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Whole Sky Infrared Remote Sensing of Cloud

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Abstract

Clouds are important factors in weather and climate change. Cloud amount, type and height are measured by means of both visual observation on ground and satellites ever before. In recent years, instruments of measuring clouds on ground have been developed. This paper introduces our progress on ground based whole sky infrared remote sensing of cloud. Some results are given. A method for determining clear sky radiance threshold was suggested, and cloud identification combined threshold method with texture method was discussed. An algorithm retrieving cloud base height from downwelling infrared radiance was suggested. Cloud classification of ground based whole sky cloud images was discussed. Structural features are better than texture features in classifying clouds.

Keywords: cloud; cloud amount; cloud classification; cloud base height; whole-sky infrared remote sensing

1. Introduction

Clouds play an important role in the earth's radiation budget and climate change. Their shape, size, distribution and movement indicate the condition of atmosphere. Cloud amount, type and height are measured by visual observation on ground and satellites ever before. Satellite images can provide global cloud coverage, but they could not display the lower clouds under upper clouds. Visual observation can provide detail information of local clouds on days, but the accuracy of observation at nights is very low and cloud data are sparse on time and space. In recent years, Some instruments of measuring clouds on

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ground ,such as WSI [1], TSI [2], ICA[3],ICI [4] ,ASI [5] and WSIRCMS[6] , have been developed. Most of them are only used to estimate cloud amount. Few of them can both measure cloud amount, cloud height and classify cloud. Instruments of measuring clouds on ground are important supplements for Satellite observations. Neither of these instruments is superior; they support each other [1]. The whole Sky Infrared Cloud Measurement System (WSIRCMS) which we developed recently retrieves clouds from the downward infrared radiance in 8～14μm measured by an uncooled microbolometer detector array, and It provides a way to identify clouds, obtain clouds distributions and calculate clouds amounts every 15 minutes during day and night for zenith angles less than 75°. Some results are given in this paper.

2. Cloud identification

In clear sky, the downwelling infrared radiance in 8-14μm varies with zenith, aerosol type and content, water vapor content, etc. At a given aerosol type, visibility and zenith, the relationship of downwelling infrared radiance and water vapor content can be expressed as equation (1) according to radiation transfer modeling results:[7]

$$L=a\times PWV^2+b\times PWV+c \tag{1}$$

Where, coefficients a、b、c are different with visibility and zenith. PWV is precipitable water vapor. If vapor density logarithmically decreases with height, the PWV can be calculated from equation (2):

$$PWV=\rho_0\times Hsc/\rho_{H2O} \tag{2}$$

Where, ρ_{H2O} is density of liquid water. ρ_0 is density of water vapor near surface. *Hsc* is scalar height of vapor which indicates the vertical distribution of vapor. *Hsc* can be statistically estimated from history upper sounding data.

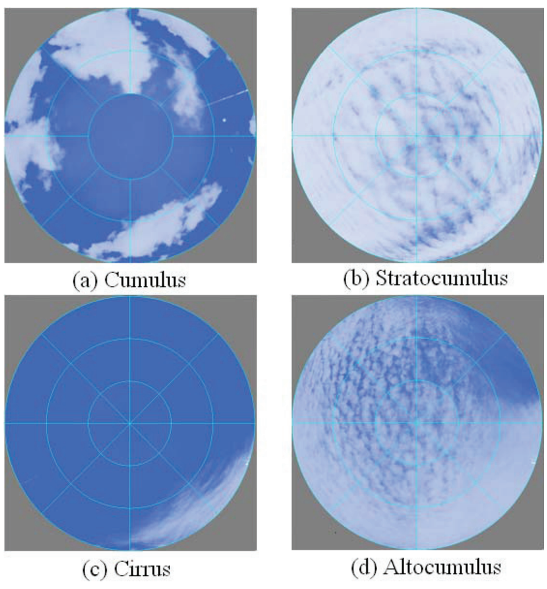

Fig. 1. Cloud maps identified from sky downwelling infrared radiance

In cloudy sky, the downwelling infrared radiance of cloud pixel in 8-14μm increases. The lower the cloud height is, the lager the radiance is. Therefore, if the measured radiance of a pixel is lager than the clear sky radiance, the pixel is cloud pixel. The clear sky radiance can be estimated from the equation (1) according to real time meteorological parameters such as temperature, humidity, visibility and aerosol type. The accuracy of estimated clear sky radiance may affect the identification accuracy of cloud. Because of large range, complex terrain and different weather system, the PWV from equation (2) may have some difference from the PWV in real atmosphere. So the estimated clear sky radiance from equation (1) has some uncertainty. But for most of situations, the estimated clear sky radiance can be set as clear sky threshold for identification of cloud. Every pixel can be identified as if it is cloud or clear sky based on the threshold method.

The figure 1 is some cloud maps identified from sky downwelling infrared radiance using the above method. In figure1 (a), there are some cumulus scattered in the area of zenith lager than degree 50. In figure1 (b), Stratocumulus occurs on all sky. In figure1 (c), a little cirrus occurs at the direction of north of east. In figure1 (d), almost all sky was covered by altocumulus.

In order to improve cloud identification, the texture information of sky radiance image was extracted to provide information of if there is cloud on sky. The information can be combined with thresholds method to identify cloud. The Local Binary Pattern(LBP) is often used in the study of classifying image. The LBP spectrum of the sky radiance image is clearly different from that of clear sky. So the LBP spectrum could be used to identify clear sky from cloudy sky. But the LBP spectrum can only be used to identify cloud on whole sky or larger area. It can not be used to identify cloud on pixel. The threshold is adjusted according to the recognition results based on LBP spectrum. A new threshold is set until the recognition results based on thresholds is in accordance with that based on LBP spectrum.

3. Cloud base height

The downwelling infrared radiance varies with Cloud Base Height (CBH). Figure 2 gives the downwelling infrared radiance at different CBH and optical thickness in 8 ~ 14μm band, in the mid-latitude summer and winter atmosphere modeled by SBDRT. It shows there is a monotonic relationship between CBH and downwelling infrared radiance, which means for a given optical thickness of cloud, the higher the cloud base height is, the less the downwelling infrared radiance is. This can be used to retrieve CBH from the measured downwelling infrared radiance[7]. Further more, for the same cloud-base height, the more the optical thickness is, the more the radiance is. However, if the optical thickness is greater than 8, the radiance almost does not increase, which suggests that for most of water cloud, CBH can be determined well. But there should be a big error of CBH for optical thin layer cloud if the optical thickness could not be known.

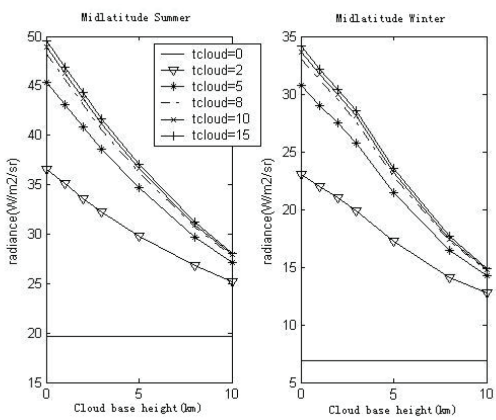

Fig. 2. Downwelling infrared radiance at different CBH and optical thickness

A preliminary comparison experiment is made. The CBHs measured by laser ceilometers were compared with that retrieved from downwelling radiance. The results show high accuracy of CBH of middle and low cloud determined according to the proposed method. The average error is 107m.

4. Cloud classification

Studies stressed on cloud classification based on the whole sky images were carried on only in recent years. Buch et al. [8] studied cloud classification using whole-sky imager data. A method to classify WSI images into five types: clear, stratus, cumulus, cirrus, and altocumulus was studied. They suggested some texture features and obtained a misclassification rate of 39% when compared with visual classification. Peura et al.[9] considered that the method for ground-based cloud classification should treat whole sky images as compositions of objects. They used visual appearance of clouds such as sharpness of cloud edges, fibrousness and specks of different size to recognize ten cloud genera. The agreement rate with manually classification was 65%. Singh and Glennen [10] used five different feature extraction methods such as autocorrelation, co-occurrence matrices, edge frequency, Law's features and primitive length to perform an exhaustive analysis of the cloud images from a color digital camera. Hundreds of features from the gray scaled images were investigated to classify sky conditions into five different classes for air traffic applications, but classification was not good according to authors themselves. Calbo and Sabburg [11] used three different kinds of features such as statistical features, features based on the Fourier transform of the image, and features describing the distinction of cloudy pixels and clear sky pixels. They get an index of agreement of 62% when sky conditions were classified to eight types. The index of agreement increased to 76% when only five different sky conditions such as clear, low cumuliform clouds, stratiform clouds (overcast), cirriform clouds, and mottled clouds (altocumulus, cirrocumulus) were classified.

We have studied ground-based cloud classification for several years. Firstly, a method using Fuzzy Uncertainty Texture Spectrum and essential information in cloud images is proposed to classify five sky conditions (stratus, cumulus, altocumulus, cirrus and clear sky). Typical cloud sample sets have been collected according to visual observations. The classification accuracy rates increase sharply after adding essential information in cloud images. It shows the importance of the characteristic of cloud in cloud classification. Then, a method using the LBP operator and the contrast of local cloud image texture (VAR) to classify sky conditions is proposed. The complex sky conditions are not discussed in both of above studies.

Experiments show poor results when texture method is used to classify complex sky conditions. We have to find another method to improve the classifying accuracy rate. It is known that visual classification of cloud takes cloud shape as the basic factor, together considering the cause of its development and the interior micro-structure. It classifies the cloud into 29 varieties of 10 genera in 4 families with high, mid, low levels and clouds of significant depth [12]. This is the criteria used by surface observers but is difficult to be used in automatic cloud classification. Based on previous works mentioned above and on our own experience, we defined five different sky conditions to be used as a basis for our classification methodology (see Table 1). Note that some cloud types can be found in more than one of our classes. Stratiform clouds are horizontal, layered clouds that stretch out across the sky like a blanket. Cumuliform clouds are usually puffy in appearance and like large cotton balls. Waveform clouds occur in sheets or patches with wavy, rounded masses or rolls. Cirriform clouds are very wispy and feathery looking.

Table 1. An example of a table

Sky condition classes	Description	Cloud types
Cirriform Clouds	Thin clouds with very wispy and feathery looking	Ci
Waveform Clouds	Thin or thick clouds occurring in sheets or patches with wavy, rounded masses or rolls.	Sc, Ac, Cc
Cumuliform Clouds	Thick clouds that are puffy in appearance and like large cotton balls	Cu, Cb
Stratiform Clouds	Horizontal, layered clouds that stretch out across the sky like a blanket	St, As, Cs ,part of Sc, Ac, Cb and Ns
Clear	Clear	No clouds

We have demonstrated a pilot study on structural feature extraction and cloud classification in the sky infrared images from WSIRCMS. Seven structural features are explored including the mean gray value (ME), estimated cloud fraction (ECF), edge sharpness (ES) and cloud mass and gap distribution parameters SMG, MG, MSG, MM[13]. It is found that they are suitable to be used to classify cloud on the ground-based cloud images with high spatial resolution. A simple but efficient supervised classifier called rectangle method is used to do cloud classification. The performance of the classifier is assessed with an a priori classification carried out by visual inspection of 277 images. The index of agreement is 90.97%.Further research should be taken into this interesting field. Size distributions of cloud mass and gaps are extracted to describe structural information in this study. There are still other features that are useful for cloud type recognition such as regularity, fibrousness, etc.

5. Conclusion

The Whole Sky Infrared Cloud Measurement System (WSIRCMS) which we developed recently retrieves clouds from the downward infrared radiance in 8～14μm measured by an uncooled microbolometer detector array. With the Algorithms we developed, it can provide a way to obtain cloud distribution, cloud amount, cloud base height and sky conditions every 15 minutes during day and night for zenith angles less than 75°. The system has been used for several years and at several locations such as Yangjiang, a south coastal town, and Nanjing city, Beijing city, rural of Baicheng, etc. The experiments show that the system can be used in different climate regions.

References

[1]Shields J E, Johnson R W, Karr M E and Wertz J L. Automated day/night whole sky imagers for field assessment of cloud cover distributions and radiance distributions. Tenth Symposium on Meteorological Observations and Instrumentation. 1998.

[2]Long C N and DeLuisi J J.. Development of an automated hemispheric sky imager for cloud fraction retrievals. In Proc. 10th Symp. on Meteorological Observations and Instrumentation, Phoenix, Arizona. 1998

[3]Genkova I, Long C N, Besnard T and Gillotay D.. Assessing cloud spatial and vertical distribution with infrared cloud analyzer. New Mexico: Fourteenth ARM Science Team Meeting Proceedings, 2004:22-26.

[4]Shaw J A, Thurairajah B, Edqvist E and Mizutani K.. Infrared cloud imager deployment at the north slope of Alaska during early 2002. 12th ARM Science Team Meeting. 2002

[5]Huo J and Lv D R.. Preliminary study on cloud-cover using an all-sky digital camera, Journal of Nanjing Institute of Meteorology, 2002,25(2):242-246.

[6]Sun X J,Gao T C and Zhai D L.. Whole sky infrared cloud measuring system based on the uncooled infrared focal plane array. Infrared and Laser Engineering, 2008, 37(5):761-764.

[7]Sun X J.. Study on the ground-based infrared remote sensing of whole sky cloud. Beijing：Institute of physics, Beijing University, 2009

[8] Buch, J. K. A., and C. H. Sun, Cloud classification using whole-sky imager data. 9th Symposium on Meteorological Observations and Instrumentation, Charlotte, North Carolina, 1995:353-358.

[9]Peura, M., A. Visa, and P. Kostamo, A new approach to land-based cloud classification. 13th International Conference on Pattern Recognition (ICPR'96), Vienna, Austria, IEEE Comput. Soc. Press, 1996:143-147.

[10]Singh, M., and M. Glennen, Automated ground-based cloud recognition. Pattern Anal, 2005: 258-271.

[11]Calbo, J., and J. Sabburg, Feature extraction from whole-sky ground-based images for cloud-type recognition. Journal of Atmospheric and Oceanic Technology, ,2008, 25:3-14.

[12]World Meteorological Organization (WMO), International Cloud Atlas: Manual on the Observation of Clouds and Other Meteors, Volume I, WMO No. 407, Geneva.,1975

[13] Liu L, Sun X J, Chen F, etc.Cloud Classification Based on Structure Features of Infrared Images, Journal of Atmospheric and Oceanic Technology, 2011,28:410-417.