Single Thresholding and Rain Area Delineation from Satellite Imagery

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ABSTRACT

In this paper the evaluation of very simple approaches to delineate the rain area from satellite imagery is assessed in terms of single thresholding. Results and comparison with other more complicated techniques indicate that single thresholding may be quite adequate in delineating instantaneous rainfall areas from a single visible or a single infrared image. The implication of these findings for large scale (space/time) rainfall retrieval from satellites is also discussed.

1. Introduction

The delineation of rainfall from satellite visible and/or infrared imagery has received well-deserved attention in the past 10 yr. The first step in the rainfall from space problem is the discrimination between rain and no-rain. This rain area then serves as an input to various techniques which yield point rainfall rates, volumetric rain rates, rain accumulation (at a point or over an area) etc. It is then not surprising that many techniques that delineate rain area for visible and/or infrared imagery have been developed. One set of such techniques are the so-called indexing techniques. According to the indexing techniques (for a review see Barrett and Martin 1981) rainfall depends on the cloud type. The rainfall area is found after the clouds have been classified to various types according to their spectral properties. Another set of relatively popular techniques are the bispectral methods. According to the bispectral methods, the rain area is determined using information from both images (Lovejoy and Austin 1979 and Bellon et al. 1980). Basically, these techniques define an optimum "boundary" in the visible/infrared domain that is used to discriminate between rain and no-rain. This optimum boundary is defined using a pattern recognition technique involving satellite and coextensive radar data. Apparently, these methods depend on radar data and therefore their applicability is limited only to areas over which adequate radar coverage is available. Tsonis and Isaac (1985) recently developed a technique according to which the above mentioned optimum boundary is determined without the need of coextensive radar data. Their technique makes use of the bivariate frequency distribution in the visible/infrared domain. It has been shown (Tsonis 1984) that the observed peaks of such distribution correspond to different classes. Tsonis and Isaac (1985) showed that the peaks that correspond to raining clouds tend to cluster in a well-defined region of the visible/infrared domain, thus allowing their discrimination from the other classes (clear skies, nonraining clouds, etc.). After that, the delineation of the rain area from the raining clouds is based on an optimum visible threshold which depends on the day, time and type of precipitation. Lately, Wu et al. (1985) and Tsonis (1987) presented pattern recognition approaches for classification of the satellite derived rain area into light moderate and heavy rain rate subareas.

All the above mentioned and other techniques have reported good results and have added to our knowledge of rainfall estimation from satellite imagery. However, even though each one of these techniques satisfies a need for the region for which it was developed, it is not certain that it will work in some other region of the world. Part of the problem may be that most of these methods exhibit a high degree of sophistication, which is usually coupled with the climatology of the region. This combination, on the one hand, results in good rain area estimation in a specific region but, on the other hand, makes the scheme "rigid" and "localized." This may be the reason that, in practice, much simpler approaches are employed (e.g., Martin and Howland 1986 and Arkin and Meisner 1987). Undoubtedly, simpler approaches are more flexible and, therefore, more easily applied over different regions and in larger time and space scales. Simple approaches can result in realistic convective rainfall estimates (Arkin and Meisner 1987) but a detailed evaluation of their performance has not yet been given. This is partly due to the lack of adequate ground truth systems.

In view of these facts, a very interesting question arises: What is the price paid by employing simple ap-

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proaches? What is the accuracy loss due to simplicity? The purpose of this work is to evaluate, in detail, the skills of simple approaches in estimating mesoscale instantaneous rainfall and to compare the results with results obtained by more elaborate techniques on the same and on different datasets. The verifying dataset used in Tsonis and Isaac (1985) will be used to achieve the objectives of this work. Complete description of the dataset can be found there.

2. Approach

A method which delineates the rain area by using a single threshold from a single image (visible or infrared) is apparently the simplest possible. Since the purpose of this work is to evaluate the skills of very simple approaches, the accuracy of single thresholding is evaluated in detail.

The evaluation of the rain are delineation techniques is usually based on the following variables.

N_N number of points correctly classified no-rain.
N_R number of points incorrectly classified no-rain (misses).
R_N number of points incorrectly classified rain (false alarms).
R_R number of points correctly classified rain (hits).

Accordingly, the satellite delineated rain area can be expressed as

$$\hat{A}_R = R_N + R_R.$$

For the following formulations, A_R will denote the radar rain area as indicated by the radar echo top maps. From the above notation, many statistics have been devised in order to evaluate a rain area estimation method using satellite data. The most commonly used are:

1) the *probability of detection* (POD) defined as

$$\text{POD} = R_R/A_R;$$

2) the *false alarm ratio* (FAR) defined as

$$\text{FAR} = 1 - (R_R/\hat{A}_R);$$

3) the *percent error* f defined as

$$f = (N_R + R_N)/(R + N),$$

where

$$R = R_N + R_R,$$

$$N = N_N + N_R.$$

A perfect method will give POD = 1, FAR = 0 and $f = 0$. However, none of these statistics can be considered as more representative of the success of the method. Each statistic gives additional information about the success of the rain area delineation from the satellite data. For example, the POD gives an idea of the ability of the scheme to "find" the rain. However, a scheme could create a rain area five or ten times larger than the actual area and still give a POD of one. Therefore, high POD should be accompanied by a small FAR in order to be meaningful. The percent error is representative of the error in rain area delineation with respect to the total area over which the method is applied. The percent error could be small even when POD is low and FAR is high, especially when we are dealing with small precipitation areas. The reverse could also be the case. For a direct comparison between different techniques, more than one statistic should be used.

3. Results and comparison with other methods

Figure 1 shows the average values for POD, FAR and the percent error as a function of the visible threshold. Selective error bars indicate observed standard deviations. Figure 2 is similar to Fig. 1, but for the infrared threshold. The general shape of these curves is justified. For very low threshold (visible or infrared), too much rain area is usually delineated. This means that $R_R \rightarrow A_R$ and $R_R/\hat{A}_R \ll 1$. Thus, POD $\rightarrow$ 1 and FAR $\rightarrow$ 1. At the same time $N_R \rightarrow 0$ and, thus, $f = R_N/A$ where $A = R + N$ (the radar covered area). For very small thresholds the average percent error will be proportional to the average R_N, which should be close to $A - \bar{A}_R$ ($\bar{A}_R$ is the average rain area for the cases studied). As we increase the threshold we obviously delineate smaller rain areas (FAR $\rightarrow$ 0), but at the same time we may miss some rain (POD will decrease). Therefore, by this method we approach some optimum threshold that balances the POD and FAR and effectively avoids some of the potential discrepancies mentioned in the previous section. Thus, we should expect that the percent error will decrease as well. For very high threshold values we delineate very small rain areas. Therefore, in this case $R_R \approx \hat{A}_R \rightarrow 0$. Thus POD $\approx$ FAR $\rightarrow$ 0. At the same time $R_N \rightarrow 0$ and thus $f = N_R/A$. Thus, for very high thresholds the average percent error will be proportional to the average N_R which will be close to $\bar{A}_R$. Therefore, POD and FAR should decrease monotonically as a function of the threshold (visible or infrared). The percent error should decrease up to some threshold and then may increase for high thresholds. In addition, for very low thresholds one always delineates too much rain with the consequence that one always obtains POD $\approx$ 1. Similarly, for very high thresholds one always delineates very little rain thus always obtaining POD $\approx$ 0.0. Because of this, a smaller standard deviation is expected for very low and very high thresholds. Similar arguments can be extended for FAR. Unfortunately, the above statistics can not be unified in order to quantitatively evaluate a technique.

The evaluation of the results is therefore left to the user and should be compared to results reported in a similar fashion from other methods.

As Figs. 1 and 2 indicate, using a visible threshold of 50 (which may constitute an optimum threshold), the following mean (standard deviation) values are obtained: POD = 0.62 (0.13), FAR = 0.38 (0.16) and f = 0.22 (0.06). The corresponding values for a visible threshold of 52 are 0.53 (0.14), 0.34 (0.16) and 0.19 (0.06). In the infrared domain, a threshold of 170 (−28°C) yields the following values: POD = 0.60 (0.14), FAR = 0.40 (0.18) and f = 0.30 (0.07). These values change to 0.48 (0.14), 0.30 (0.17) and 0.26 (0.08), respectively, if an infrared threshold of 180 (−35°C) is used. In general, it seems that an optimum threshold in the visible will be more efficient than an optimum threshold in the infrared. This is consistent with previous findings (Tsonis and Isaac 1985; Lovejoy and Austin 1979; and many others) that the visible images are about 10–15% more efficient than the infrared images in delineating the rain area. These values are very comparable to those reported in Tsonis and Isaac (1985) for the same dataset obtained using a much more elaborate technique. Tsonis and Isaac (1985) reported the following average statistic values: POD = 0.66 (0.12), FAR = 0.37 (0.14) and f = 0.20 (0.055). These values are only slightly different than those obtained by using, for example, a visible threshold of 50 (mean accuracies decrease by approximately 5%) or by using an infrared threshold of 175 (mean accuracies decrease by approximately 20%). These results are also comparable to those reported by Lovejoy and Austin (1979). According to their approach, the rain area is obtained by pattern recognition between visible, infrared and coextensive radar data. For a specific area (over which coverage by a training radar is available), the probability of rain is derived by considering the bivariate frequency distributions in the visible/infrared domain of the raining and of the nonraining points. The derived probability of rain is then applied outside the area covered by the training radar. The success of the method outside the training area is usually evaluated by another radar (verifying radar). The above technique shows good skill in delineating the rain area over the range of the training radar, but accuracy decreases with distance outside that range. In their analysis of the area covered by radar, Lovejoy and Austin report an average value for the POD of 0.55 (0.14) and an average value for the percent error of 0.13 (0.04). Both of these techniques are highly sophisticated and reportedly have high accuracies. However,

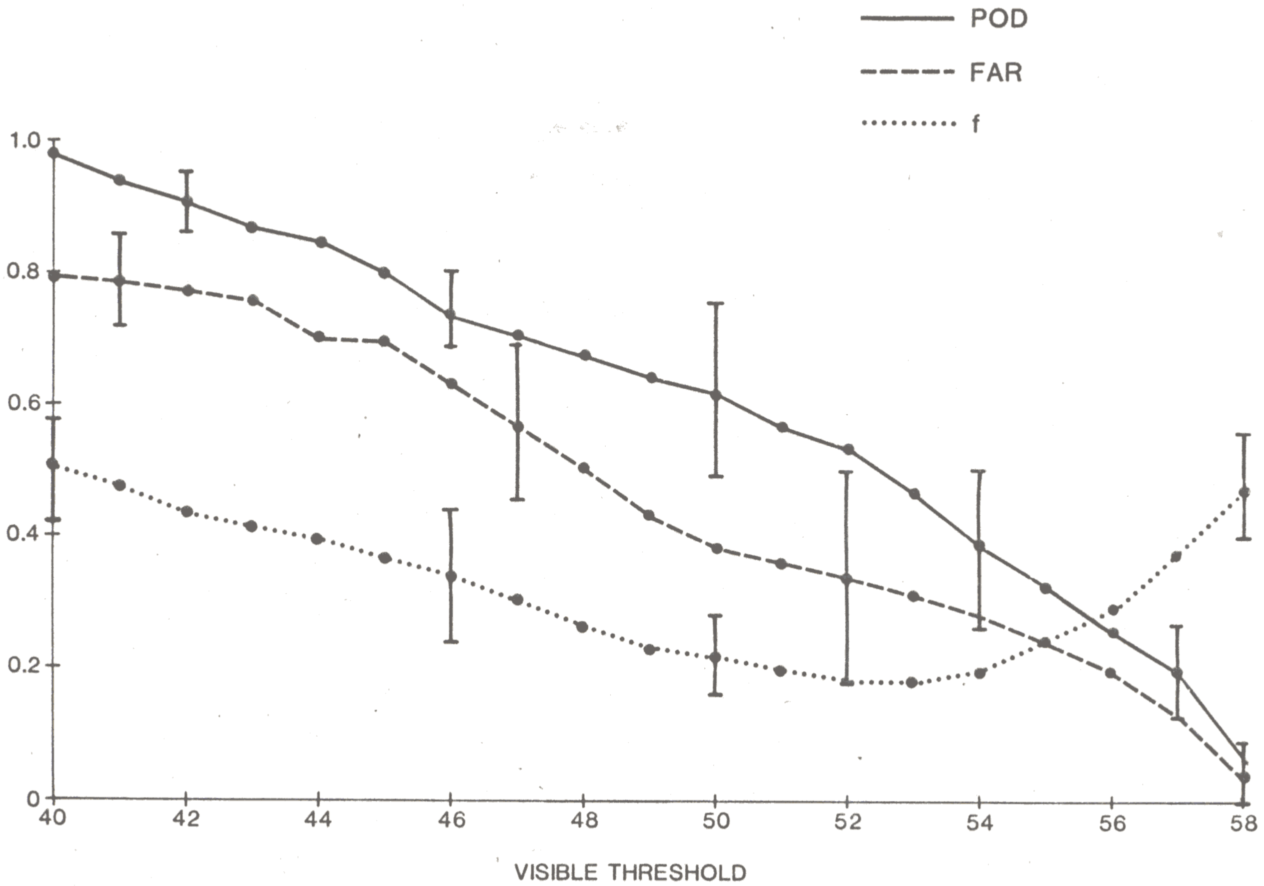

FIG. 1. Average probability of detection (POD), false alarms ratio (FAR) and percent error (f) as a function of the visible threshold. Selective error bars indicate observed standard deviations.

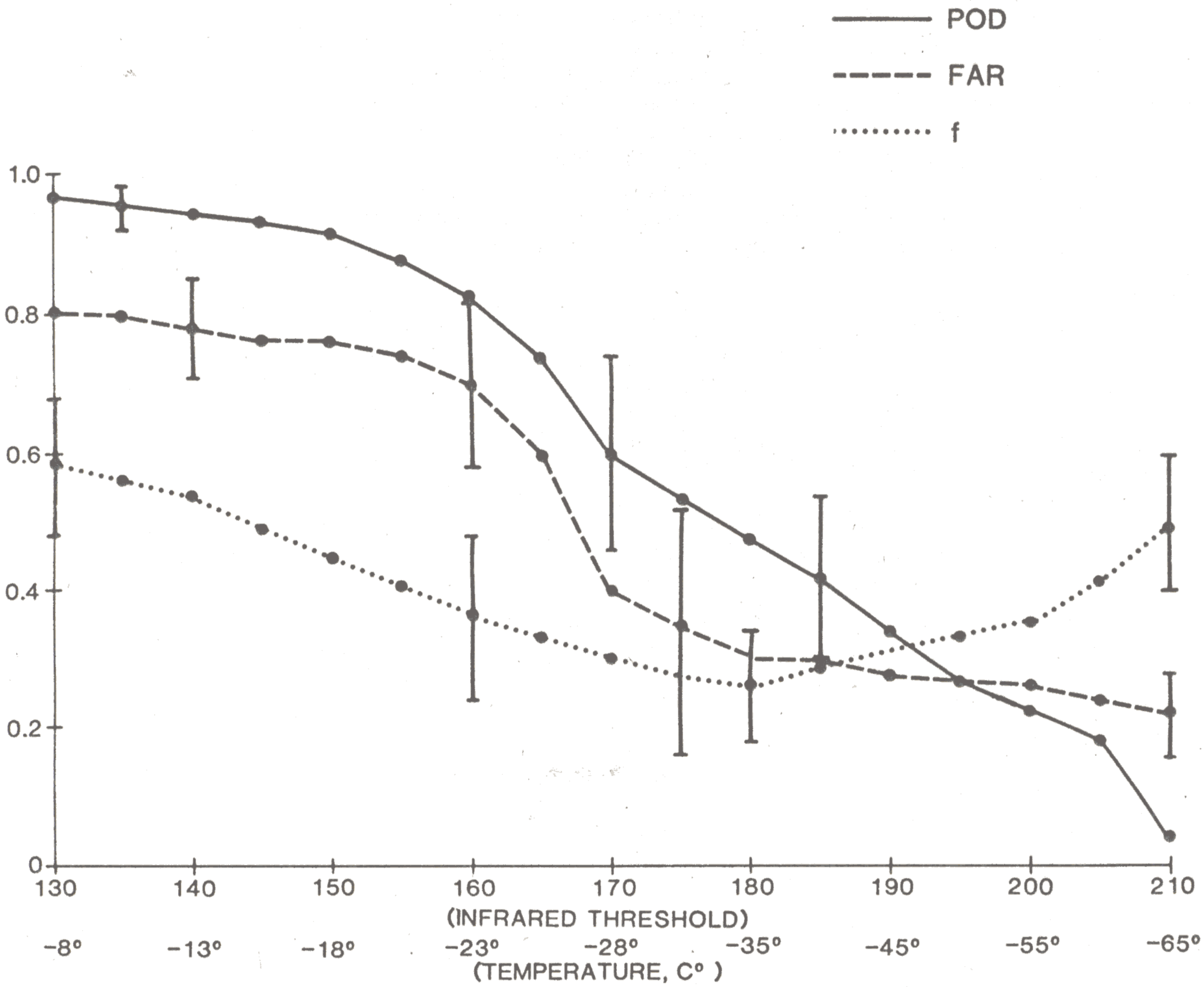

FIG. 2. As in Fig. 1 but for infrared thresholds.

their sophistication may result in only slightly better estimation of rain area compared to very simple single thresholding. Direct comparison with other techniques is rather difficult mainly because 1) a detailed evaluation of the accuracy of many schemes has not been performed, and 2) the statistics used to evaluate their performance are different. Most will agree that very few techniques dealing with the estimation of rainfall in the midlatitudes by satellite imagery result in a success on the order of 60–70%—and/or are often accurate to within a factor of two of what actually occurred.

This analysis considered convective and nonconvective cases together. The results do not change significantly when they are considered separately, but, in general, single thresholding works somewhat better in convective cases. A classic example which supports the findings reported here is the work by Negri et al. (1984) in which a detailed evaluation of the Griffith-Woodley Technique (GWT, Griffith et al. 1978) was performed. The GWT technique calculates rain amounts using an elaborate method that involves the past history of clouds. Their analysis suggests an average percent error of about 130%. Negri et al. simplified the GWT by effectively eliminating the need for cloud life history. The result was a much lower estimate for the percent error (about 40%). They then concluded that ". . . the GWT rain volume calculation and the GWT apportionment algorithm are unnecessarily complicated. . . ." Although Negri et al. refer to rain amounts and not to rain area, their point is similar to that being made in this work.

4. Conclusions and remarks

Lately, it has been recognized that the need for rain estimation on a large or a global scale is necessary if we are to improve our understanding of climate and its changes in time scales longer than one month. Towards this goal, a rain area estimation scheme which could be easily applied over large areas should be developed. Such a scheme—if it is to be applied on a global scale—should be as accurate and as simple as possible. Thus, an assessment of the accuracy of simple approaches and an investigation of the accuracy loss when results obtained by simple methods are compared to results obtained by more elaborate techniques should be made.

This assessment was made in terms of single thresholding and instantaneous rain area delineation in the midlatitudes at a spatial resolution of 4 × 4 km. It was found that, in general, very little accuracy will be lost if simple approaches will be considered. This loss of accuracy will be compensated for by less time for processing the data, more flexibility (and therefore applicability of the results), and less cost. Lately, (and while this work was being reviewed) Negri and Adler (1987) reported that single thresholding resulted in very accurate rain area estimation in the tropics. The results reported here deal specifically with instantaneous rain area delineation and do not imply that more elaborate techniques are useless. We suggest, however, that accuracy requirements should be critically addressed and investigated before a scheme is employed. The results reported here may have implications for the large scale and long time-scale estimates of rain, which are the result of averaging many sequences of smaller scale estimates. The link or interaction between smaller and larger scales is not very well understood. Nonlinearities in the atmosphere may result in large fluctuations in the large scale from a small deviation in a smaller scale. In such a case, if the error in estimating some variable (such as rain) in a smaller scale is significant, should a large scale mean be considered as adequate? The results reported here suggest that the loss of accuracy is rather small. Therefore, simple techniques may be our hope for a future scheme which can be easily adjusted to delineate rain area from satellite imagery over different (in a climatological sense) areas of the globe.

Why do simple approaches perform as well as more complicated approaches? Delineation of rain from visible and infrared imagery is based on the fact that thick (high visible response) and tall (high infrared response) clouds will most likely precipitate. That is all the physics that enter this problem. Rainfall, however, is not that simple. Rainfall exhibits an extreme variability and complicated physics. When the sources of detecting precipitation are based on one or two parameters which may not even be directly related to precipitation, it is suggested that the simple approaches have as good a chance of success as the very complicated techniques.

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