compared with the observations obtained by a human operator and solar catalogs, showing very good results. Evolution of the solar activity in the solar cycle 24 have been in focus. To validate the capabilities of the software tool we compared the results of detection for the solar cycle 23 obtained using the presented method with those obtained using a software tools developed in the OGAUC already in 2004.

1. INTRODUCTION

We developed a software tool based on the *mathematical morphology*, an image analysis theory, that uses mathematical morphology operators to evaluate the structure and shape of studied objects. This study is based on CaII K3 series to detect automatically and analyse the chromospheric plages during the solar cycle 24 (from 2008 until 2016). These spectroheliograms are 8 bit images, with 1200 x 1000 pixels. Facular regions are bright areas in the solar chromosphere, due to the activity of magnetic fields.. More details on the state-of-the-art, input data, basic concepts of the mathematical morphology, automatic method of plages or facular regions detection and their area determination, the results and their validation can be found in Barata et al. (2018).

2. DATA

The Geophysical and Astronomical Observatory of the Coimbra University has a collection of solar observations on a daily basis that spans near nine decades until today. Regular observations of the full solar disk in the spectral line of Ca II K started in 1926 and in 1989 started also the observations in the spectral line Hα.

The spectroheliograms from 1926 until 2007 were photographed to plates in the wavelengths 393.37nm (CaII K3), 393.23nm (CaII K1) and 655.87nm (Hα) after 1989. Photographic plates and films were in 2007 replaced by a 12–bit CCD camera, making possible to add observations in 656.28 nm (Hα continuum) and, after an upgrade of the data processing software in 2009, to obtain also Hα Dopplergrams (Garcia et al., 2010). All this *extensive collection* acquired with the same instrumentation is already in *digital format*.

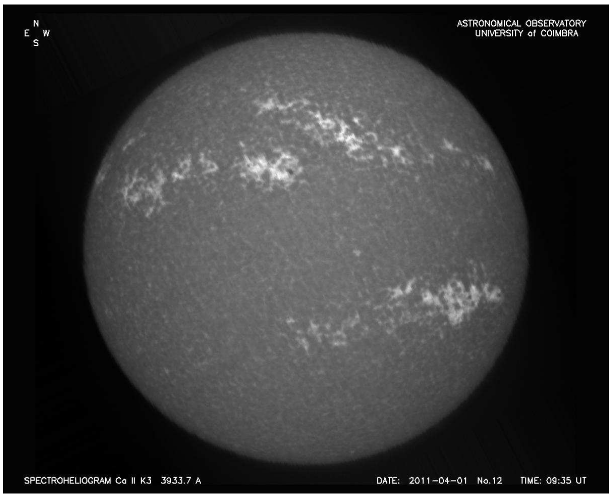
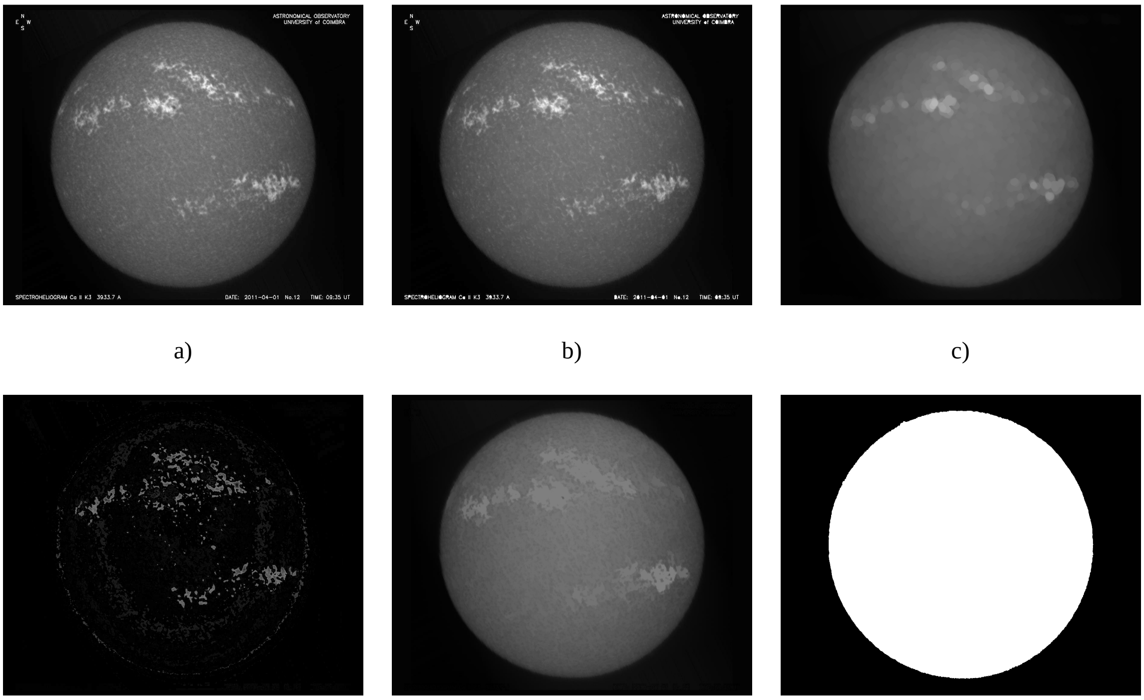


Figure 1. Illustrative image of the CaII K3 spectroheliogram, 1 April 2011.

3. MORPHOLOGICAL DETECTION METHOD

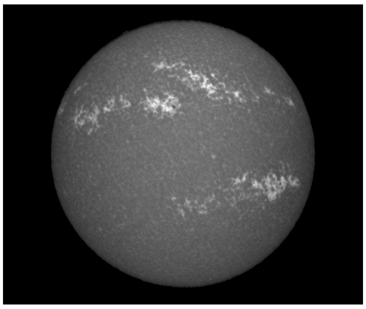
Mathematical Morphology is an image analysis theory created in the middle 1960s. Its initial purpose was related to an application in porous media to describe the geometric features of structures (Matheron, 1967). The further developments since then have permitted to construct a solid framework (Matheron, 1975; Serra, 1982) and have successfully reached new application areas (good overview in Soille, 2002), including solar physics (Aschwanden, 2010).

Prior to the identification of the solar facular regions it is necessary to define the solar disk region within the image. Also, it is necessary to remove the letters providing information about the image acquisition (date, orientation and place) because they make difficult the application of any automatic processing algorithm. Due to the heterogeneousity of the background of the spectroheliogram images a morphological filter is applied, starting by an area closing, then continuing by linearization applied to previous steps. The final result of this pre-processing algorithm is shown in Figure 2 (g). This image is the starting point for the automatic recognition of facular regions.



a) b) c)

d) e) f)



g)

Figure 2. Identification of solar region in spectroheliograms: a) original image of a spectroheliogram; b) area closing of (a); c) closing of (b); d) difference between (a) and (c); e) reconstruction operation; f) linearization of (e); g) final image, obtained by the multiplication of the original image (a) and (f).

The binary image, obtained by linearization, is used to determine the solar disk center coordinates (Xc, Yc) and its radius (Figure 3). Figure 4 shows the solar region and the respective contour of the spectroheliogram of Figure 1. The determination of the center and the radious will be use to identify the facular regions in the hemispheres (north and south). The contour of solar region (Figure 4 (b)) is be determined by the application of the morphological gradient to the binary image (Figure 4 (a)).

The algorithm of morphological detection of facular regions starts by applying a white top–hat to the clean image, i.e. the image with a homogeneous background and without letters (image of Figure 2 (g). After the top–hat operation a hole filling is performed to connect and fill in the dark areas inside facular regions. It is then necessary to isolate the facular regions through the application of a threshold since not all bright areas correspond to facular regions. The next step of the algorithm is to remove small areas that resisted to the threshold operation, but does not correspond to facular regions. This can be done through the application of an erosion of the threshold image followed by a reconstruction procedure. After this step segmentation using the watershed algorithm was applied to the image resulting from the previous step. The gradient operation applied to the image of the watershed basins, allows then to obtain the contours of facular regions. All steps of the morphological detection are illustrated in Figure 5. The final result of the algorithm of automatic detection of facular regions can be observed in the image of Figure 6. This image shows the contours of facular region superimposed to the original image.

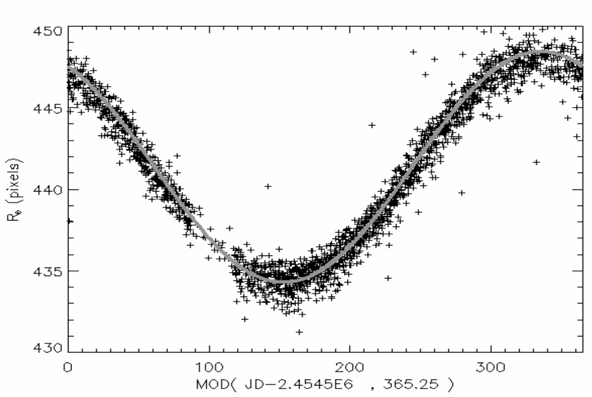
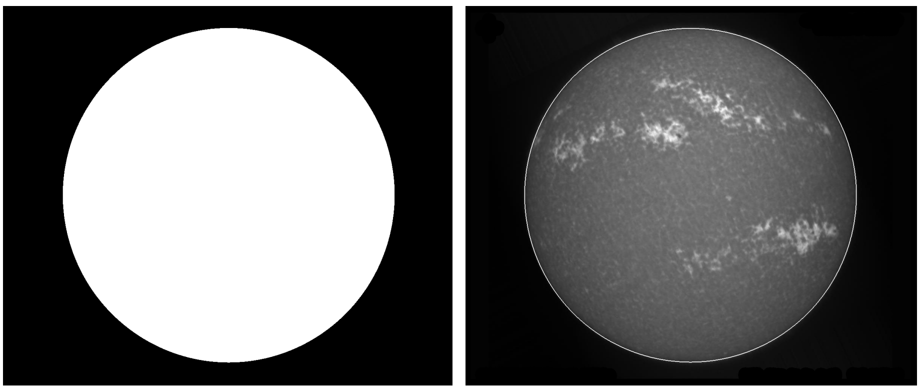


Figure 3. Disk radius for 2083 spectroheliograms taken at the Coimbra Observatory during solar cycle 24 (2008–2016) with a best fit (solid line).



a) b)

Figure 4. Solar disk region and respective contour: a) binary image of the spectroheliogram of Figure 1 and b) spectroheliogram without noise and with the superimposed of the solar region contour.

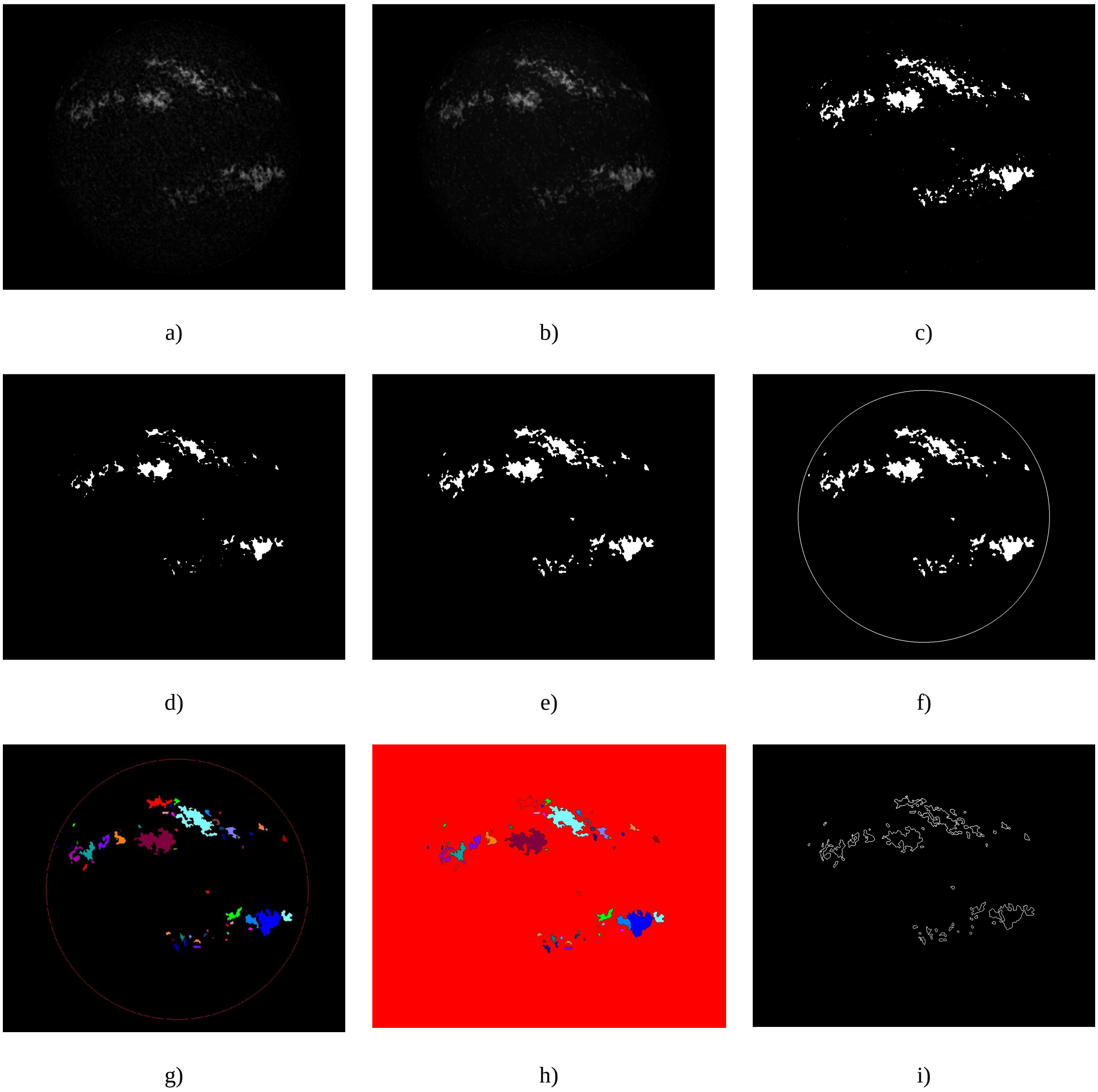


Figure 5. Algorithm of automatic detection of facular regions: a) white top–hat applied to the image of Figure 2 (g); b) hole fill operation; c) threshold image; d) erosion of the threshold image; e) reconstruction; f) reconstructed image with the contour of solar disk; g) markers of the facular regions; h) basins obtained by the watershed operation, that corresponds to facular regions and i) contours of facular regions.

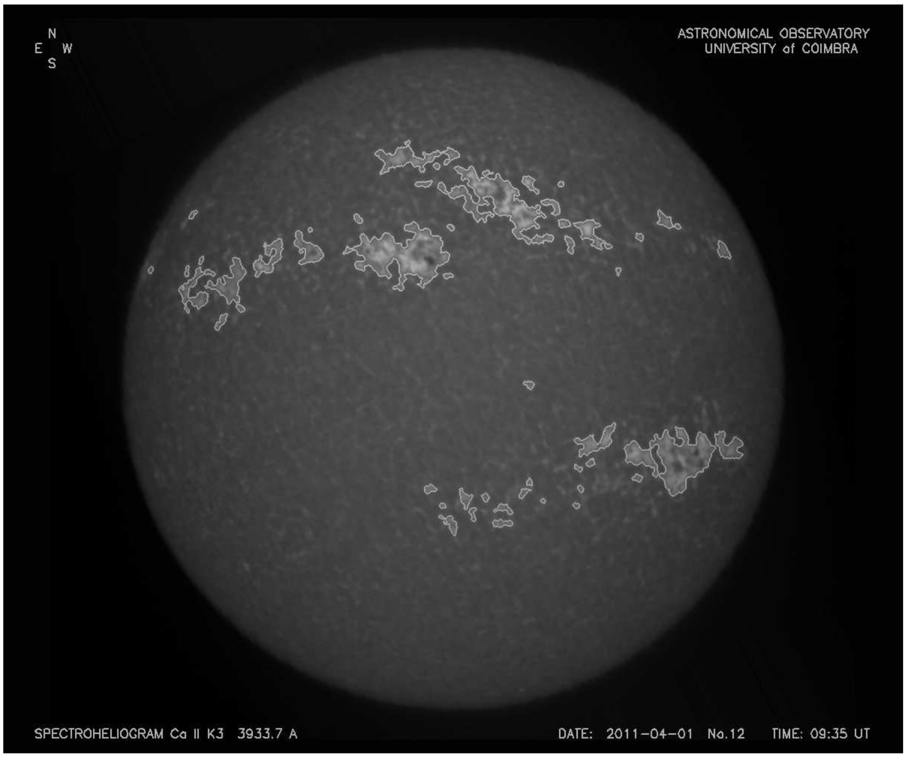
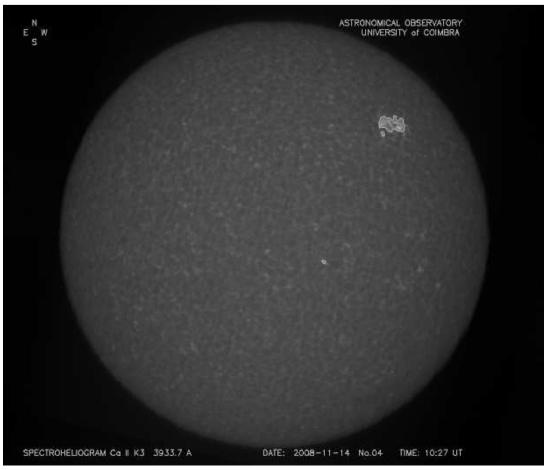


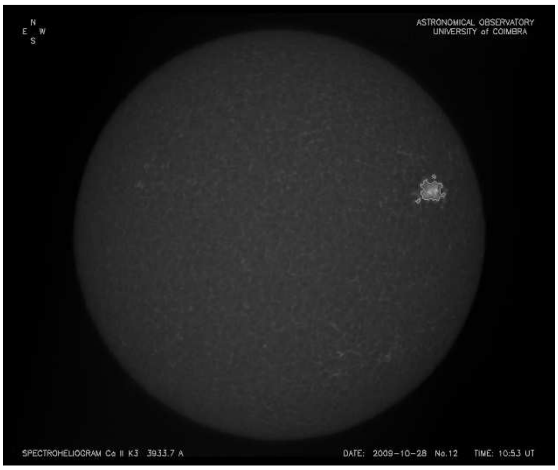
Figure 6. Facular regions superimposed of the original image.

4. DATA ANALYSIS AND DISCUSSION

The automatic algorithm to detect facular regions was applied to the Coimbra' spectroheliograms of the solar cycles 24 and 23. While the application of the algorithm to the images of the cycle 24 was the automatic detection of facular regions, for the images of the cycle 23 the objective was to obtain results to validate the performance of the method. These images were compared with the images of cycle 23 already processed by the method developed by Dorotovič et al. (2007, 2010). The results obtained by the ASSA (Automatic Solar Synoptic Analyzer) method, a software developed by the Korean Space Weather Center of the Radio Research Agency, were qualitatively compared with the results obtained by the application of the automatic method to the HMI SDO images. Our algorithm was applied also to spectroheliograms from the Astronomical Observatory of Kharkiv State University, available through the database http://www.astron.kharkov.ua/ssm/. The objective was to test the applicability of the method to other images, using the same parameters for morphological operators and threshold values. Detailed analysis of the validation results are presented in Barata et al. (2018).



a)



b)

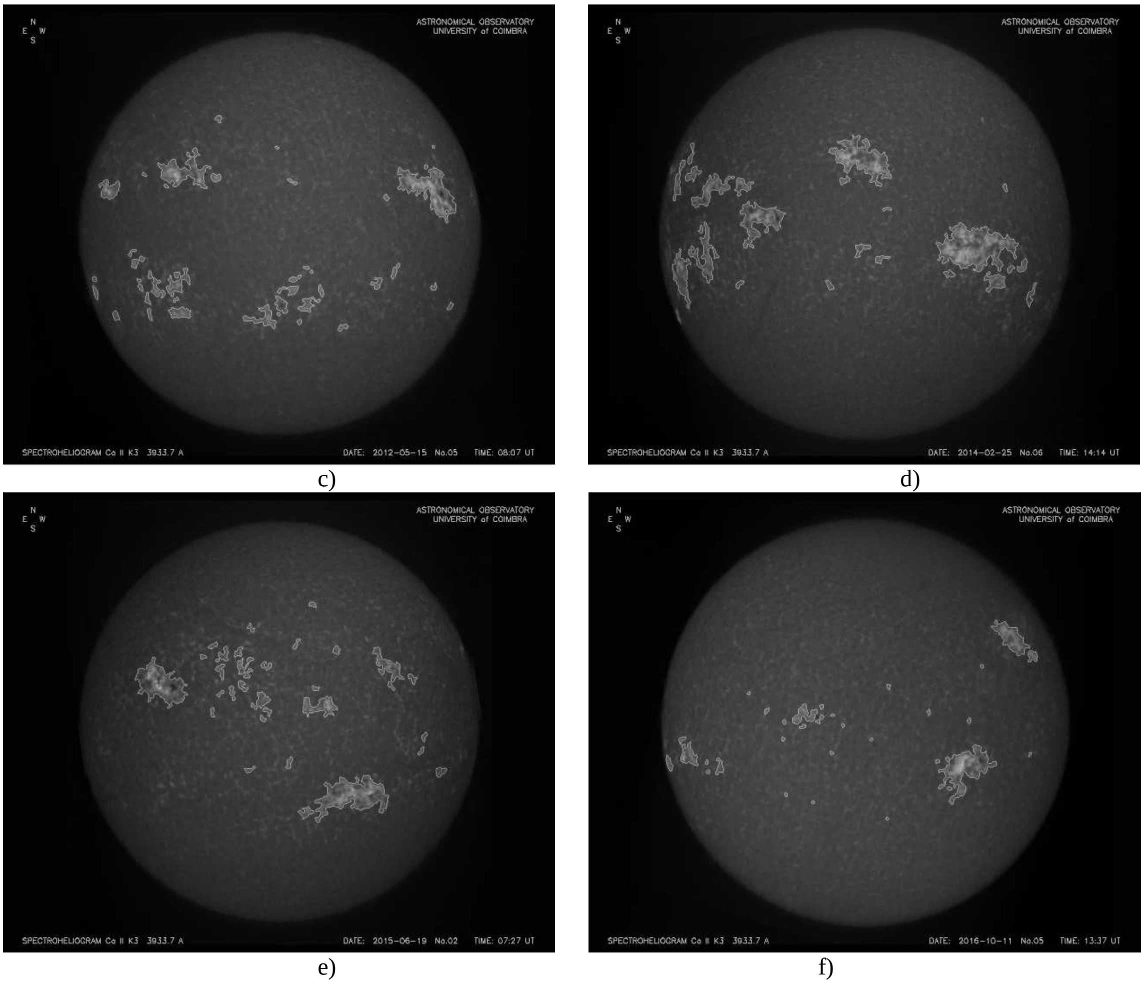


Figure 7. Automatic detection of facular regions applied to spectroheliograms acquired during cycle 24: a) 14 November 2008; b) 28 October 2009; c) 15 May of 2012; d) 25 February of 2014; e) 19 July of 2015 and f) 11 October of 2016.

5. CONCLUSIONS

A mathematical morphology algorithm was developed to be applied to the CaII K3 series spectroheliograms of OAGUC, with the purpose of creating an automatic method to detect the chromospheric plages during the solar cycle 24. It is important to highlight that the algorithm developed in this work does not need to pre–process the images to remove the atmospheric effects, the intensity and contrast. Additionally, the procedure proposed here has the added advantage of being unaffected by the limb darkening effect and thus requiring no pre–processing of the data with the sole purpose of removing it. Moreover, the results obtained from the morphological transforms agree with the results obtained from other approaches, including on images obtained with atmospherics artifacts (e.g. some clouds).

As our future work it is intended to analyze the whole Coimbra’s data series and make all the data set available for the public.

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