SMALL-SCALE CLOUD DYNAMICS STUDIED BY SYNERGISM OF TIME LAPSED DIGITAL CAMERA AND ELASTIC BACKSCATER LIDAR

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ABSTRACT

Sky digital pictures recorded in equally elapsed times have been used in synergy with measurements of a backscatter Lidar for monitoring the small scale temporal evolution of clouds. The images are recorded in 8-bit grayscale and in an array of 1000×1500 pixels. Intensity cross correlation calculations between successively recorded pictures, specify the angular velocity profile of the clouds respect to the camera. To perform the correlation calculations, each picture was meshed into an array of 20×30 cells, each cell containing 50×50 pixels. Calculation of time correlation have been carried out for all the cells of successive images recorded at increasing elapsed times. Histograms of maximum value of the correlation gave a measure of the cloud evolution in time. To explain the behavior of cloud evolution a proper fitting function to the histograms also presented. All the correlation calculations in this work were performed on the basis of the code that we have written in MATLAB.

1. INTRODUCTION

Cloud track wind application is in use in operational meteorology to provide valuable information on large scales dynamics derived from geostationary satellite data [1][2][3][4]. Along the same line, several studies have been conducted at the research stage with Lidar to improve altitude assignment that is still a significant drawback of the technique. Another drawback is due to small scales dynamics, specially associated with cumuliform clouds that may bias the results. As a matter of facts, the cloud internal dynamics may modify drastically the shape of clouds even at short time [5]. Regarding the last point, a preliminary study has been conducted in order to look at the reliability of the cloud track wind technique according to the internal dynamical state of target clouds and also to characterize the features of small scales processes taking place in various cloud types. [6].

The present study combines altitude assignment and its variability by an elastic 532-nm Lidar and cloud track wind measurements using a digital camera. The digital camera tracks the cloud motion in two dimensions in a horizontal plane whereas the Lidar tracks the cloud motion along the vertical dimension. The time evolution of cloud boundaries and shape at short time scales are studied using a correlation technique. The 532-nm backscatter Lidar has been developed in house [7], whereas a wide angle Nikon D100 Digital camera enables to record full sky images (63 FOV, 1000×1500 pixels array). The images are digitized to an 8-bit grayscale and in JPG format. A numerical code has been written in MATLAB to compute the correlation matrix between successively recorded images, which meshed each image in 20 × 30 cells. The size of each cells is 50 × 50 pixels. By computing the correlation parameters for all the cells of successive images recorded at increasing elapsed time, we obtain the position of maximum correlation of each cells. The displacement of the cloud during one elapsed time can be determined by knowing the initial position of each cells and the position of maximum correlation and so the cloud velocity is calculated [6].

As time goes on, the cloud structure changes and the correlation function changes as well. Calculations of time cross correlation for all the cells of successive images recorded at increasing elapsed times, gave a measure of the small scale evolution of cloud in time. For a given cloud type, the distribution of the set of correlation coefficients varies in time. The shape of the distribution remains the same for calculations at different times. At short time, the distribution tends to be equal to unity, but as time increases, the weight tends to be normally distributed. The results show that for a given type of clouds and a given spatial scale, there exist a characteristic time such the correlation coefficient has a significant value so when the elapsed time is much larger, then it is randomly (normally) distributed. The proposed technique and more examples will be presented at the conference.

2. EXPERIMENTS AND CALCULATIONS

As in our previous works [7][6] a 532-nm backscatter Lidar has been used as a cloud altimeter. In synergy with the Lidar a Nikon D100 digital camera (FOV 63°) was recording the sky images in equal time lapses of 2 seconds. The images are recorded in 8-bits gray-scale and jpg format in arrays of 1000×1500 pixels. To monitor the cloud motion during the elapsed time between successive images, time correlation between the images was

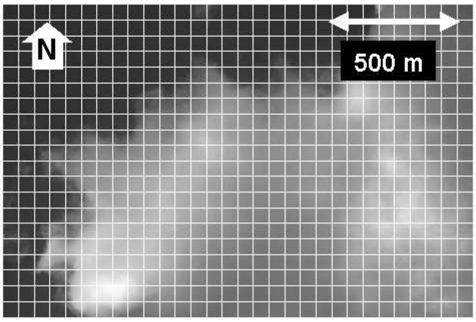

Figure 1. Sample of cloud images recorded on December 25, 2005, the image contains 1000×1500 pixels and meshed into an array of 20 × 30 cells. Size of each cells is 50 × 50 pixels

calculated using a code written in MATLAB. To carry out the calculations each image was meshed into an array of 20×30 cells. Fig. 1 is an example of such meshed images. Intensity correlation between respective cells of the successive images determines how the cell moves during a time lapse. In other words, the cell displacement is obtained in x and y directions in terms of pixels over the image.

As in our previous work [6], the intensity of each pixel in an image can be shown by 5 indices as ${}^{a}I^{ij}_{nm}$ when a is a label for the picture, the two lower indices, n and m, specifies the cell which contains the pixel and upper indices i and j correspond to the position of the pixel in the cell. In this way, the cross correlation between two similar cells of two successive images a and b, when the cell in the second image has displaced by $k(l)$ pixels in $x(y)$ direction${}^{ab}C^{kl}_{mn}$ can be written as.

$$ {}^{ab}C^{kl}_{mn} = \frac{\sum_{i,j=1}^{50} \left({}^{a}I^{ij}_{mn} - {}^{a}\mu_{mn}\right)\left({}^{b}I^{i+k,j+l}_{mn} - {}^{b}\mu^{kl}_{mn}\right)}{\sqrt{\left(\sum_{i,j=1}^{50} \left({}^{a}I^{ij}_{mn} - {}^{a}\mu_{nm}\right)^2\right)\left(\sum_{i,j=1}^{50} \left({}^{b}I^{ij}_{mn} - {}^{b}\mu^{kl}_{mn}\right)^2\right)}} \quad (1) $$

$$ k,l = 0-49, \quad m = 1-20, \quad n = 1-30 $$

In Eq. (1), ${}^{a}\mu_{mn}$ denotes the average intensity over cell nm of image a. To find the value of displacement of the cells during one time lapse, cross correlation is calculated between respective cells of successive images(Fig. 1).To maximize the value of correlation between two respective cells, position of the cell in the second image also swept the first nearest neighbor cells in steps of one pixel. This means that:

$$ {}^{ab}C^{k_M l_M}_{mn} = \mathrm{Max}\left\{{}^{ab}C^{kl}_{mn}\right\} \qquad k,l = 0-49 \quad (2) $$

When k_M and l_M correspond to the values of k and l for maximum cross correlation between the two cells, ${}^{ab}C^{k_M l_M}_{mn}$. For simplicity we write ${}^{ab}C^{k_M l_M}_{mn} \equiv C^{Max}_{mn}$. We used the value of C^{Max}_{mn} for each cell in combination with the Lidar data for the cloud altitude to obtain the cloud velocity profile at small scales [6].

Here again, we used Eqs. 1 and 2 as a measure of time evolution of the cloud at small scales when the correlation calculations carried out between every two images recorded at different time lapses (i. e. every two images which recorded at 1, 2, 3, 4, ... time lapses). C^{Max}_{mn} shows how much that part of cloud that is surrounded in cell mn remains unchanged as the cloud evolves in time. therefore evolution of histograms of C^{Max}_{mn} calculated for different time steps shows the time evolution of cloud at a scale of one cell. Solid lines in Fig. 3 are envelops to C^{Max}_{mn} histograms for 1, 4, 6 and 10 time lapses. All of the calculations have been done through the codes that we wrote in MATLAB.

3. RESULTS AND DISCUSSIONS

As we have mentioned in sections 1 and 2, we have monitored the small scale time evolution of clouds by use of time lapse digital photography and codes that we have written in MATLAB for calculating the cross correlation between images recorded with in different elapsed times. The spatial dimensions of the area under investigation is obtained by combining the camera viewing angle to one cell over the image (Fig. 1) and the measured cloud altitude by the Lidar. Fig. 2 is a sample of recorded time series by our backscatter Lidar in December 25, 2005. Fig. 2 shows that cumulus clouds are passing over the Lidar site at altitudes about 1.3km (the Lidar site is at 1890m above the see level).

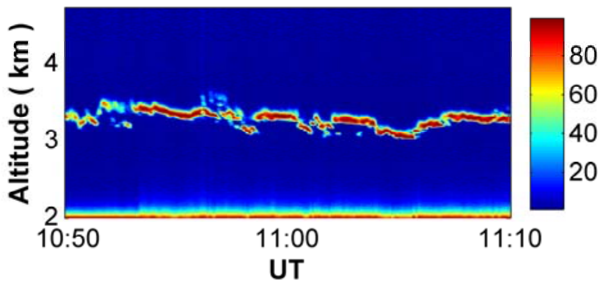

Figure 2. Recorded time-series by our backscatter Lidar in December 25, 2005, during the photography, cumulus clouds are at about 3.2km above the sea level and the Lidar is at 1890m above the sea level.

Tracking the cloud in synergy with a Lidar as an altimeter can provide different information. Wilkerson [8] and Pal [9] and their coworkers have used analog video imaginary for cloud tracking to monitor the velocity of whole cloud body. Also we used the time lapsed digital photography to track the cloud and so we have been able to specify the small scale cloud velocity profile in two dimensions (parallel to the earth surface) [6]. Here we are interested in

Table 1. The fitting parameters a, b and c for envelope of C_{mn}^{Max} histograms calculated for 6 different elapsed times

Time lapsed(2 sec)	a	b	c
1	43.4	2.5	0.2
2	49.5	2.9	0.4
3	53.3	3.1	0.6
5	62.6	3.2	0.7
5	80.0	3.1	0.9
6	80.0	3.4	1.0

small scale temporal evolution of cloud. As the calculations show, histograms of C_{mn}^{Max}, calculated for different elapsed times is a good measure of the evolution. Fig. 3 shows examples of such histograms. Eq. 3 is a proper fitting function to the envelops of the histograms.

$$y = a(1 - x)\exp((bx + c)^2) \quad (3)$$

In Eq. 3, y represents the population and x is the value of C_{mn}^{Max}. Values of fit parameters a, b and c for 6 different time lapses are appeared in Tab. 1. Eq. 3 shows that for $x = 1$ the population vanishes. This is in agreement with temporal evolution of cloud.

For the curves fitted to the envelope of each histogram (Fig. 3), the coordinates of maximum peak are represented by (C_0, P_0) and the half-width by W_0. P_0 is the population at the correlation value of C_0. Temporal behavior of these three parameters is shown in Fig. 4

As Fig. 4 shows W_0 almost has a linear increasing behavior in time while C_0 and P_0 are decreasing linearly. After a specific time the correlation is no longer significant. The specific time depends on the cloud velocity profile, the cell size and the camera FOV. For the cloud that is shown in Fig. 1, the specific time is in orders of 20 sec(10 elapsed time). This behavior can be seen in Fig. 3d, when the distribution of C_{mn}^{Max} became normal for the mentioned time.

In summary, by combining time-lapsed digital photography and the Lidar data for cloud altitude, we have been able to find a technique for monitoring the small scale temporal evolution of cloud. It should be noted the time correlation technique presented here can be used in many cases concerned with the evolution of nonrigid object.

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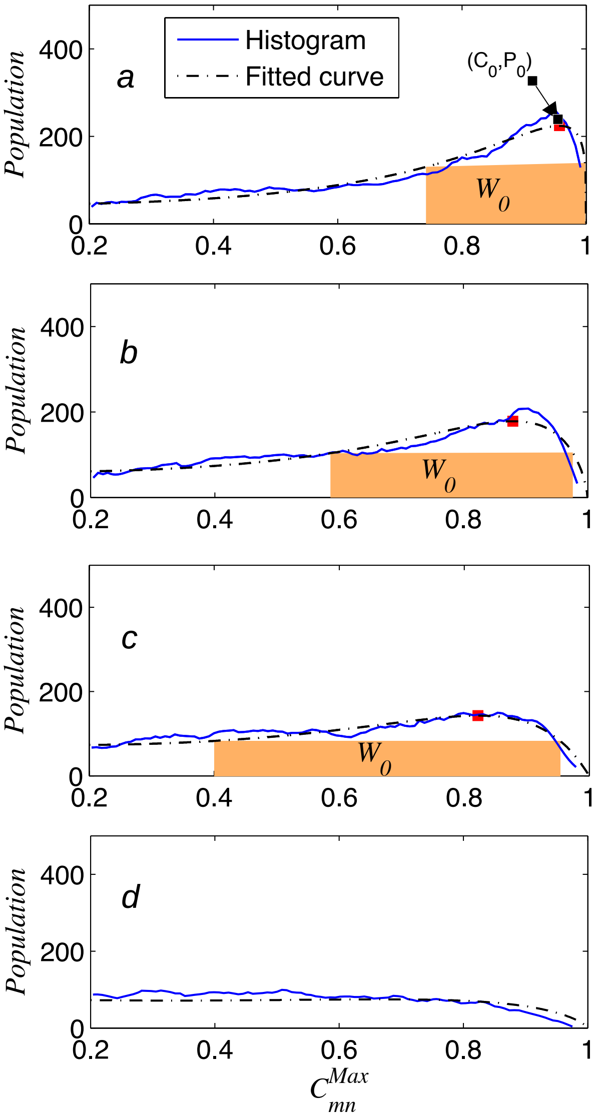

Figure 3. a, b, c and d envelope to histograms of C_{mn}^{Max} for 1, 4, 6 and 10 elapsed times (solid lines) and their corresponding fits obtained from Eq. 3 (dashed lines), As the time goes on, the weight of histograms tends to normal distribution and its half width increases.

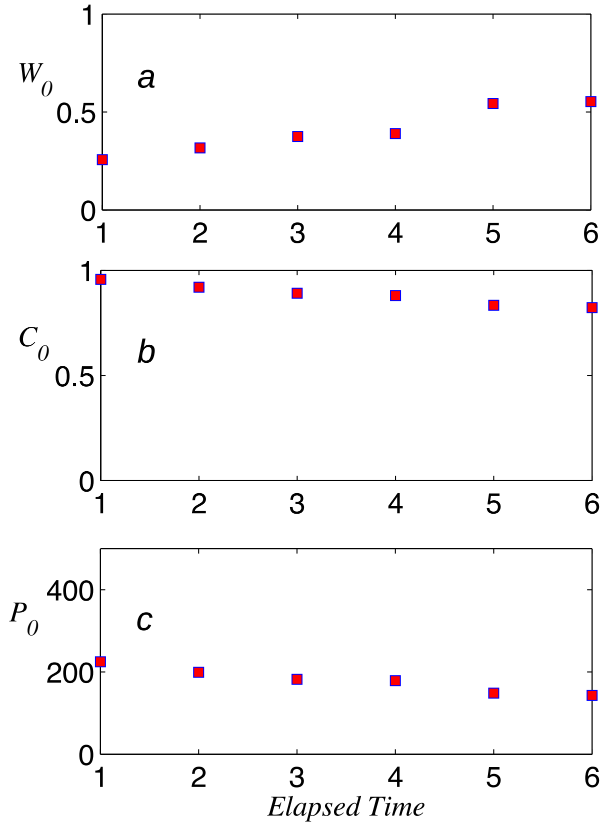

Figure 4. a, b and c temporal behavior of the width, W_0, the maximum peak position, C_0, and maximum peak of population, P_0, for the fitted curves at different elapsed times.