SATELLITE-DERIVED CLOUD PROPERTIES OVER CHINA

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ABSTRACT:

Low-level water cloud (cloud top temperature more than 273K) properties such as the optical depth, particle radius, and vertically-integrated droplet number concentration are derived from satellite remote sensing technique with Advanced High Resolution Radiometer (AVHRR) over the East Asia, mainly China area. Their annual mean characteristics thus obtained are consistent with what the Twomey effect indicates, showing larger optical depth and droplet number concentration, and smaller particle radius over land generally compared to those over ocean. Long-term analysis of cloud particle radius from 1985 to 1994 reveals gradual decrease with time for clouds over both land and ocean. This trend, however, would be affected by some crucial reasons. We need to be careful when we use long-term satellite data. Also, we estimate cloud spherical albedo and shortwave radiative flux by a fast parameterization method. Development of fast computation of cloud-relevant quantities will contribute to better understanding of climate problems.

1. INTRODUCTION

In considering the earth's climate formation and maintenance, clouds play very important roles in terms of radiative and hydrological processes. For example, they reflect solar radiation and absorb and re-emit infrared radiation, and they produce precipitation. Among climate issues, the aerosol indirect effect, in other words, cloud modification due to interacting with aerosol particles is one of the most uncertain (IPCC, 2001). There are mainly two aspects in the aerosol indirect effects. One is the change of cloud radiative properties, increasing the optical depth and decreasing the particle size due to an increase in droplet number. The other is the change of hydrological cycle, prolonging cloud lifetime due to reducing precipitation efficiency. They are called the aerosol indirect effect of the first kind and the second kind, respectively. It is important to monitor cloud properties such as the optical depth and particle size for the aerosol indirect effect study, and satellite remote sensing is a very effective method in terms of wide area analysis.

Low-level water clouds covers about one thirds of the globe, and have dominant effects on the earth radiation budget (Harrison et al. 1990). Low clouds are expected to interact with aerosols more than other types of clouds such middle and higher clouds, since aerosols are also suspended in the lower part of the atmosphere. Also water droplets are assumed to be sphere, so we can apply the exact scattering in radiative transfer calculation. On the other hand, ice clouds like cirrus and tropical deep convective clouds have non-spherical and complicated shape, and no exact scattering theories have been proposed so far.

China had experienced substantial economic development with the advent of so-called 'open door policy' from the late 1970s. Due to this change, the energy consumption rapidly increased, and emitted aerosols are also expected to increase. China area is known to be a complex aerosol system of mixing various chemical species from natural and anthropogenic origins. For example, there are dust particles from desert as natural origin and sulfate and nitrate aerosols as anthropogenic origin. Carbonaceous aerosols are generated both from industrial activity and biomass burning. Kawamoto et al. (2001) established an algorithm for deriving the water cloud properties, and they argued annual mean features, seasonal changes and altitudinal contrast of water cloud parameters on a global scale. In this work, we concentrate on over China area (E.90- E135, N15-N55) for the target region and discuss water cloud properties about the annual mean and long-term (from 1985 to 1994) time series.

In chapter 2, algorithm and data used in this study are described. In chapter 3, characteristics of cloud parameters over China are illustrated. Finally, we summarize the results in chapter 4.

2. Data and method

The algorithm of Kawamoto et al. (2001) was adopted for retrieving the cloud optical depth at visible wavelength τ, effective particle radius r_e and cloud top temperature T_c of water clouds whose top temperatures were warmer than 273K. The definition of r_e is as follows.

$$r_e = \frac{\int r^3 n(r)dr}{\int r^2 n(r)dr} \qquad (1)$$

where $n(r)$ is the number size distribution at a particle radius r. Log-normal size distribution was assumed for $n(r)$. It uses two cloud-reflected solar radiances and one cloud-emitted thermal radiance. The retrieval principle is that cloud-reflected solar radiance at non-absorbing visible wavelength is a function of τ, while that at water-absorbing near-infrared wavelength is a function of r_e (Nakajima and King 1990). The current algorithm was developed improving Nakajima and Nakajima (1995)'s

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drawbacks in the limitation of regional application. It incorporated new treatments on thermal emission and water vapor absorption in the atmosphere. A pre-computed numerical table (lookup table) was prepared to compare with satellite observed radiances, and it determined the best-matched combination from the comparison to be the retrieved cloud properties. To construct lookup table, they used a general radiative transfer (RT) code which solves RT with a combined discrete-ordinate-matrix-operator method (Nakajima and Tanaka 1986, 1988) and LOWTRAN-7 gas absorption model (Kneizys et al. 1988). About ancillary data for actual data analysis, NCEP/NCAR reanalysis data were used for input meteorological data such as humidity, pressure and temperature profiles, and the minimum value for the month was determined as the monthly ground albedo. Retrieved results were well validated with in situ aircraft measurements (Kawamoto et al. 2001).

This algorithm was applied to AVHRR (Advanced Very High Resolution Radiometer) GAC (Global Area Coverage) radiance data for 1985 - 1988 (NOAA-9) and 1989 - 1994 (NOAA-11). 4-month analysis (April, July, October and December) was performed, and the annual mean was taken as their arithmetic average. As for calibration of sensor signals, the calibration constants from Rao and Chen (1994) were used for channel 1 visible channel, and those from on-board internal blackbody for channel 3 near-infrared and channel 4 infrared channels. Potentially analyzed pixels were selected whose satellite zenith angles less than 25 degrees in order to avoid the effect of cloud inhomogeneity. According to Iwabuchi and Hayasaka (2002), that effect would be reduced for the most part when viewed from angles less than about 25 degrees. For efficient processing, target area was divided into 0.5-degree spatial segment and one segmented-box stores 100 pixels. We constructed this segmented data daily for the analysis period, and analyzed one pixel which had the median value of visible reflectivities among those classified as cloudy in each segmented box.

3. Results and discussion

1) The annual-mean cloud characteristics over China

First, we begin with the annual features of cloud properties over target area in 1990. Fig.1 shows the annual mean of τ. Generally τ over the land is larger than that over the ocean. Especially large τ is observed in the southern part of China. This cloud would be occurred mainly due to active convection. These general features are consistent with ISCCP (International Satellite Cloud Climatology Project) statistics (Rossow et al. 1996). Fig.2 shows the annual mean of r_e. Unlike τ, r_e over land is smaller than that over the ocean. Particularly r_e over the eastern and central parts of China is smaller, although that over the north and west part are larger. Fig.3 shows the annual mean of the integrated cloud droplet number N_c.
N_c is estimated from τ and r_e with the assumed size distribution of log-normal. We find large N_c areas for small r_e and large τ. Values of N_c reported here are compatible with the preceding study (Han et al., 1998). These features on r_e, τ and N_c can be explained by Twomey effect. An idea was proposed that additional aerosol particles can decrease the cloud particle size and increase the cloud optical depth, with increasing cloud droplet number (Twomey, 1977). In general, aerosols are less over ocean, and more over land. The above phenomena are consistent with this idea. Note that cloud properties near the east coast are affected by continental airflow, that is, r_e is smaller, while τ and N_c are larger over land compared to those of remote oceanic area.

As stated above, patterns of cloud properties over land are not geographically uniform. Kawamoto et al. (2003) investigated their relationships with SO2 emission, which is location-dependent. SO2 emission is more in highly populated coastal areas and inland industrial cities, and SO2 is known as a precursor gases for sulfate aerosols. They found good agreement between the two.

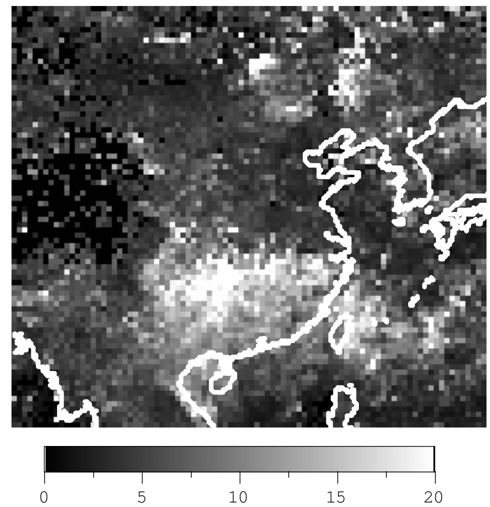

Fig.1 The annual-mean of low-cloud optical depth

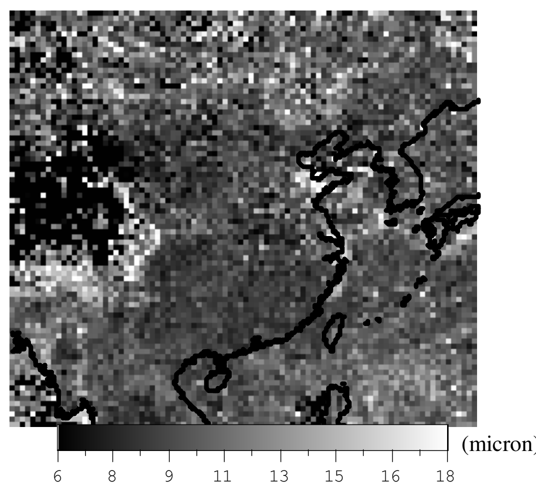

Fig.2 The annual-mean of low-cloud effective particle size

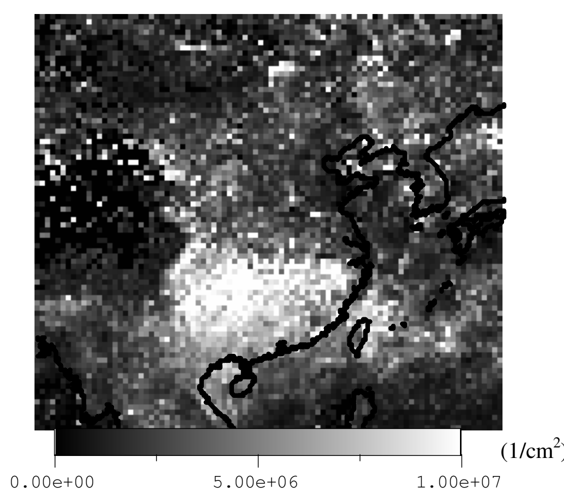

Fig.3 The annual-mean of low-cloud droplet number

2) Long-term variation of r_e over China

Next we examine long-term change of r_e. Due to calibration uncertainty, here we do not mention τ and N_c, whose estimate τ is used for. Fig. 4 indicates the time-series of r_e from 1985 to 1994 over China area. We can observe gradual decreasing trends for both oceanic and continental clouds with gap in 1989. This gap is caused by satellite platform change from NOAA-9 to NOAA11. The seasonal change of r_e, such as large values in July and small values in January, would be driven by precipitation (scavenging of aerosols) discussed in existing studies (Han et al. 1994, Kawamoto et al. 2001). Apart from shorter time scale like seasonal scale, long-term the absolute values do not seem to be realistic. As pointed out for the global results in Kawamoto and Nakajima (2003), we need to be careful to use satellite data for the long-term analysis. There exist some factors that generate artifacts such as satellite platform change, degradation of sensors, calibration uncertainties and orbital shift and so on. As for orbital shift, NOAA-9 (1985 – 1988) had more than 2hours, and NOAA-11 (1989 – 1994) had more than 3hours difference in the equator crossing time (ETC) from the launch to the end of the mission. The difference of ECT would bring diurnal change to the analysis. This means that obtained time-series of r_e are mixed with diurnal, interannual changes and technical influence. To further understand the absolute variation of r_e, we need to make efforts to separate the influence caused by the above factors.

Summary

We have performed remote sensing analysis of low-level water clouds, targeting over China area. First, we describe the annual mean characteristics of cloud parameters. Their land/ocean contrasts of τ, r_e and N_c (larger τ and N_c, and smaller r_e over land) is consistent with Twomey's idea. Their geographical patterns over land are implicated in anthropogenic SO2 emission (Kawamoto et al. 2003).

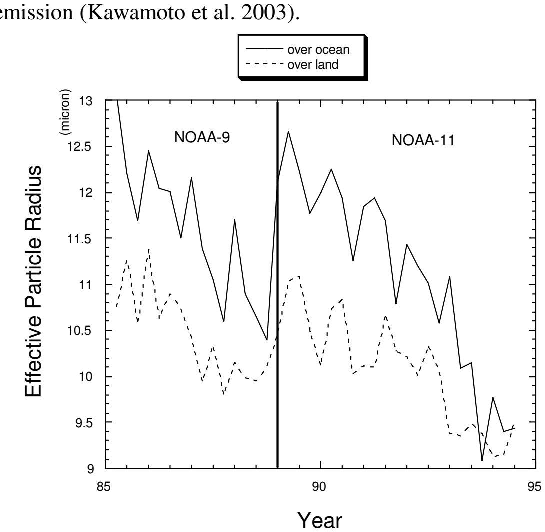

Fig.4 Time series of low-cloud effective particle size

Then we showed long-term trend of r_e. Absolute values generally decrease, indicating seasonal cycle with a gap due to satellite platform change in 1989. This steep decrease would not be realistic. This trend would be caused mainly by artifacts as pointed out in global case in Kawamoto and Nakajima (2003).

For future tasks, it is urgent to cope with reducing artifacts caused by the above factors such as sensor degradation, orbital shift, etc.. And to use recent sensors such as MODIS (Moderate resolution imaging spectroradiometer) and GLI (Global Imager), comparison with historical AVHRR results would be of interest to study the variation of cloud fields.

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