Determination of the Cirrus Outflow Divergence as Seen by Satellite

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ABSTRACT

Certain methods are tested to estimate the divergence of the outflow anvil of tropical cloud clusters. These methods are based on the change of digitized brightness values given by a sequence of satellite pictures. From five consecutive pictures of the geostationary satellite ATS 1 a magnitude of the divergence is deduced which is compatible with the results of other investigations.

1. Introduction

Most observational studies of tropical cloud clusters are based upon direct measurement of the basic atmospheric variables (temperature, humidity, wind, etc.) obtained from rawinsondes or by aircraft. Other studies use cloud photography in the visible and microwave range which are either ground based or airborne. But only a few investigations make use of satellite data to yield quantitative information on the internal dynamics of convective systems. Exceptions are the studies at the University of Wisconsin, Madison (Sikdar *et al.*, 1970) who use geostationary satellite cloud *photographs* to evaluate convective transports. Their investigation is based on a time change of brightness as a quantitative measure of the outflow divergence from a cloud cluster in the form of cirrus plumes. They interpret these data according to a simple three-layer model to derive the convective transports of latent heat. It is the purpose of this note to show how *digitized brightness data* can be used to study tropical cloud clusters, their changes with time, and the resulting horizontal divergence. Digitized brightness data provide far more information than cloud photographs and they are easier to handle with respect to data processing. We also show some techniques of the data processing for calculating the outflow divergence of a cloud ensemble using digitized satellite pictures. As an example the method is applied to a sequence of five ATS-I pictures for 16 September 1967 taken at 50 min time intervals (see Fig. 1, where the investigated cloud clusters are indicated).

2. Methodology

Satellite photographs show the time change of brightness for a given object (a convective cell, a cloud cluster, etc.), the brightness change resulting from a

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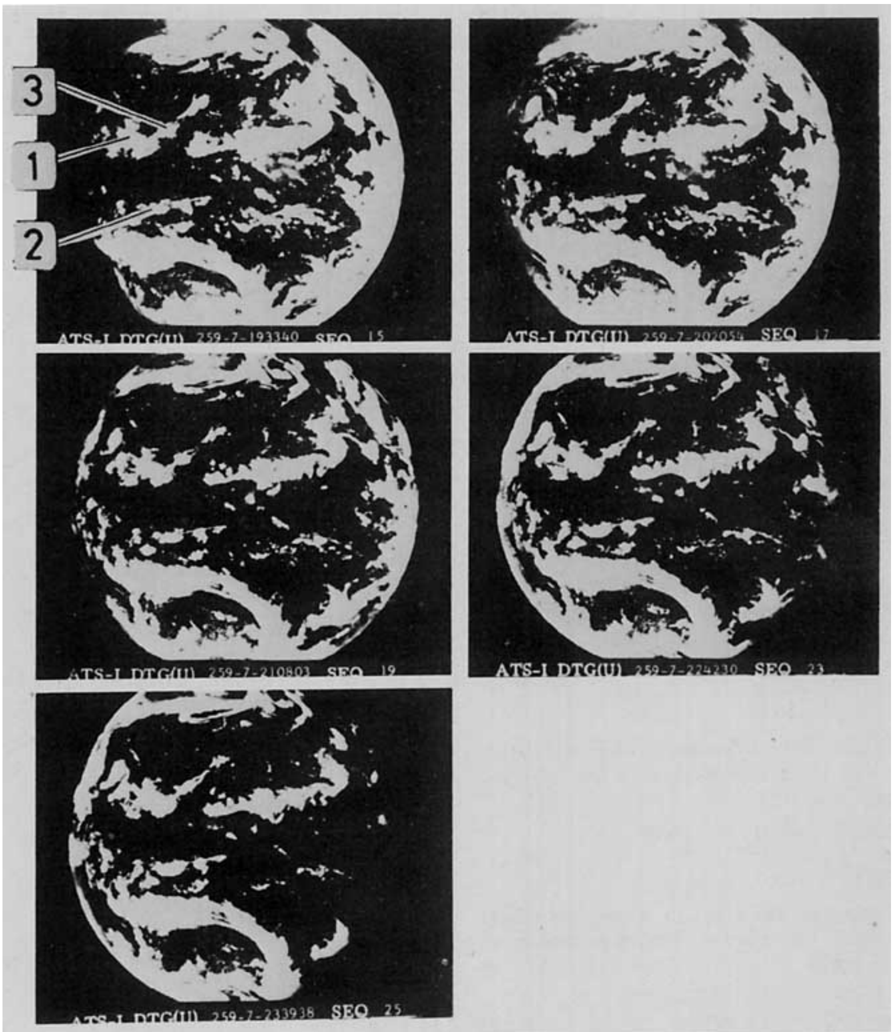


FIG. 1. Time sequence of the ATS 1 satellite photographs with three different cloud clusters indicated by the numbers 1, 2, 3.

change of the object itself which is the item of interest or a change of external influences (e.g., direction of solar radiation) which should be filtered out. In the following we consider an area defined by brightness values higher or equal to a prescribed limit. Assuming that such an area is representative of a cloud cluster or, more precisely, for the cirrus outflow anvil, the change of this area may provide a measure of the outflow divergence. If the time interval Δt between two consecutive satellite photographs is smaller than the half-lifetime of the object, the area change of the cirrus shield can be physically interpreted as follows.

The fractional rate of change of a horizontal area A representing the cross-section area of an air parcel is equal to the area-averaged horizontal velocity divergence

$$\frac{1}{A}\frac{dA}{dt}=\nabla_h\cdot\mathbf{V}. \tag{1}$$

Consequently, the area- *and* time-averaged divergence $(\overline{\nabla_h\cdot\mathbf{V}})$ is given by the time integral of (1), i.e.,

$$\frac{\ln(A_2/A_1)}{\Delta t}=\overline{\nabla_h\cdot\mathbf{V}}, \tag{2}$$

where the area is changing from A_1 to A_2 during the time interval $\Delta t=t_2-t_1$.

Now the problem is to find a suitable procedure to make use of the area changes of (digitized) brightness values so that the representative divergence [Eq. (2)] of the cirrus outflow can be deduced. The following two different methods are tested (minimum brightness defines the outer boundary of the area considered):

A The brightness remains the same throughout the sequence of satellite pictures.

B The brightness changes relative to the instantaneous maximum brightness of the picture.

Additionally, several classes of refinement are introduced for both methods by a stepwise decrease of the *minimum* lower brightness in order to determine the most suitable area of the object to be investigated.[3] Method A with a constant lower boundary of brightness throughout the sequence of pictures takes the cloud clusters as seen from satellite to be more or less invariant for changes of influences from external or internal origin (e.g., a height change of the cirrus outflow anvil, a change of its thickness, or a shift of the brightness scale within the electronic system of the satellite). All of these processes may lead to a change of brightness which does not need to be correlated with a change of divergence. Method B is an attempt to eliminate such processes.

Before applying the procedure described above a correction is introduced to eliminate the time change of reflectivity due to the position of the sun. The actual brightness values are diminished according to a cosine

[3] The curves in Figs. 2–4 are based on brightness value limits for areas considered as given below.

METHOD A [values based on the difference between the absolute brightness maximum and those associated with the following brightness values (curves k–s)]

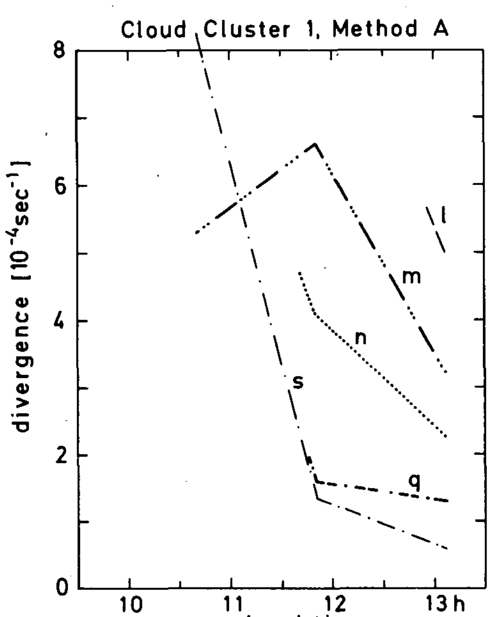
k≈180	n≈150	q≈120
l≈170	o≈140	r≈110
m≈160	p≈130	s≈100

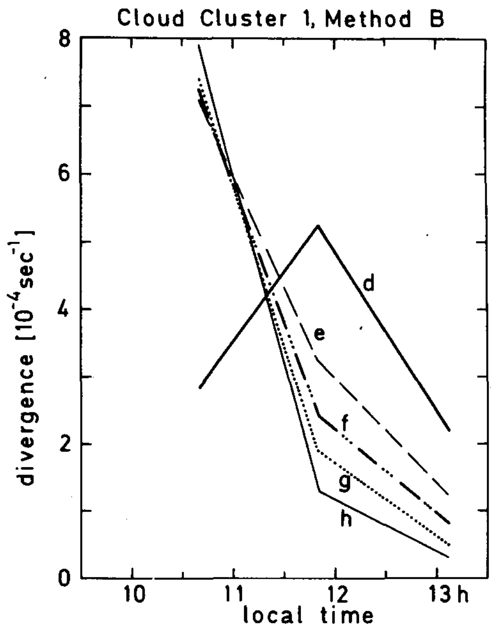
METHOD B [values based on the difference between the relative brightness maximum and those associated with the following lower boundary values (curves d–j)]

d≈10	g≈40	j≈70
e≈20	h≈50	
f≈30	i≈60	

[values based on the following percentage reductions from the relative brightness maximum (curves t–w)]

t≈0%	v≈25%
u≈10%	w≈40%





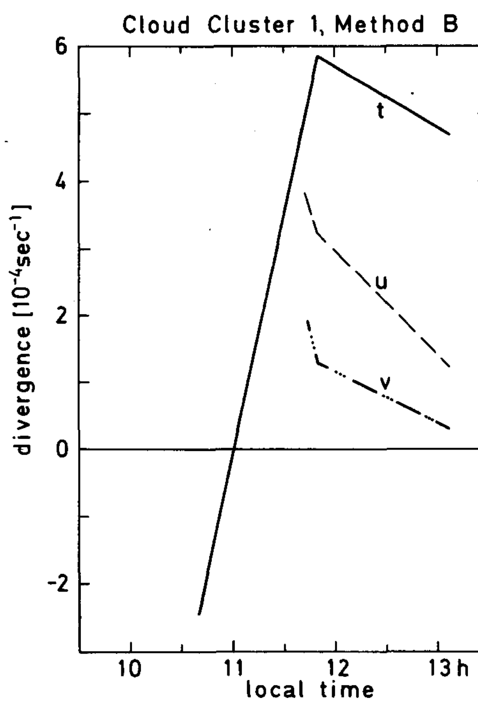
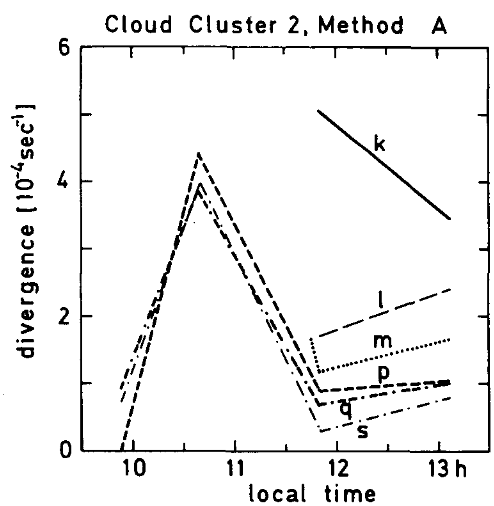


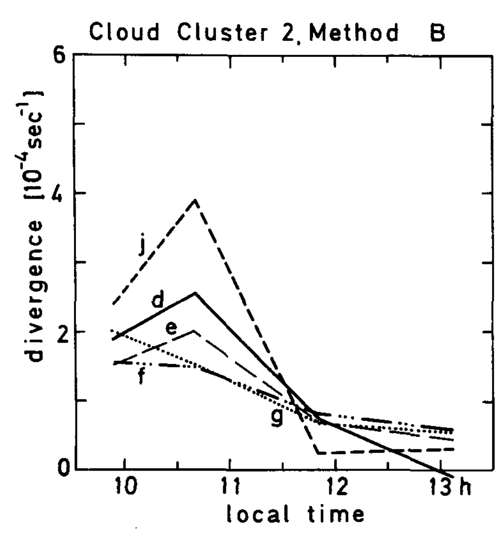
FIG. 2. Variation of divergence of the cloud cluster 1 determined from the digitized satellite pictures according to methods A and B (see text for definitions and areas considered).

law [amplitude—30% of the highest observable brightness (256 units)] with respect to amplitude and time, i.e., from the position of the sun glint toward the east or the west the brightness reduction decreases according to this cosine law. The satellite subpoint is at 0° latitude, 151°W longitude. The variation with latitude has not been considered because only tropical cloud clusters are investigated.

3. Application and results

Three cloud clusters over the Pacific Ocean are chosen for a test of the method described in Section 2. The positions of these systems are indicated in Fig. 1. Despite the different sizes of the cloud cluster (Fig. 1) they seem to be composed of the same type of clouds. The maximum brightness for all three cloud clusters is between 180 and 200 units. The divergence of the cirrus outflow is calculated according to Eq. (2) using the time interval between two consecutive pictures ($\sim$1 h) which is assumed to be small enough for our purposes. The results are shown in Figs. 2–4 for each cloud cluster separately. The results seem to be very reasonable. The divergence has the same magnitude as the values published by Sikdar *et al.* (1970), but is an order of magnitude larger than the west Pacific cloud cluster divergence deduced from composite rawin data by Ruprecht and Gray (1974). Their cloud cluster areas, however, are an order of magnitude larger due to the compositing technique. There appears to be no large difference between methods A and B although method B seems to be the most applicable because external noise of the brightness data is almost totally eliminated. Of greater importance is the stepwise increase of the representative area of the cirrus shield (due to a decrease of the lower boundary of the brightness) as might have been expected. See, for example, the different forms of the curves type d, k, c, t which are based on very small areas. The most suitable area for calculation of outflow divergence appears to be one defined by a lower boundary brightness of 25% ($\pm$10%) less than the instantaneous brightness maximum of the cloud cluster (types u, v or e, f). They show the smallest variations comparing all three cloud clusters. This result appears to be reasonable since a small brightness area does not characterize the total cloud cluster but rather a hot tower, whereas a much larger area may be significantly influenced by boundary effects (e.g., ice crystals evaporating due to subsidence lead to a reduction of brightness but not to a change of real divergence). Thus, in calculating the outflow divergence of a cloud cluster, the time change of a medium sized characteristic brightness area seems to be most suitable. The limiting values which we used are as follows: upper boundary, maximum brightness; lower boundary, maximum brightness minus 25% ($\pm$10%) of the maximum.





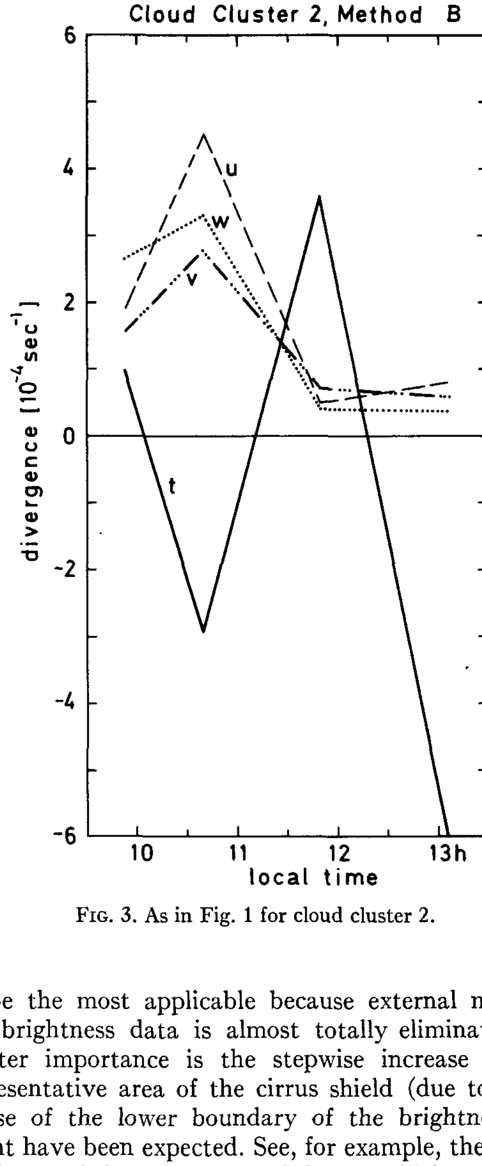
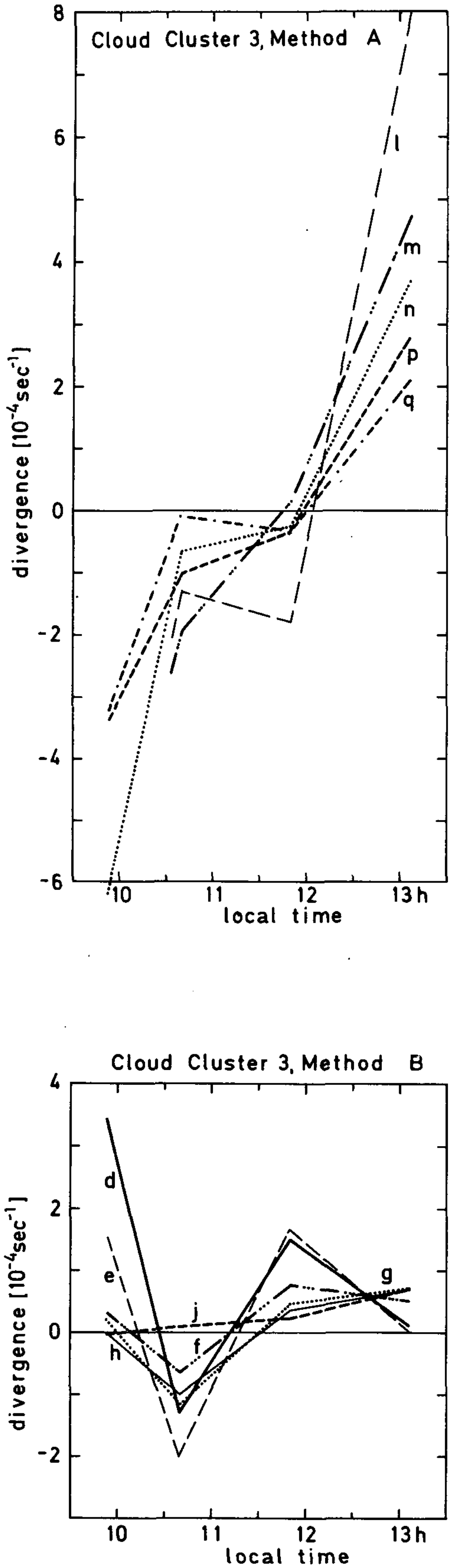


FIG. 3. As in Fig. 1 for cloud cluster 2.



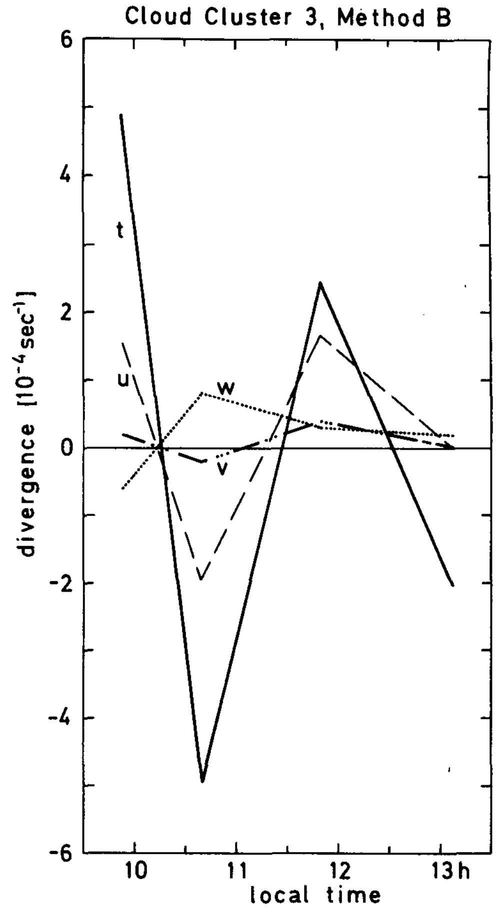


FIG. 4. As in Fig. 1 for cloud cluster 3.

4. Outlook

This note shows an attempt to deduce a quantitative measure of the outflow divergence of a tropical mesoscale convective system. The second step should lead to a vertical profile of the outflow divergence in order to obtain a measure of the vertical mass flux with these systems, which provides an independent procedure to test the techniques of parameterization of cumulus convection. Possibly, information from more advanced geostationary satellites (e.g., Meteosat) may yield this result.

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