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STUDY ON THE RELATIONSHIP BETWEEN BRIGHTNESS TEMPERATURE FROM GMS-5 INFRARED CLOUD IMAGERY AND SURFACE RAIN RATES DURING THE RAINING SEASONS OF FUJIAN PROVINCE

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ABSTRACT: The GMS-5 infrared cloud imagery for two yearly first raining seasons in 1998 and 1999 are used to study the relationship between brightness temperature and surface rain rates. The result shows that it is likely to have large probability of heavy precipitation with the decrease of brightness temperature and the gradual increase of rainfall intensity; for areas of low temperature, the brightness temperature is better determined for atmosphere above rain gauge stations with multiple points sampling than with single point one; for the yearly first raining season, the threshold brightness temperature is set at –4.6℃ for indication of heavy precipitation in the Fujian area.

Key words: yearly first raining seasons; GMS-5; cloud top temperature; rainfall intensity

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1 INTRODUCTION

In recent years, the infrared cloud imagery from the GMS series satellites has used more and more in studies of heavy precipitation in the yearly first raining seasons in China. The use in the analysis of heavy rain processes and quantitative estimation of rainfall is one of the aspects that witness wide application. Quantitative estimation of rainfall with satellite cloud imagery has been an important research subject for meteorologists at home and abroad. In his efforts to studying ways of estimating severe convective precipitation, Scofield (1987) uses the infrared and visible cloud imagery from geostationary meteorological satellites, together with cloud features shown on two consecutive cloud imagery[1]. Gilberto et al. (1998) set up a relationship between the brightness temperature and precipitation intensity by treating as “true values” the precipitation retrieved through GOES-8 brightness temperature and radar echoes taken simultaneously[2]. Xia et al[3]. estimate precipitation by establishing a relationship between the levels of brightness temperature of convective cloud clusters in infrared imagery and the area they take up and the 3-hr surface rainfall. It is well known that the genesis, evolution, maturing and decaying of cloud bodies can be described with the variation of their brightness temperature and corresponding surface rainfall. It is our attempt to discuss and determine, with the brightness temperature, the conditions for cloud bodies to develop to cause heavy precipitation over the region of Fujian. Strictly speaking, the brightness temperature is related to precipitation in a complicated way, making it essential to properly analyze and utilize it based on infrared cloud imagery data. Indefiniteness, as reported by a number of researchers, does exist when it comes to quantitative

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estimation of rainfall with brightness temperature. Does it have something to do with the technique used in sampling? Is it appropriate that the brightness temperature observed at a moment at a given point of the cloud body is used to reflect the variation of surface rainfall within 1 hour? These are the issues worth more earnest study. It is also an issue of common interest whether the threshold brightness temperature for severe precipitation is a range. T_{BB} is used to express the brightness temperature.

For the purpose, the hourly infrared cloud imagery of GMS-5 and surface rain rates observed from 68 weather stations of the province are selected in the work. Two sampling methods (single-point and 9-point averaging) are used to get values of the cloud brightness temperature. They are then compared with corresponding rain rates to determine the relationship between the brightness temperature and surface rain rates over the Fujian area during the yearly first raining season. In the final step, the brightness temperature for heavy precipitation is calculated in terms of accumulative frequency distribution to determine the thresholds, in the hope to assist relevant forecasting.

2 DATA COLLECTION AND PROCESSING

For the months April to June in 1998 and 1999, 2182 sets of GMS-5 infrared cloud imagery data, with a resolution of $0.05° \times 0.05°$, are collected. To make it more illustrative, the relationship between the greyness of infrared channels of the GMS-5 and the temperature is followed to convert observed cloud-top greyness into brightness temperature so as to describe directly how the clouds vary. Setting 1° as a level, a total of 111 levels are divided for the range between –81.5°C and 30.2°C. Particularly, $T_{BB} \leq -80°C$ and $T_{BB} \geq 30°C$ are each a level on their own. In the meantime, corrections are made to the singular points of one or two brightness temperatures due to signal noise. To investigate whether changes would be resulted in the relationship between the brightness temperature and surface rain rates because of the difference in the coverage of sampling, comparisons of value assumption are made between the single-point approach and the 9-point averaging technique and the methods are given as follows:

Single-point: $T_{BB1} = T(i, j)$

Nine-point: $T_{BB9} = [T(i-1, j-1)+T(i-1, j)+T(i-1, j+1)+T(i, j-1)+T(i, j)+T(i, j+1)+T(i+1, j-1)+T(i+1, j)+T(i+1, j+1)]/9$

in which T_{BB1} and T_{BB9} are respectively the average values taken with the single-point and 9-point samplings, with $T(i, j)$ the brightness temperature or surface temperature for a given rain gauge station (i, j).

The surface rain rates are from hourly rainfall observations from rain gauge stations. There are 148376 sets of efficient data covering 2 years and 6 months, which include cases with and without precipitation. For cloud imagery over a specific period, the surface rainfall within 1 hour of the hour is used to match it.

To establish the relationship between the brightness temperature and surface rain rates, five levels are divided for the latter (R) following a relevant category method[1]: rainless (R = 0 mm/h), mild rain ($0 < R \leq 2.5$ mm/h), moderate rain ($2.5 < R \leq 7.9$ mm/h), heavy rain ($8 < R \leq 15.9$ mm/h) and extra-heavy rain ($R \geq 16$ mm/h). Specifically, precipitation above the level of $R \geq 8$ mm/h is defined as severe precipitation. $\overline{R}$ is the mean rain rate (mm/h).

3 STATISTIC ANALYSIS AND RESULTS

3.1 *Relationship between brightness temperature and surface rain rate*

Firstly, it is assumed that brightness temperature at any levels of intensity can be with precipitation. The whole sample (147735 pairs of data) for the brightness and surface rain rates collected for April – June in 1998 and 1999 are studied by seeking averages for the latter based on each of the levels of the former. A curve is thus obtained indicating the relationship between the two for the Fujian region (as shown by the fine solid line in Fig.1, called Curve A). In the same way, the two kinds of data (26835 pairs of precipitation in all) are also studied that correspond to appearance of precipitation to determine another curve of relationship (as shown by the bold solid line in Fig.1, called Curve B).

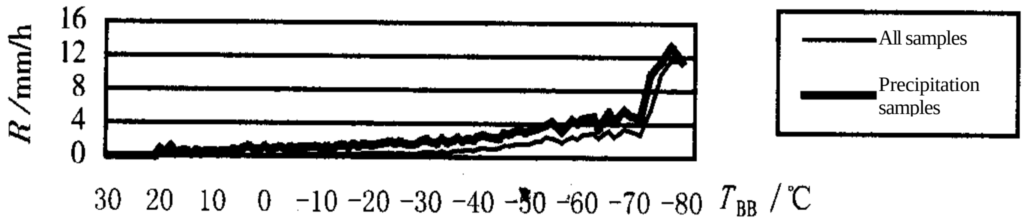

Fig.1 The relationship between brightness temperature and surface rain rates (single-point sampling)

It is clear from Fig.1 that the surface mean rain rate is almost zero when the brightness temperature stays above 0°C, in the case of Curve A, which begins a slow ascent with the decrease of the brightness temperature. It is interesting to note that the mean rain rate gradually climbs from 0.6 mm/h at the point of –30°C to 4.2 mm/h when it is –73°C. When the brightness temperature drops below –73°C, the surface rain rate increases rapidly, acquiring, say, the intensity of 11.7 mm/h. While Curves A and B have the same trend of variation, the surface rain rate on every point on Curve B is about twice as large as that on Curve A, especially so in regions where the brightness temperature is higher than –40°C, though the difference gradually decreases with the reduction of the brightness temperature. When it falls to –78°C, the rain rate is 13.3 mm/h at a corresponding point of Curve B, only 1.6 mm higher than that on Curve A. It indicates that the lower the brightness temperature of a cloud, the more likely it is for precipitation to appear at corresponding locations on surface. The two samples tend to be close to each other within this section of temperature in terms of precipitation probability, resulting in small gaps of mean rain rates.

The results above have much in common with the relationship curves between cloud-top greyness and surface rain rates, as reported in [2], suggesting that the brightness temperature be indeed related to the surface rain rates to some extent. They are not, however, linearly distributed, as shown in the variation trend of the curves in Fig.1. It is desirable to separate the zones of brightness temperature by the magnitude of the value and calculate section by section when one gives quantitative precipitation estimation with the aid of the brightness temperature of the infrared cloud imagery.

3.2 *Relationship between brightness temperature and surface rain rates with varied sampling methods*

Fig.2 and Fig.3 give the curves of the variation of the surface rain rates with the brightness temperature in all samples and precipitation samples, with the two sampling methods. It is not hard to see that the relationship is generally tangled by either of the two sampling methods when the brightness temperature is over –70°C; the difference is large between the single-point and 9-point approaches. When it is, for example, –78°C, the mean surface rain rates with the two methods are 11.7 mm/h and 19.3 mm/h for the whole sample, and 13.3 mm/h and 19.3 mm/h for the precipitation sample, respectively. With the 9-point sampling, the mean rain rate is generally the same for the two samples. It is contributed by the fact that the probability is almost as high as 95% for precipitation to appear when the brightness temperature is –78°C; the mean rain rates should be reasonably the same as the size is basically the same between the total sample and precipitation sample. With the single-point sampling method, the difference is quite large between the two mean rain rates. It is due to the fact that as the brightness temperature is cooler than –72°C, most of the cloud bodies are well into the mature phase, with the appearance of a strong center that is much smaller in size than the cloud systems adjacent to it. It can be inferred that when the brightness temperature is in a low area, the 9-point approach may give more objective and accurate results than the single-point approach, because the former takes into account the factor of cloud body movement. For the single-point sampling, observation is often absent of the movement of severe centers so that the variation of brightness temperature and surface precipitation thus reflected are far from what is actually observed.

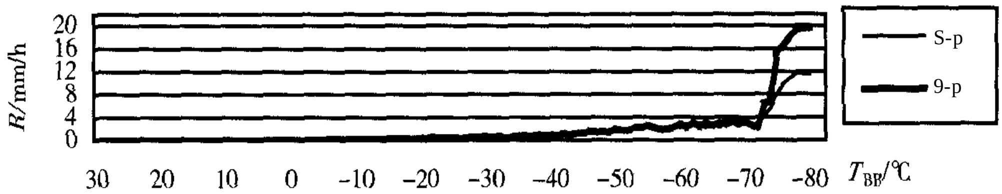

Fig.2 The relationship between brightness temperature and rain rates with two sampling techniques (all samples). "S-p" and "9-p" stand for single-point and nine-point samplings, respectively. They carry the same meaning in Fig.3.

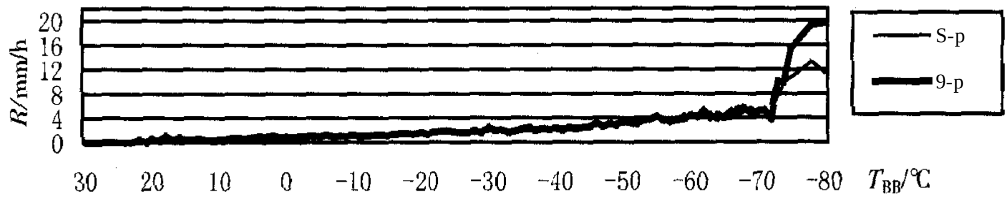

Fig.3 The same as Fig.3 but for precipitation samples.

3.3 *Precipitation probability with brightness temperature*

The relationship between the brightness temperature and surface rain rate is, as shown in the study, complicated, so that lower temperature does not necessarily indicate the company of precipitation. When clouds develop from maturing stage to decaying stage, the brightness temperature remains low while the ability to precipitate has weakened. It is indicated that precipitation can vary much even if the brightness temperature is comparable between the front and rear sides of the body in different stages of the evolution. It is then necessary to study the probability for all levels of precipitation to appear on surface corresponding to a particular level of brightness temperature.

Fig.4 gives the statistical results of the probability for all intensity levels of precipitation to appear with the change of cloud brightness temperature, in the case of single-point sampling. It shows that there is 1% of the chance that heavy rain occurs when brightness temperature is above –30°C, which is small enough to be ignored. So is the case of extra heavy rain when brightness temperature is above –40°C. In contrast, there is nearly 60% of the chance that no precipitation occurs with the brightness temperature is above –40°C. When it falls from –40°C to –70°C, precipitation is mainly of mild intensity at corresponding locations with probabilities ranging between 30% and 33%; the moderate rain takes place with frequency increasing from 7.9% to about 18%; the heavy and extra heavy rains appear with frequency increasing from 2% to 8.7%

and from 1% to 7.2%, respectively. It shows that the chance for moderate, heavy and extra heavy rains to occur is increasing with the decrease of brightness temperature. When it falls below –72°C in the cloud, the chance for heavy and extra heavy rains to occur will double. For instance, the probability is 37% for moderate rain to appear at –78°C, 40.9% for heavy rain at –76°C and 33% for extra heavy rain at 33%.

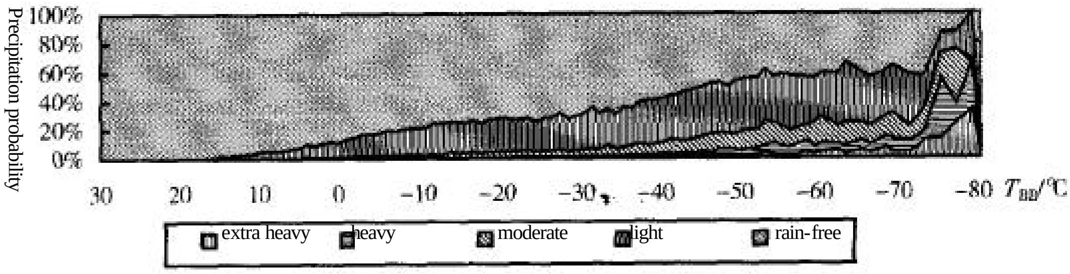

Fig.4 Probability of occurrence of precipitation levels with cloud-top temperature variation (single-point)

Comparing the results of single-point and 9-point samplings (figure omitted), we know that the trend of precipitation intensity varying with brightness temperature is generally the same except when it is cooler than –72°C. It is suggested that difference in sampling methods will have large impact on the mean brightness temperature so determined, as far as the relatively cool clouds are concerned. It attributes to the fact that low brightness temperature of the clouds is often accompanying severe convection centers inside the clouds, most of which are in the maturing stage; brightness temperature is not as accurately measured with the single-point sampling as with multiple-point sampling, due to factors like small scales and migrating nature of the clouds.

3.4 *Brightness temperature thresholds for severe precipitation*

Analyzing the GMS-5 infrared cloud imagery, we find that there are isolated convective cells among patches of low-level clouds, with the brightness temperature decreasing and cloud scale enlarging, with time, corresponding to the occurrence of severe precipitation on surface. Usually, the brightness temperature is used as an indicator for judging whether clouds are in the developing stage and a given level of the temperature (i.e. the thresholds) is used to determine whether severe precipitation will occur from the clouds. For the purpose, the sets of brightness temperature are selected that accompany severe precipitation in April – June in the two years to calculate the distribution of accumulative frequency, F (T_{BB}); the brightness temperature with F (T_{BB}) being equal to 50% is isolated to be the threshold for severe precipitation. When the brightness temperature falls to the point, it is observed, the probability increases dramatically for clouds to precipitate severely, in conjunction with the results of Fig.1.

Fig.5 gives the curves for the variation of F (T_{BB}) of severe precipitation with brightness temperature, using the sampling techniques. It shows that the distribution curves are basically consistent with each other with the thresholds being –46°C and –45°C, respectively. It suggests that the determination of brightness temperature thresholds be generally independent of the ways in which samples are taken and it is set to be –46°C for severe precipitation during the yearly first raining season of Fujian.

As shown in past studies[3], cloud-top mean temperature tends to drop over Fujian in April – June, making it necessary to study the thresholds for severe precipitation within each of the three months. Fig.6 gives the curves for the variation of F (T_{BB}) of severe precipitation in the months with brightness temperature, using the single-point sampling technique. It shows that the difference is quite large among the months, generally consistent with the trend of mean brightness temperature variation in clouds over the region, which is falling as it progresses from April to June. It is –39°C for April, –49°C for May and –53°C for June, respectively. It is therefore necessary to choose the right threshold of severe precipitation over a specific period when we employ infrared cloud imagery for the study.

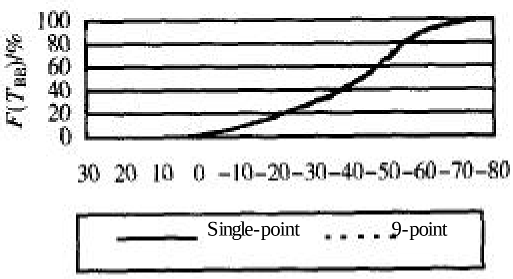

Fig.5 Accumulative frequency distribution of cloud-top temperature for severe precipitation with the two samplings

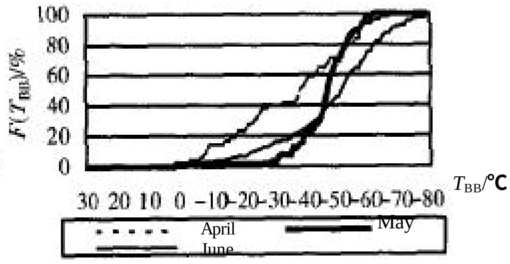

Fig.6 Same as Fig.5 but for April – June

4 CONCLUDING REMARKS

a. As found in GMS-5 infrared cloud imagery, specific relationships exist between brightness temperature of clouds and surface rain rates; the intensity of precipitation and the chance for heavy and extra heavy rains to appear are increasing. The increase of rain rates is particularly obvious when the brightness temperature drops below –72°C.

b. For clouds with relatively high brightness temperature, the methods in which samples are taken have little effect on value assumption. When clouds develop to the maturing stage, the multiple-point sampling method yield better results than the single-point one. It should be emphasized more in quantitative estimation of precipitation in future.

c. For the Fujian region, the threshold brightness temperature is –46°C for severe precipitation to occur. Dividing by the month, the thresholds are –39°C for April, –49°C for May and –53°C for June, respectively.

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