Latitudinal and Seasonal Variation of the Cloud Characteristic Parameters and their Effects on the Cloud Classification

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Abstract

Latitudinal and seasonal trend of variation of the cloud characteristic parameters and some effects on the objective cloud classification are investigated using an accumulated histogram derived from GMS IR and VIS imagery. We study the data of cloud features on nine specified cloud classes separately. Definite tendencies of the latitudinal and seasonal variations of two main cloud characteristic parameters, a cloud top temperature and cloud maximum albedo are found. These variations result in systematic failure in the cloud classification especially in winter. A large decrease in the accuracy of classification in winter occurs and is caused by mainly the latitudinal variation of air temperature near cloud top and the low solar zenith angle. It is noteworthy that the albedo data both in summer and winter have an identical linear relationship and suggest that thick clouds have almost the same albedo in summer and winter. One simple method to remove the influence of these variations on the cloud classification is to calculate discriminant coefficients in each latitude zone.

1. Introduction

An objective cloud classification in the satellite imagery is very effective in forecasting, cloud tracking to determine satellite wind and in the study of cloud climatology. Many authors have developed the methods of cloud classification using IR and VIS imagery data. The kinds of cloud type specified are somewhat different from each other due to their own object.

Booth (1973) showed that it was possible to classify into five and six cloud classes with reasonable accuracy. Parikh (1977) classified into four classes. Kato and Ishikawa (1982) classified into eight classes for the use of nephanalysis chart. Recently Garand (1986) showed the possibility of detailed cloud classification including the two dimensional cloud pattern, such as cirrus streak or cloud street and could retrieved the atmospheric condition from 20 classified class on the Atlantic Ocean. The required accuracy by ISCCP for cloud climatology is partially cleared by Garand (1986) while he showed only in winter time. A simple classification technique to five classes using IR features and objective analysis of the preceding day is used to construct Cloud Information Chart (Motoki, 1987), which is disseminated to meteorological observatory in Japan for weather forecasting in a quasi-real time. Using IR split window data (Inoue, 1987), new method of classification is initiated, but tractable cloud types are yet limited.

Among many cloud characteristic parameters, a cloud temperature and albedo are always required to classify into specified cloud types. These two parameters make a remarkable contribution to the cloud classification. The former distinguishes the height of the cloud layer and the latter the cloud thickness. Clouds in one cloud type distribute over very wide area

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and the property of the cloud characteristics is varied to in different areas. Although it is well known that cloud top temperature and albedo vary in time and space, the variability of cloud features is poorly known. Therefore it is very important to make the nature of these cloud features clear to understand the results and to improve the accuracy of cloud classification. Then, operational cloud classification can work in a wide area and for all seasons.

In section 2 extracted cloud features and the outline of classification are described. We show a latitudinal and seasonal variations of two main cloud features and some effects on the cloud classification in section 3.

2. Feature extraction and cloud classification

As our primary concern is the property of cloud features, we present some basic data in the classification procedure. We used the same computer programme by Kato and Ishikawa (1982) and details of classification procedure are given there.

We specify nine cloud classes (CB, CID, CIM, CIT, AS, SC, CU, ST and CLR) in the GMS imagery. CB is cumulonimbus, CID is dense cirrus with middle and low level clouds, that is, thick clouds, CIM is cirrus with low level clouds, CIT is cirrus only, AS is middle level clouds, CU is cumulus, SC is stratocumulus, ST is stratus or fog and CLR is no clouds. The authors determined "truth" data of classification by inspection of IR and VIS imagery. An area calculating characteristic parameter is 17 line * 45 pixels in IR imagery and 68 line * 90 pixels in VIS imagery, about 120 * 120 km near Japan. Training data sets are ones on 17, 25, 28 May and 20, 28 July 1985. Total number of samples are 489. Testing data sets are on 22 June and 4, 22, 31 July 1985 (summer) and 3, 5 January 1986 (winter). Total number of samples are 299. All images were obtained at 0300 GMT. Two groups of testing data set are referred to as summer and winter.

The training data set is classified by the step-wise discriminant analysis and a few cloud features which highly contribute to the classification are extracted. Then we classify the testing data set using these cloud features. Extracted cloud features are (symbols are after Kato and Ishikawa, 1982); using only IR features

- I12: a 16% level in the IR accumulated histogram, which is about a cloud top temperature
- I117: mean of angular second moment, A (ρ, θ)*

using IR and VIS features

- I12: a cloud top temperature
- V14: a 84% level in the VIS accumulated histogram, which is about a cloud maximum albedo.
- V63: contrast, C $(\rho = 1, \theta = -45°)$*

We define a cloud albedo as the ratio of reflected intensity from clouds to direct intensity of solar radiation received by GMS, which we assume to be a constant. Therefore, a cloud albedo is proportional to the reflected intensity.

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* Difference histogram information

A feature is calculated from the difference of brightness level between two pixels. Space arrangement is specified by distance ρ (ρ = 1, 2, 4, 8) and direction θ (θ = vertical, horizontal, right diagonal, left diagonal).

1) Angular second moment A (ρ, θ) is defined as: $A(\rho, \theta) = \sum_{i=1}^{nl} \left(\frac{f(i)}{N}\right)^2$

2) Contrast C (ρ, θ) is defined as: $C(\rho, \theta) = \sum_{i=1}^{nl} i^2 \left(\frac{f(i)}{N}\right)$ where N is number of total pairs of pixels. nl is a difference between maximum and minimum brightness level and f(i) is a frequency of the difference i.

Among these features a cloud top temperature and a cloud maximum albedo dominate the contribution to the classification and are investigated in this study.

3. Cloud features

Fig. 1 shows the configuration of nine specified classes derived from a cloud top temperature and a cloud maximum albedo and is similar to Booth (1973)'s Fig. 5. This figure is evaluated from the training data set. A mean location of each class is marked with a dot. Bar indicates 1 sigma dispersion on both sides. The scatter of the data is resulted from inhomogenity in a cloud class and a spatial variation of cloud features.

As cloud temperatures for low level cloud classes are nearly the same, it is difficult to classify CU, SC and ST by using only IR features. For classes with Ci (CID, CIM, CIT), the same situation occurs and a cloud albedo is required to separate them. Furthermore, as the location of CU and SC are close to in this diagram, we cannot distinguish CU and SC by using these two features. As the locations of CB and CLR are away from that of other class, the accuracies of classification for both classes are higher than other class.

3.1. Latitudinal and seasonal variation of the cloud features

We give interesting examples of variation of cloud top temperature and cloud maximum albedo for several representative cloud classes.

3.1.1. Cloud top temperature

Cloud top temperature versus latitude for low level classes CU, SC and ST is shown in Fig. 2 in summer (a) and winter (b). There is little systematic change in summer, while in winter a definite decrease of a cloud top temperature to higher latitude is present. The decrease is governed by an air temperature near cloud top, say, 850 or 700 mb. In winter temperature difference is enlarged to about 50°K.

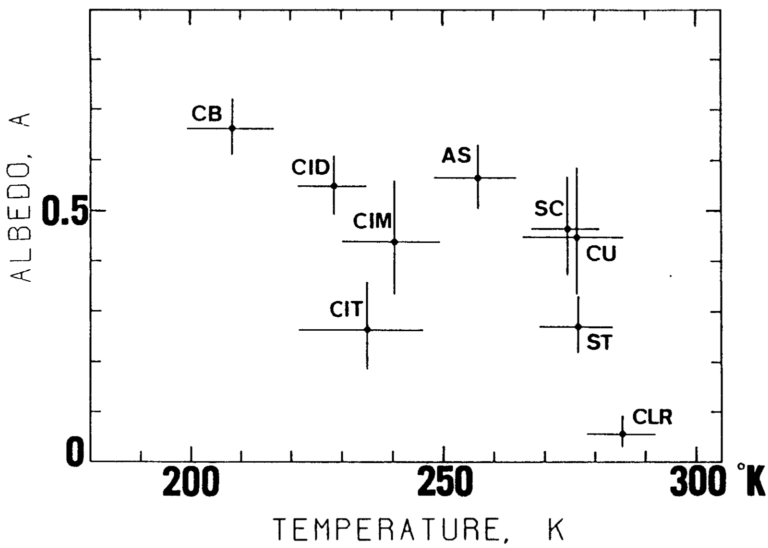


Fig. 1. Configuration of nine specified classes derived from a cloud top temperature and a cloud maximum albedo for a training data set. Dot represents a mean location of a class and bar indicates 1 sigma dispersion.

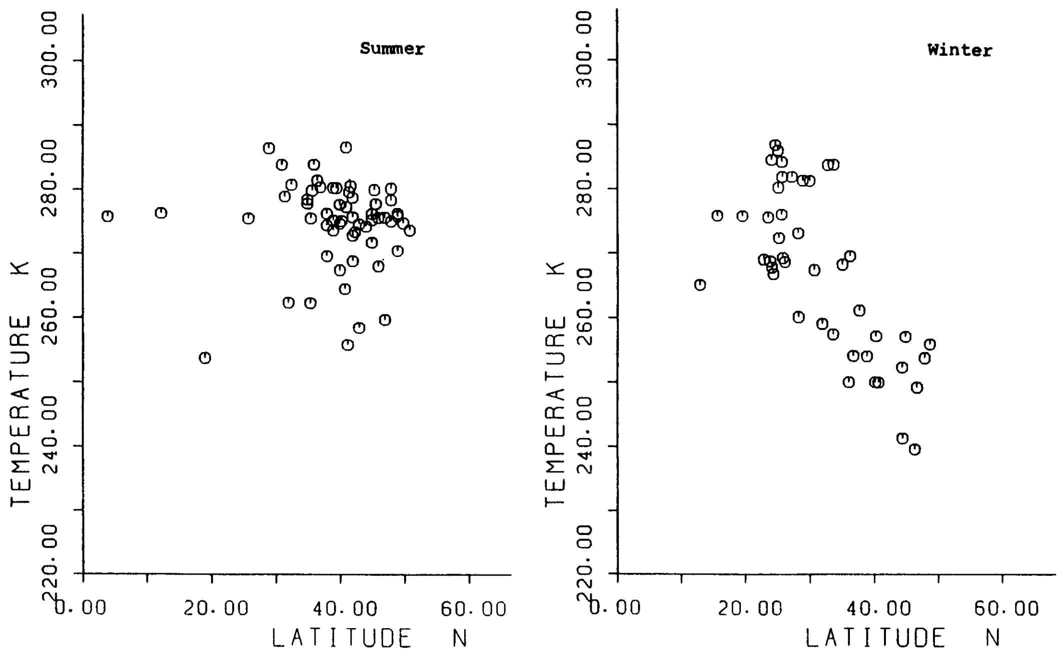


Fig. 2. Latitudinal variation of the cloud top temperature for low level cloud classes CU, SC and ST in summer (a) and winter (b).

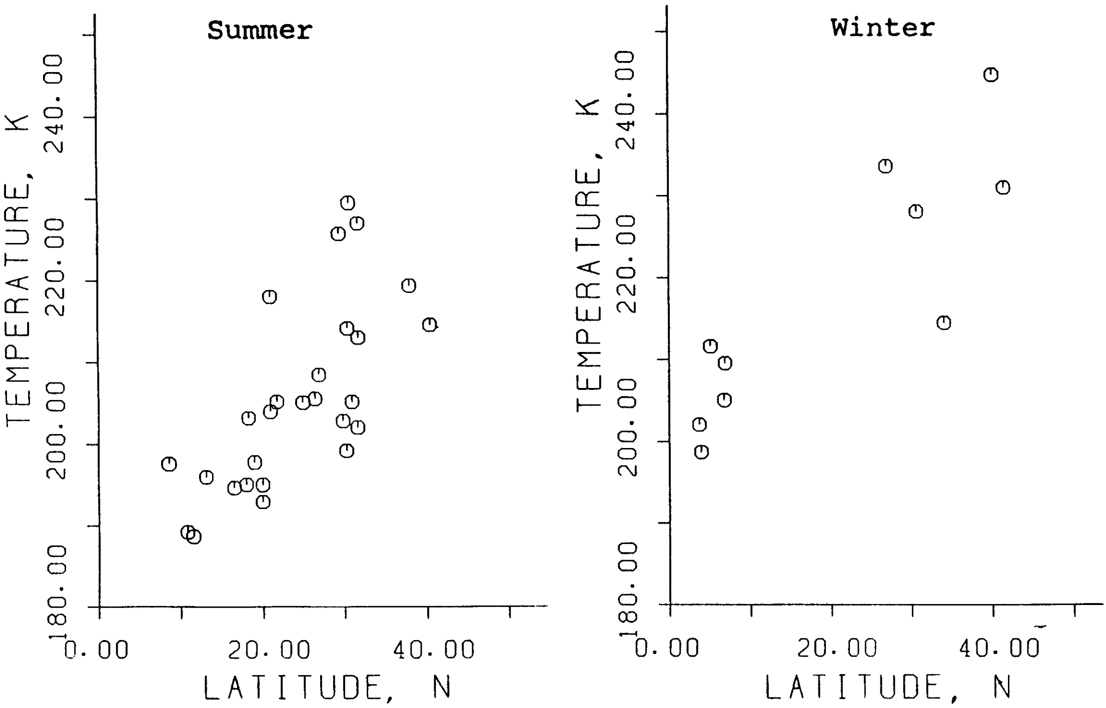


Fig. 3. The same as in Fig. 2 except for a class CB (Aso et al., 1987).

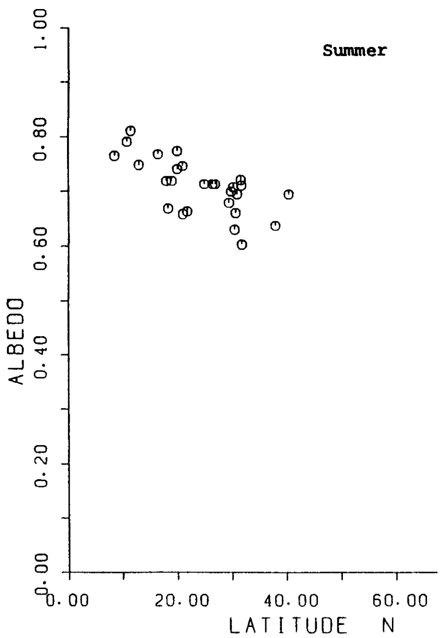
We should notice that a tendency of the variation for one class is different from one for another class. In Fig. 3 we show a case for a class CB (Aso et al., 1987). In this case a cloud top temperature increases to higher latitude contrary to low level classes. The temperature difference between the 10°N and 40°N is about 30°K both in summer and winter. The cloud top temperature in summer is about 20°K colder than in winter on the average. As we chose only mature CB clouds with an anvil cirrus, these differences roughly correspond to the change of the hight of the tropopause.

In the lower latitude, an atmospheric condition depends largely on the convective activities and the location of ITCZ. Therefore we would have some other tendency of the cloud top temperature change for a CB case, if we analyse other imageries.

3.1.2. Cloud maximum albedo

In Fig. 4, a latitudinal and seasonal variation of cloud maximum albedo are shown for a class CB. The difference of albedo between summer and winter is 0.1 ~ 0.2 in the lower latitude. In summer there is a weak decrease in albedo to higher latitude, while in winter a large decrease occurs. Two unlike tendency of decrease is caused by the change of solar zenith angle between summer and winter. However, two data near 40°N in winter (b) are derived from inactive cumulonimbi in the cold air mass on the North Pacific Ocean, a large decrease in albedo to higher latitude is somewhat questionable.

Fig. 5 shows a case for a class CID, dense cirrus with thick clouds. The upper part of the data is for a summer case and the lower for a winter case. The data in winter are much smaller than the data in summer. At latitude 40°N the difference of albedo is about 0.3. In winter an albedo is about a half in summer. The decrease to higher latitude is also due to the solar zenith angle dependency. The data



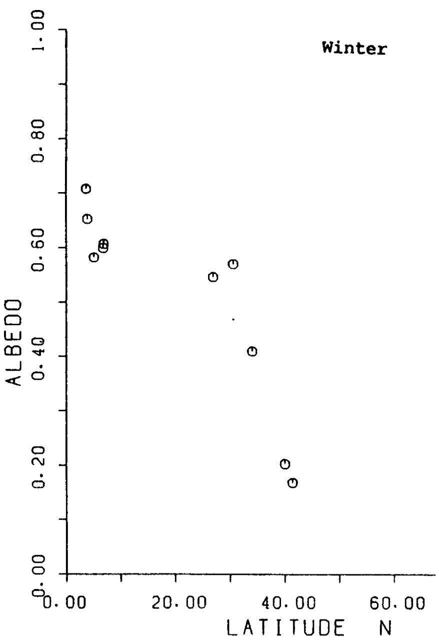


Fig. 4. Latitudinal variation of the cloud maximum albedo for a class CB in summer (a) and winter (b).

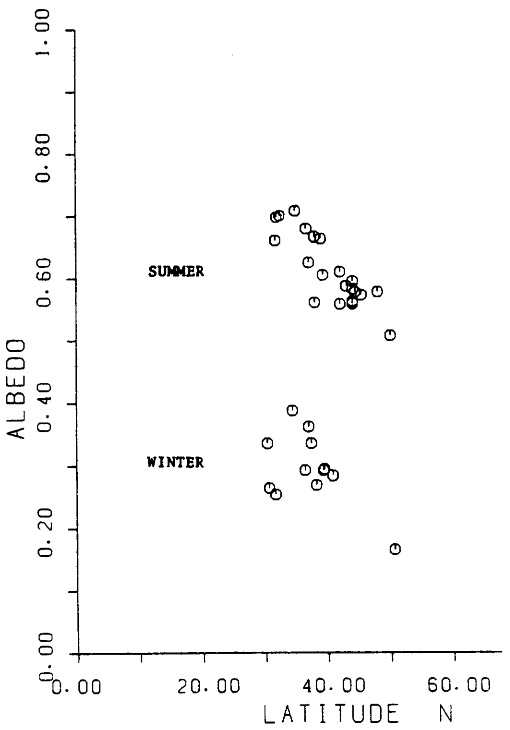


Fig. 5. The same as in Fig. 4 except for a class CID.

in summer locate nearly at the same position in albedo-latitude space at about 30°N for CB (Fig. 4) and extends to higher latitude as an extrapolation of CB trend. Therefore most of the albedo difference between CB and CID (Fig. 1) is interpreted as resulting from the difference of solar zenith angle.

3.2. Effects on the cloud classification

Now we discuss some effects of latitudinal and seasonal variations of cloud features on the cloud classification. The variations of cloud features influence the accuracy of classification considerably where magnitude of change is large enough. Shown in Fig. 6 is the results of classification using IR features for low level cloud classes CU, SC and ST as one single class. Triangle (△) represents misclassification into middle or high level cloud class and plus (+) represents into CLR. In this figure a cloud misclassified into middle or high level cloud

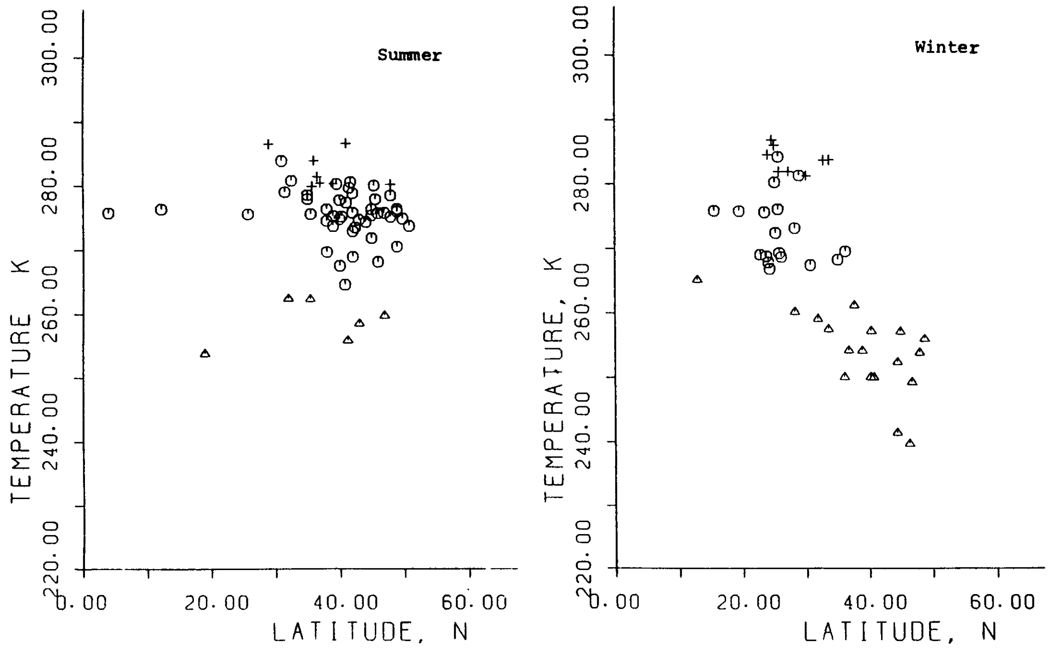


Fig. 6. Result of cloud classification for low level classes CU, SC and ST using IR features. ○ is correctly classified as low level cloud classes. + is classified as CLR and △ is as middle or high level cloud class.

class has a cloud top temperature colder than about 265°K and into CLR has a temperature warmer than about 280°K. Since there is a latitudinal variation of cloud top temperature, low level clouds north of about 35°N are all classified as middle or high level clouds. Hence we have a strong latitude dependency of misclassification in winter.

Results of classification for a class CID using IR and VIS features are given in Fig. 7. Plus (+) mark represents misclassification into CIM, cirrus with low level clouds, cross (X) into CIT, cirrus only. In winter all clouds are classified into wrong classes, that is, these clouds are recognized as optically thin clouds because of their low albedo. Hence we have a strong seasonal dependency of misclassification due to the change of solar zenith angle. In summer, failures to CB result from a colder cloud top temperature. The accuracies of classification for a testing data set are 53% in summer and 34% in winter using IR features and 74% in summer and 43% in winter using IR and VIS features.

When a threshold technique is simply applied, these results indicate the importance of using a reasonable threshold temperature and albedo. It means that threshold value is seemed to be dependent on the latitude and season. One simple methods to remove the influence of these variations on the cloud classification is to calculate discriminant coefficients in each latitude zone.

3.3. Arrangement of cloud maximum albedo by solar zenith angle

Cloud albedo is determined by the intensity of solar radiation, thickness and shape of clouds, water or ice contents in the clouds and cloud coverage on the calculated area. When one cloud type is specified, the determination of cloud albedo is dominated by the intensity

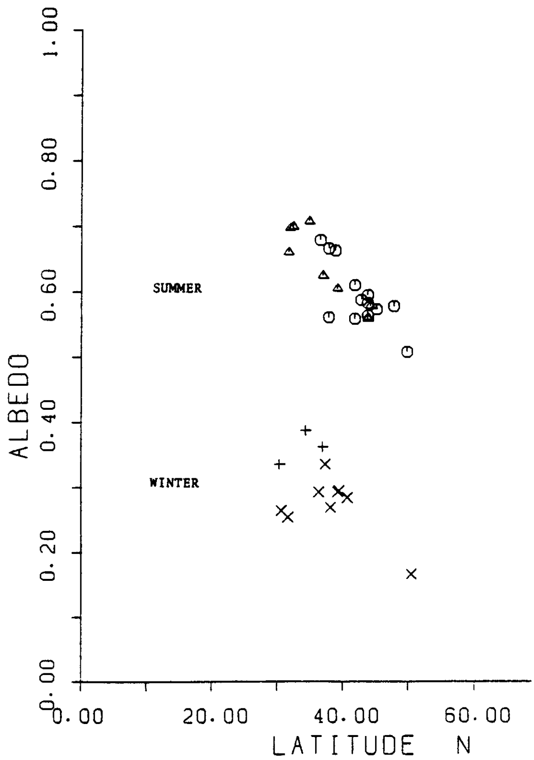


Fig. 7. Result of cloud classification for a class CID using IR and VIS features ○ is correctly classified as CID. + is classified as CIM and × is as CIT.

of solar radiation. Although it is well known that simple "cos ζ" law works for the intensity of the solar radiation, the solar zenith angle dependency of cloud albedo has not been clearly shown. In this study, we limit clouds into one single cloud type and force other characteristics homogeneous.

Fig. 8 shows the relation between cloud maximum albedo and cosine of solar zenith angle for a class CID in summer and winter. The data are the same as in Fig. 5. The right part of the data are for summer case and the left are for winter. In this figure cloud maximum albedo varies linearly with cosine of solar zenith angle. It is noteworthy that the albedo data both in summer and winter have an identical linear relationship and suggest

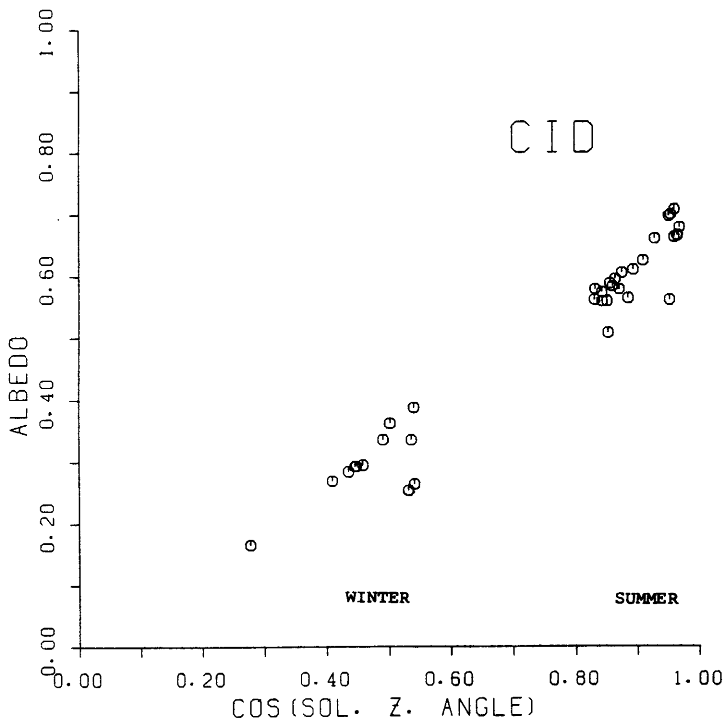


Fig. 8. Cloud maximum albedo versus cosine of solar zenith angle for a class CID.

that thick clouds have almost the same reflectivity in summer and winter.

For a class CB in Fig. 9, the same situation with Fig. 8 exists, but the data are somewhat more scattered likely because CB cloud has an irregular shape. From these two figures an observed albedo is seemed to be only a function of solar zenith angle. Extrapolating the line to the zero solar zenith angle, the "true" cloud maximum albedo can be estimated. It is about 0.8 for CID and 0.8 ~ 0.85 for CB and 0.7 for AS (figure not shown).

Fig. 10 shows for low level cloud classes CU and SC. The scatter of the data are more increased, while the upper envelope of the data is nearly linear and the "true" albedo is about 0.7. The scattered data are caused by lesser coverage of these cloud types. A cloud classified as a class CU or SC has an open region even in each pixel contrary to a class CB or CID which we have chosen in the overcasted area and seemed to be a full coverage on each pixel. A low albedo on the sea or land shifts the location to lower portion under the envelope.

For thick, uniform clouds it is also easy to extrapolate the line to zero solar zenith angle. When we use "true" albedo for thick clouds to characterize cloud types, the scatter of the data in Fig. 1 is expected to be reduced considerably.

For a class CLR, which we chose only the data on the sea, the data doesn't show linear relationship such as CID or CB case (Fig. 11-a). Albedo for a no cloud region is about 0.05 in the open sea. In Fig. 11-b we show the relation of albedo with a satellite-viewing zenith angle. We can see no definite spatial and seasonal variations of albedo for a class CLR in these

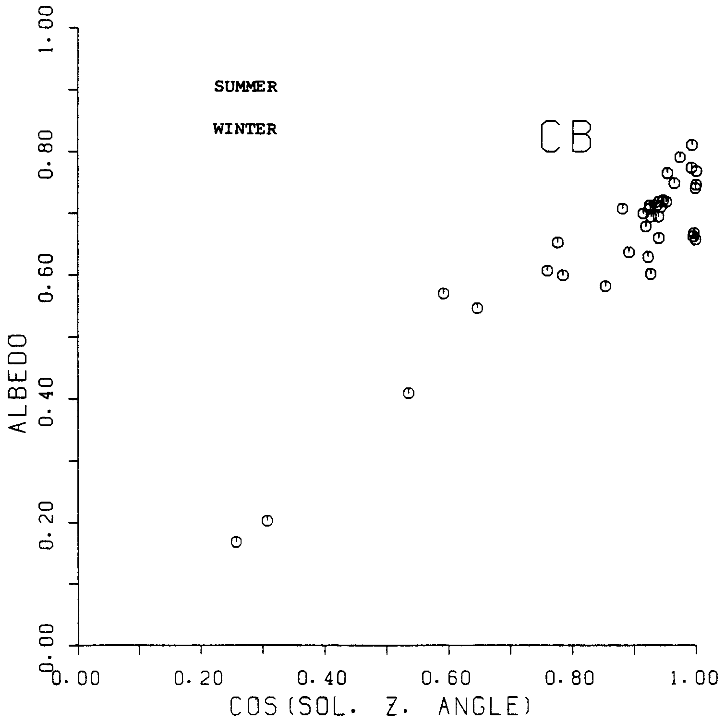


Fig. 9. The same as in Fig. 8 except for a class CB.

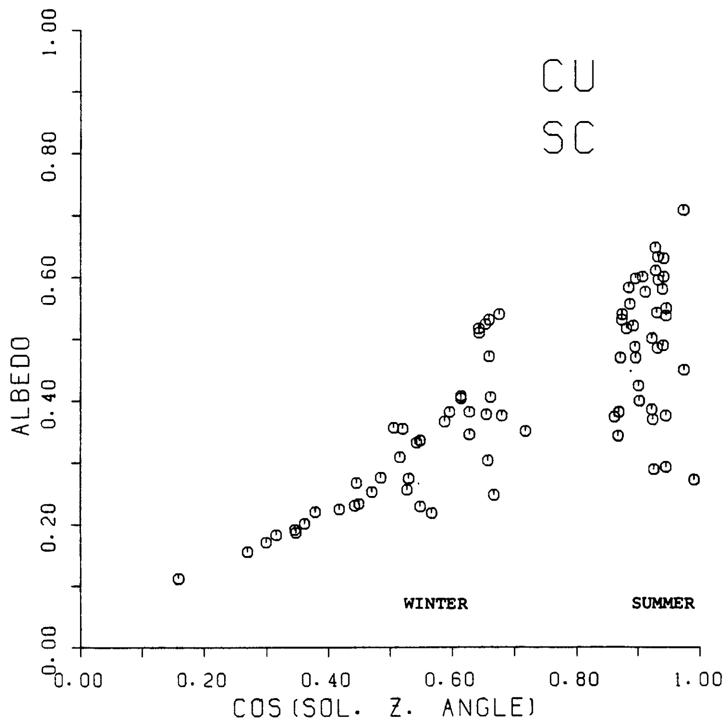


Fig. 10. The same as in Fig. 8 except for low level cloud classes CU and SC.

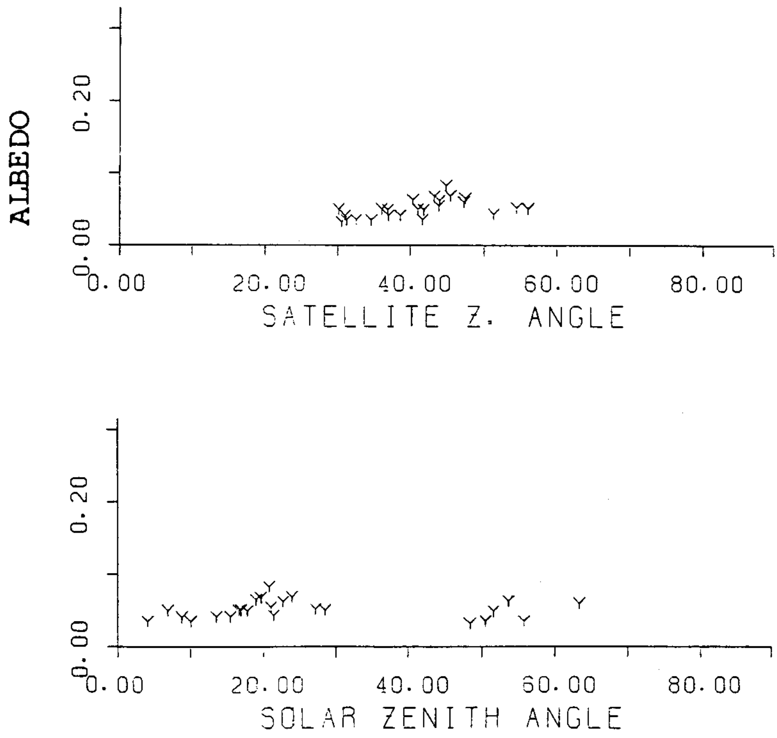


Fig. 11. Cloud maximum albedo versus solar zenith angle (a) and satellite-viewing zenith angle (b) for a class CLR.

figures. The almost constant albedo is thought to result from very low reflectivity of the sea surface and the existence of scattered solar radiation.

4. Concluding remarks

We have studied the latitudinal and seasonal variation of cloud characteristic parameters used for the cloud classification in the satellite imagery. Extracted features are a cloud top temperature and a cloud maximum albedo, which influence the accuracy of the classification. The characteristics of the two cloud features on a few representative cloud classes have been shown.

The results of the study are summarized as follows.

1) Cloud top temperature: For a class CB, temperature increases with latitudes, which roughly corresponds to the change of the height of the tropopause. For low level classes CU, SC and ST, there is little systematic change in summer, while in winter a definite decrease to higher latitude is present. The decrease is governed by an air temperature near the cloud top.

2) Cloud maximum albedo: For a class CID, there is a large change in winter compared with in summer and cloud albedo decreases with latitudes. The decrease is caused by a decrease of a solar zenith angle. For a class CB, almost the same variation as for CID case is present.

For a class CB and CID, cloud maximum

albedo both in summer and winter is linearly related to cosine of solar zenith angle. It means that the intensity reflected from thick cloud area is mostly determined by the intensity of solar radiation, regardless of season. For low level classes CU and SC, although there are the scatter of the data, an envelope line of the data also indicates a linear relationship between albedo and cosine of solar zenith angle.

3) The above-mentioned variations of cloud features have a systematic effect on the results of cloud classification especially in winter. For low level classes CU, SC and ST using IR features, clouds north of about 35°N are all misclassified into middle or high level cloud class. For a class CID using IR and VIS features, all clouds are misclassified into thin clouds, such as CIM and CIT.

4) If a "true" albedo of cloud area is estimated from the linear relationship between cloud albedo and cosine of solar zenigh angle and is used for cloud classification, the accuracy of classification would be increased. For a cloud top temperature, one simple method to removed the influence of these variations on the cloud classification is to calculate discriminant coefficients in each latitude zone.

Acknowledgements

The authors wish to express our thanks to Mr. S. Osano for his encouragements and helpful discussions and to Mr. T. Hamada for his careful review of the manuscript. They also express our thanks to Mr. K. Kato and K. Ishikawa for helpful comments to use cloud classification programme.

References

Aso, T., K. Oosawa and Y. Takeuchi, 1987: Cloud classification in the satellite imagery – A latitudinal and seasonal variations of the cloud characteristic parameters, Tropical Precipitation Measurement, to be published.

Booth, A.L., 1973: 3rd Conference on Probability and Statistics in the Atmospheric Sciences, Am. Meteor. Soc., Boulder, Colorado, 220-227.

Garand, L., 1986: Automated recognition of oceanic cloud patterns and its application to remote sensing of meteorological parameters, Ph. D. Thesis, University of Wisconsin-Madison.

Inoue, T., 1987: A cloud type classification with NOAA-7 split window measurements, J. Geophys. Res., 92, 3991-4000.

Kato, K. and K. Ishikawa, 1982: Objective cloud top-height estimation system for GMS imageries, Meteorological Satellite Center Technical Note, 5, 1-24.

Motoki, T., 1987: Satellite Cloud Information Chart – Advanced TBB contour chart-, Meteorological Satellite Center Technical Note, 15, 21-26.

Parikh, J.A., 1977: A comparative study of cloud classification techniques, Remote Sensing of Environment, 6, 67-81.

雲特徴パラメーターの緯度，季節変化と雲型判別に及ぼす影響

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衛星画像を用いた自動雲型判別の精度を向上させるために，雲特徴パラメーターの季節，緯度変化について調べた。判別する雲型はCB（積乱雲），CID（中下層雲を伴う厚い上層雲），CIM（下層雲を伴う上層雲），CIT（上層雲のみ），AS（中層雲），CU（積雲），SC（層積雲），ST（霧，層雲），CLR（雲無し）の9雲型とし，加藤・石川（1982）の判別解析プログラムを使用した。調査し

た特徴パラメーターは判別への寄与率の高い雲頂温度と最大アルベドで，各雲型ごとに層別化して行った。

二つのパラメーターはともに顕著な緯度・季節変化を示した。代表的な例について以下に述べる。

1) 雲頂温度は雲型CBにおいては高緯度に向かって増大するが，CU, SC, STなどの下層雲型では逆に低下した。この原因は，雲型CBでは圏界面温度が高緯度に向かって増加することに関係し，一方，下層雲型では雲頂付近の気温の南北の変化が関係していると思われる。また，冬季は夏季に較べていずれの雲型においても雲頂温度が低下する。

2) 雲の最大アルベドはCLRを除いて高緯度へ向かって減少するが，冬季は夏季よりもその減少傾向が大きい。この原因はアルベドの太陽天頂角依存性にあり，太陽天頂角の関数として図を描き直すと，厚い雲型ではアルベドと太陽天頂角の余弦は直線関係を示す。夏と冬のデータが同一の直線関係にのることから夏と冬で天頂角を0に戻したときのアルベドはあまり変化していないことが分かる。

3) 上述のパラメーターの変化は雲型判別結果に特に冬季のデータに対して大きな影響を与える。例えば冬季，雲型CIDは全て薄い上層雲の雲域（CIM, CIT）へと誤判別される。

以上のことから，判別精度を向上させるためには判別領域をいくつかの緯度帯に分ける，アルベドに関しては天頂角0の“標準値”に直して判別を行うなどが考えられる。

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