Atmospheric Research 143 (2014) 250–264

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Scheme for detection of low clouds from geostationary weather satellite imagery

Haruma Ishida [a,*], Kentaro Miura [a], Teruaki Matsuda [a], Kakuji Ogawara [a], Azumi Goto [b], Kuniaki Matsuura [b], Yoshiko Sato [b], Takashi Y. Nakajima [c]

[a] *Graduate School of Science and Engineering, Yamaguchi University, 2-16-1 Tokiwa-dai, Ube, Yamaguchi 755-8611, Japan*
[b] *Japan Weather Association, Sunshine 60 Bldg. 55F, 3-1-1 Higashi-Ikebukuro, Toshima-ku, Tokyo 170-6055, Japan*
[c] *Research and Information Center, Tokai University, 2-28-4 Tomigaya, Shibuya-ku, Tokyo 151-0063, Japan*

ARTICLE INFO

Article history:
Received 26 September 2013
Received in revised form 15 January 2014
Accepted 21 February 2014
Available online 27 February 2014

Keywords:
Satellite remote sensing
Low cloud detection
Algorithm development
Geostationary weather satellites

ABSTRACT

A simple and practical scheme for low cloud detection at sea based on geostationary weather satellite data is proposed. The scheme consists of several threshold discrimination tests, and time-consuming procedures are eschewed in order to enable near-real-time analysis. This scheme also minimizes the use of data other than from geostationary weather satellites, leading to a convenient low cloud detection procedure without ancillary data. Careful investigation of the radiative properties of low water clouds from radiative transfer simulation and satellite observations enables full utilization of the characteristics of satellite data and realization of the simple scheme. The threshold values, which should possess high generality, for the discrimination tests are obtained from statistical comparisons of Multi-function Transport Satellite-2 data to grid point value data, which allows for extensive data collection and eliminates the localities and anomalies. Verification by comparisons with radiosonde and lidar on satellite suggests that results obtained from the proposed low cloud detection scheme are reasonable.

1. Introduction

Low cloud has distinctive effects and is related to particular meteorological phenomena. Low stratiform clouds that occur very near the surface sometimes cause severe weather-related hazards by reducing visibility and interfering with land, air, and sea transportation (e.g., Gultepe et al., 2009). The occurrence, development, and types of low clouds are governed by meteorological conditions especially of the atmospheric boundary layer, such as the vertical stability (e.g., Norris, 1998; Pyatt et al., 2005). Low clouds change the structure of the atmospheric boundary layer through heat flux modification (e.g., Koracin et al., 2001). Consequently, low cloud causes a feedback to climate change (e.g., Clement et al., 2005). It is therefore of significant value to observe low clouds not only for meteorological research, but also for various human activities.

Satellite remote sensing is a viable solution for frequent routine observation of low clouds over a wide area, because ground-based observation sites are generally sparse, especially at sea. In particular, geostationary weather satellites are expected to be capable of near-real-time continuous observation of low clouds. However, an appropriate scheme is required for detection of low clouds separately from other types of clouds using spaceborne imaging sensors. Schemes for low cloud (including fog) detection have been developed for sensors such as NOAA/AVHRR (e.g., Bendix, 2002), Moderate Resolution Imaging Spectroradiometer (MODIS) (e.g., Bendix et al., 2005, 2006), and geostationary weather satellites (e.g., Ellrod, 1995; Lee et al., 1997; Ellrod, 2002; Ahn et al., 2003; Underwood et al., 2004; Gultepe et al., 2007; Cermak and Bendix, 2008). A key technique for nighttime low cloud detection with passive sensors is the utilization of the difference

* Corresponding author. Tel.: +81 836 85 9129.
E-mail address: ishidah@yamaguchi-u.ac.jp (H. Ishida).

http://dx.doi.org/10.1016/j.atmosres.2014.02.015
0169-8095/

between the radiative properties of water droplets in the mid-infrared region (near 3.7 μm) and the window region (near 11 μm). The emissivity of water droplets in the mid-infrared region is generally lower than that in the window region (e.g., Ellrod, 1995), and the brightness temperature difference between the two channels (hereafter referred to as MBTD) for low water clouds tends to give a small or negative value if there is no solar irradiance. However, MBTD depends not only on the liquid water path but also on the droplet radius. A larger droplet radius makes MBTD similar to that of the Earth's surface (Hunt, 1973), resulting in the inability to discriminate between low cloud layers and clear-sky regions. Therefore, low cloud detection at nighttime using MBTD requires additional procedures to deal with low clouds with larger droplets. Low cloud detection in daytime requires a different method from that used at nighttime because of solar irradiance. Low cloud detection based on radiance in the visible wavelength region is possible, but optically thick clouds, such as developed cumulus, also have large reflectance, resulting in the inability to discriminate between low and high clouds. In addition, highly reflective surfaces, such as snow and sea ice, lead to incorrect classification. The keys to low cloud detection in daytime are adequate estimation of cloud vertical location for the exclusion of middle and high clouds, and the exclusion of clear-sky regions over bright surfaces.

The low cloud detection scheme also should consist of a simple process structure and data flow in order to minimize computational effort and to implement near-real-time performance for practicality. An algorithm with several simple discrimination tests is expected to be simple. Discrimination tests need threshold values that should possess high generality, in order to carry out the discrimination with satellite data over a certain region and in a certain period. A common procedure to determine threshold values for discrimination tests is the comparison of satellite data with actual observations. However, this might cause localities or anomalies in the threshold values, because observation sites are scarce especially at sea and low clouds do not occur frequently. In addition, it is of advantage to minimize the use of data other than from a geostationary weather satellite, leading to a convenient procedure without using ancillary data. This requirement poses difficulties in low cloud detection, because geostationary weather satellites generally have fewer channels than Earth observation sensors such as MODIS. It is therefore necessary to estimate the radiative properties of low clouds in order to utilize the radiance data fully.

The purpose of this study is to provide a practical scheme for low cloud detection, especially at sea, with visible-to-infrared imaging sensors aboard geostationary weather satellites. The scheme must overcome the difficulties mentioned above: detecting low clouds with larger droplets in nighttime and exclusion of high clouds in daytime. We also intend to make the scheme simple by avoiding time-consuming procedures, such as radiative transfer calculations or inversion problem solutions, and the use of ancillary data as little as possible. The aims of this paper are as follows:

- To find simple and appropriate discrimination tests that satisfy the requirements mentioned above
- To establish an effective procedure for determining threshold values for the discrimination tests
- To verify the scheme by comparing the low cloud detection results with other observations.

Section 2 explains data used for this study. In Section 3, the radiative properties of low clouds are examined from radiative transfer calculation and satellite observation to find appropriate discrimination tests. The algorithm for low cloud detection is briefly explained in Section 4. Section 5 presents the procedure for obtaining the threshold values and its results. Section 6 shows some comparisons of the results of low cloud detection with radiosonde observation and lidar satellite data for the verification of the scheme. A summary is presented in Section 7.

2. Data

In this study, we apply Multi-function Transport Satellite (MTSAT)-2, a geostationary meteorological satellite, located at 145°E. The characteristics of the MTSAT-2 channels are listed in Table 1. The MTSAT-2 observation region includes the seas around Japan, which is a region where dense low cloud (including fog) tends to occur (e.g., Lewis et al., 2004). In particular, the northern Pacific near Japan, to which cold air is transported from the Okhotsk Sea in summer time (an air movement known as *Yamase*), sometimes experiences low stratus formation and advection (Kodama et al., 2009). We arranged the MTSAT-2 data on a grid with a resolution of 0.05° longitude × 0.05° latitude for the infrared channels, and 0.0125° longitude × 0.0125° latitude for the visible channel.

For determining threshold values for discrimination tests, other meteorological data is needed as reference. We use meteorological grid point value (GPV) data derived from the operational mesoscale model (MSM) of the Japan Meteorological Agency (JMA) (Saito et al., 2006). Although GPV data might be less accurate than in situ observation data, they enable extensive data collection for comparisons, and are expected to eliminate localities and anomalies due to the scarcity of observation sites at sea and the infrequency of low cloud occurrence, resulting in obtaining threshold values with high generality.

The domain of MSM GPV is from 22.4°E to 47.6°E and from 120.0°N to 150.0°N with a spatial resolution of 0.125° in longitude × 0.1° in latitude for the pressure levels or 0.0625° in longitude × 0.05° in latitude for the surface. The resolution of the GPV data is comparable to that of the grid used for the MTSAT-2 data. We used the temperature and humidity at the surface and pressure levels of 1000, 975, 950, 925, 900, 850, 800, 700, 500, 400, and 300 hPa. We applied only the initial values of the MSM GPV, which comprises both initial values and forecast data.

Table 1
Characteristics of MTSAT-2 channels.

	Wavelength (μm)	Resolution (km)
1	10.3–11.3	4
2	11.5–12.5	4
3	6.5–7.0	4
4	3.5–4.0	4
5	0.55–0.9	1