An algorithm for the assessment of the sky cloud fraction by using digital image processing of ground data.

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Abstract

This work describes a new method for the routine assessment of the sky cloud fraction by using digital images collected at the ground by a low-cost CCD digital camera. The aim is to produce a more consistent and time reliable data set for the cloud cover index for several applications.

Introduction

On a first order basis, clouds are characterized by high reflectance, predominantly white color with hues from the blue to red and constitute a short time-scale dynamic system of chaotic nature. Clear skies on the other hand, are predominantly blue during daytime with hues from green to red. It is a rather deterministic dynamic system insofar as the solar zenith angle is concerned, but can be considered static for short time intervals such as the time duration of a CCD snapshot (Schaefer, 1981, Salby, 1995). The deterministic nature of the clear sky radiation intensity is related to the well known equation describing the time variation of the solar radiation intensity that reaches the top of the atmosphere (Iqbal, 1983):

$$I_0 = I_{SC} E_0 (\sin \delta \sin \phi + \cos \delta \cos \phi \cos \omega_i) \quad (1)$$

Where:
I_0 = Intensity of the solar radiation at the top of the atmosphere;
I_{sc} = solar constant in energy units;
E_0 = eccentricity factor $(r_0/r)^2$
δ = solar declination angle
ϕ = latitude
ω_i = hour angle
r = Sun-Earth distance
r_0 = average Sun-Earth distance (1 astronomic unity 1UA = 1.5 x10^6km).

Therefore, any method intended to determine the cloud cover index must take into account not only the relative variation of the several wavelengths in the picture but also the total available intensity (IEA, 1992).
The visual inspection of clouds performed by field observers is rather subjective and thus bears intrinsic uncertainties and bias that may lead to unreliable results on the long-term. For the study of climate change and for validation of satellite methods the cloud fraction data generated by this visual observation method is objectionable (Blair, 1964). This work presents a new method for cloud screening that aim at to provide a more consistent and time reliable data set.

Instruments and Methods

The PIXERA model PCS20232 digital camera was employed in this work for its good cost-effectiveness factor. It has a user-friendly interface with any personal computer and can be remotely operated by software. Standard used resolution is 516 (H) x 492 (V) pixels.

In the first step of the method the standard RGB color system used by the CCD camera is converted to the HSI system. Thus, instead of dealing with the red, green, and blue colors we deal with image attributes of intensity, hue and saturation (Gonzales and Woods, 1992;

Richard, 1995). In the RGB system the colors can be represented by the scheme of Figure 1. The diagonal of the RGB cube is known as the achromatic line and represents the HSI system (Figure 2).

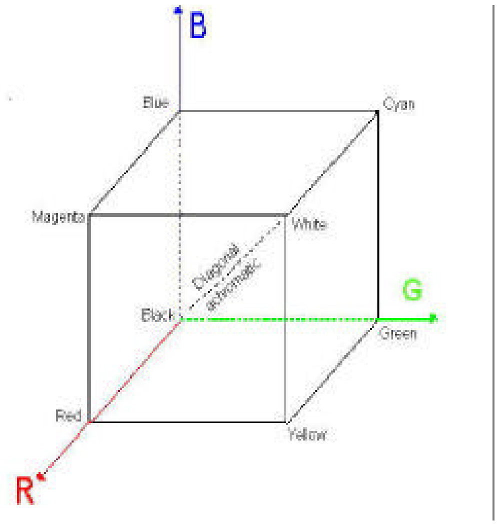

Figure 1. Colors cube shows diagonal achromatic

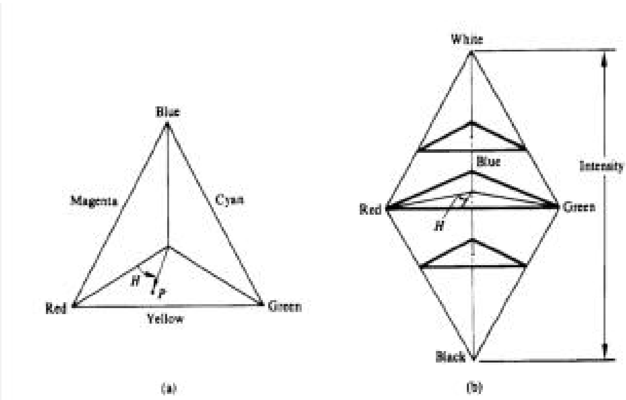

Figure 2. (a) HSI color triangle; (b) HSI color solid

This transformation was made based on the fact that saturation levels for clouds are substantially lower than for clear sky, regardless of the solar intensity I_0. Clouds have a larger reflectance than clear sky and present pale colors, characteristic of a mixture of various wavelengths. In contrast the sky displays a much higher saturation of colors in the visible range of the spectrum. This is critical to the extent that both the sky and clouds cannot be uniquely characterized by any defined sets of colors. Figure 4 illustrates this fact by showing the evolution of the saturation level in one arbitrary scan line of the image shown in Figure 3

The cloud screening process consists of applying a trained algorithm, based on selecting thresholds pixel-by-pixel in the picture mosaic of saturation levels, taken from carefully selected case images for clouds and clear sky, for several solar declination angles δ. The intersection between thresholds for these two subsystems does not intercept, within the uncertainty of this process. Once defined the characteristic threshold, the process can be repeated over to images with unknown sky condition to determine the level of cloud contamination in each image pixel.

Figure 3. CCD test image taken at São José dos Campos, 09/23/98

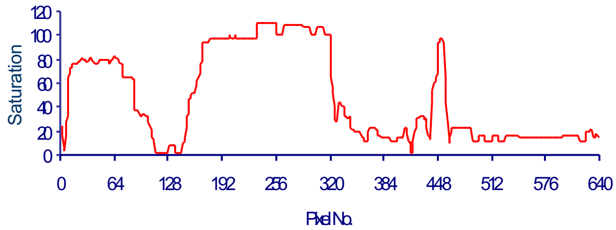

Figure 4. Evolution of saturation parameter of the scan line indicated in red in Figure 3.

Results and Discussion

Figure 5 shows the process applied to an arbitrary picture taken of the sky. The upper panel is the observed image from the CCD camera. The middle panel represents the image of the saturation levels taken for each pixel of the same image. The lower panel is the false-color representation algorithm's output showing the cloud contamination level pixel-by-pixel.

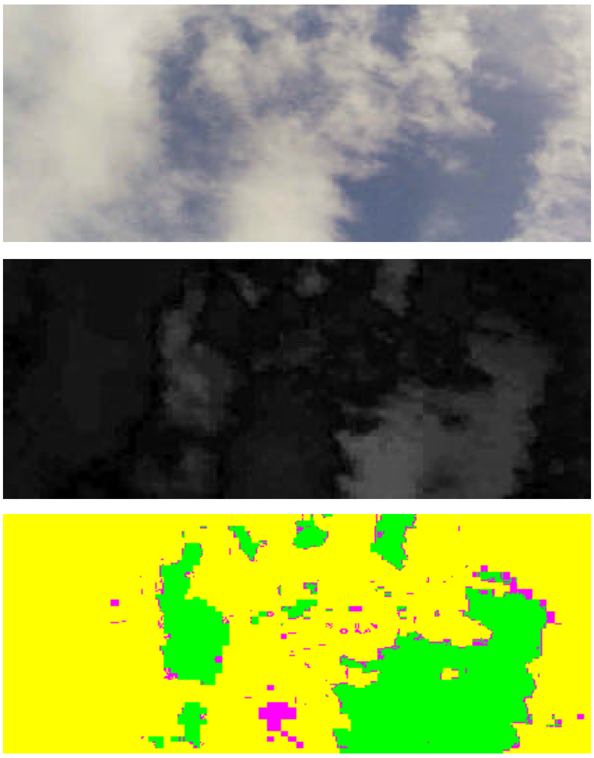

Figure 5. From top to bottom, these illustration depicts, (a) the original CCD image in RGB, (b) the mage of pixel saturation, and (c) map of false colors generate by the algorithm.

The algorithm was validated by applying this method in several sets of CCD pictures representing images of clear skies and overcast skies previously selected by visual inspection. All these groups were tested within the at confidence level of 99.73%.

Tests were performed on a set of CCD pictures representing several states of sky conditions. The pictures were previously classified by visual inspection made by skilled field observers. The method was considered successful for clear sky, overcast sky, and for partially cloudy sky with well-defined cloud borders.

For partially cloudy sky with fuzzy cloud borders, results with a higher content of pixels classified as "undefined" by the method, as expected. But here, the visual classification is also rather subjective and it is not possible to claim that the method failed in these cases.

Further development of the method is on course in order to better classify pixels with undetermined levels of cloud contamination by including the time series analyses of each pixel.

Conclusion

The algorithm was developed to classify each pixel according to a decision process. This process was derived from empirical methods used by the meteorologists to classify the sky according to its cloud cover status. The method transforms the image attributes from the RGB space to the Intensity – Hue – Saturation (HSI) space. This allows the identification of the pixel contamination by clouds by using the information of the saturation (S) component of the HSI space. The classification results obtained by applying this new methodology are adequate for the aim of this project, which is the automatic determination of the cloud fraction index from stand alone ground station.

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