Optical and Microphysical Properties of the 2003 *Yamase* Clouds Estimated from Satellite Remote Sensing and Shipboard Observation

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Abstract: '*Yamase*' clouds are one of typical marine boundary-layer clouds, for which the present state-of-the-art performance of weather prediction models and general circulation models is not good enough to simulate properly the clouds, mainly because of coarse spatial-resolution of those models. *Yamase* clouds frequently appear over the North-Western Pacific Ocean east off the Sanriku district in summer under easterly cool winds, called *Yamase*, blown out from Okhotsk anti-cyclones. In order to validate numerical simulation and satellite remote sensing of *Yamase* clouds, we have carried out cloud observations on board the *Koufu-maru* of the Hakodate Marine Observatory in June of recent years. Here we discuss the optical and microphysical properties of the *Yamase* clouds, estimated from the shipboard observation and satellite remote sensing during the 2003 *Koufu-maru* cruise, in which for the first time we observed the evolution features of *Yamase* clouds from their formation to decade. Remote sensing using the contemporary AVHRR data from NOAA-17 in the morning orbit revealed that the *Yamase* clouds were rather thin, stratiform low-level clouds with an area-averaged optical thickness and effective particle radius of about 12 and 13 μm, respectively, and with a mean liquid-water-path of about 110 gm^{-2}.

(*Key Words*: *Yamase clouds*, marine boundary-layer clouds, cloud microphysical properties, satellite remote sensing, NOAA-17/AVHRR data, shipboard observation, 2003 *Yamase* event)

1. INTRODUCTION

Marine stratiform clouds appearing in the maritime atmospheric-boundary-layer (ABL) play a significant roll in the Earth's radiation budget due to their large horizontal extent, long lifetime, and high reflectivity for solar radiation. The state-of-the-art performance of such models as numerical weather prediction and general circulation models is not good enough to simulate properly the low-level stratiform clouds, mainly because of coarse spatial-resolution of these models. Generally, the marine stratiform clouds occur in a wide regional scale under some characteristic synoptic weather condition, but within the vertically thin ABL. Recently, many studies have tried to simulate the boundary-layer clouds by using various cloud resolving models. However, even high-resolution models still have difficulties to reproduce 'correct' features of cloud structure and physical properties; the simulated cloud structure and properties tend to differ for different models and/or resolutions [1]. Moreover, there are very few observational data available to validate the model performance. The cloud physical properties are generally different for different cloud types and different stages of the cloud lifetime, so they are highly variable with time and space. Satellite remote sensing is an efficient technique to observe wide-area distributions of cloud properties. However, it is critically important to validate the performance of satellite remote sensing through comparison with in-situ measurements.

'*Yamase*' clouds are one of typical marine boundary-layer clouds, that appear over the ocean east off the Sanriku area (the east of the Northern District of the Main Island of Japan) in early summer season under easterly cool winds, i.e., the so-called *Yamase* [2], blown out from Okhotsk anti-cyclones. We are studying the formation processes of *Yamase* clouds through numerical simulations by using a non-hydrostatic cloud-resolving model [1, 3]. The preliminary results suggest that the model-produced clouds strongly depend on the used spatial resolution as well as parameterizations of such physical processes as turbulence, cloud and radiation processes. Further, we are going to retrieve the cloud properties such as optical thickness and effective particle radius of *Yamase* clouds from the AVHRR data of NOAA satellites. To validate the results from the numerical simulation and satellite remote sensing of *Yamase* clouds, we have carried out a few times of shipboard observations in June of the latest years. Here we present the cloud optical and microphysical properties estimated from satellite

remote sensing and the shipboard observation for the *Yamase* event in June 2003. The 2003 summer in the northern Japan is remembered as an unusually cool summer with severe shortages of insolation and crop damage due to the *Yamase* weather.

2. SHIPBOARD *YAMASE* OBSERVATION

The cloud observations on board a ship have been carried out within the Yamase Intensive Experiment (YIE) conducted by the Sendai District Meteorological Observatory and the Hakodate Marine Observatory (HMO) of the Japan Meteorological Agency, in collaboration with the Center for Atmospheric and Oceanic Studies (CAOS) of Tohoku University. The marine observation vessel *Koufu-maru* of the HMO operated the shipboard YIEs in an area east off the Sanriku [4] in June of the recent years. In addition to the routine marine weather observations and intensive GPS-sonde launchings, the CAOS-group conducted cloud observations for measuring cloud parameters by using various radiometric instruments as well as an aerosol particle-counter aboard the *Koufu-maru*. The measured parameters can be used in validation of the products from satellite remote sensing and numerical simulations. Among these parameters, cloud liquid-water-path (*LWP*) and cloud-base height are particularly useful parameters for the validation; they were measured by a dual-frequency microwave-radiometer (Radiometric Co., WVR-1100) and a laser ceilometer (ImpulsePhysik, LD-25), respectively. Further, the temperature, humidity and wind profiles measured by GPS-sondes can be compared with the model-simulated profiles.

In the 2003 YIE, we fortunately encountered a *Yamase* event, in which, for the first time, we observed a series of the formation and evolution processes of *Yamase* clouds from the evening of 22 June through the evening of 24 June 2003. The *Koufu-maru* stayed near the point (39ºN, 143ºE) for operating the YIE from the afternoon of 22 June to the morning of 25 June. Figure 1 shows time variation of the temperature and humidity profiles in the lower troposphere during the *Yamase* event. In the figure, the cloud-base heights measured by the ceilometer and the wind profiles measured by the GPS-sondes are also plotted. Over the location of *Koufu-maru*, the lower part of ABL became cool and humid with the inflow of *Yamase* wind in the evening of 22 June, and very low *Yamase* clouds (might be fogs) appeared with the cloud-base heights of a few tens meters in the night of 22 June through the morning of 23 June. During the daytime of 23 June, the cloud-base was lifted up, at highest, to 300 m with the development of mixing in the ABL, although the cloud layer became rather thin and patchy; the cloud-base height gradually decreased during the night down to about 100 m in the morning of 24 June. In the daytime of 24 June, the cloud-base was again lifted up, and finally it reached the heights higher than 1 km in the night, when the ABL was well mixed with an almost constant equivalent temperature up to about 1.2 km. In the morning of 25 June, the low-level *Yamase* clouds disappeared over the *Koufu-maru* site. The mean cloud-base height averaged over the duration was about 270 m, and the corresponding mean *LWP* was about 60 gm^{-2} for the *Yamase* cloud measured on board the *Koufu-maru*. The observational data of time variations of the atmospheric profiles and associated cloud fields will be useful for validation of simulations of the *Yamase* event.

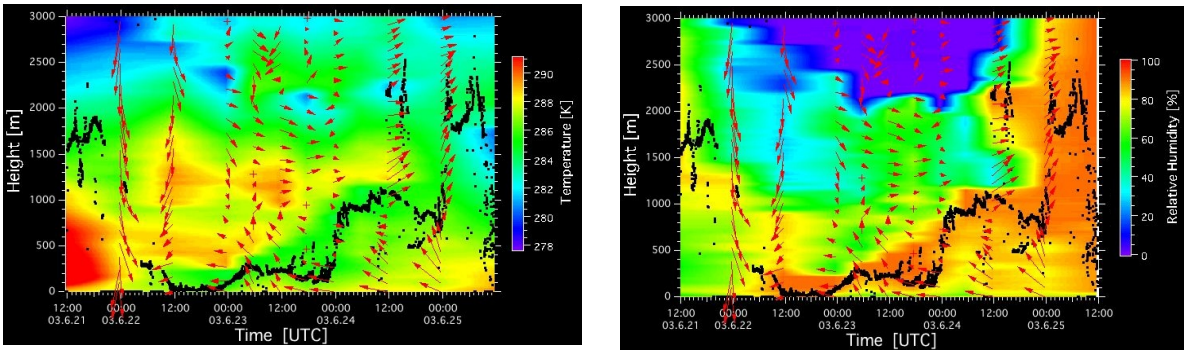

Fig. 1. Time variation in UTC of the temperature (*left*) and relative humidity (*right*) profiles, interpolated from those measured by the GPS-sondes launched from the *Koufu-maru*, in the marine lower atmosphere from 21 June to 25 June 2003. In the figure, the cloud-base heights (*black dots*) measure by the ceilometer and the wind profiles (*red arrows*) measured by the GPS-sondes are also superimposed.

3. SATELLITE REMOTE SENSING

The cloud optical thickness (τ_c) and effective particle radius (r_{eff}) of the *Yamase* clouds have been retrieved from the contemporary NOAA/AVHRR data in a wide area in the Western North Pacific region. The AVHRR data used in the present study were processed from the High Resolution Picture Transmission data of NOAA-17 satellite in the local morning orbit; the data are being archived at Tohoku University, Sendai. Simultaneous data of the visible and near-infrared reflected radiances in the AVHRR channels 1 (0.58 - 0.68 μm) and 3A (1.57 - 1.78 μm), respectively, were used to retrieve τ_c and r_{eff}. The infrared channel data in channels 4 (10.3 – 11.3 μm) and 5 (11.5 – 12.4 μm) were used to discriminate low-level water clouds from higher-level clouds by estimating the cloud-top temperatures. In the satellite data analysis, we employed the atmospheric profiles from the NCEP/NCAR reanalysis data, and the sea surface temperatures from the NGSST (new generation sea surface temperature) products released from the CAOS [5]. From the retrieved τ_c and r_{eff}, the liquid-water-path *LWP* can be estimated by using the approximate relation, $LWP=2\rho\tau_c r_{eff}/3$, where ρ is the density of liquid water. The performance of satellite remote sensing was validated by comparing the satellite-derived *LWP* and the shipborne WVR-measured *LWP* for the collocated scenes. During the 2003 YIE cruise, we had two scenes for which the *Koufu-maru* site was completely covered by low-level clouds and the NOAA-17 satellite simultaneously observed the clouds over the site. For the two cases, the satellite-derived *LWP* and the WVR-measured *LWP* agreed with each other within an uncertainty of 20 gm^{-2}. Therefore, the satellite remote sensing of the low-level clouds can be regarded as reasonable and reliable.

Figure 2 shows an example of the retrieved τ_c and r_{eff} for the low-level clouds in the morning of 24 June 2003. The easterly surface winds are also depicted by the arrows superimposed on the panels. The figure shows a wide distribution of optically thin and uniform, stratiform low-level clouds in the Western North Pacific region. However, in some locations, the cloud distribution exhibits band-like features and cellar structures, particularly, in the leeward places. The retrieved τ_c and r_{eff} are, in general, positively correlated each other with larger r_{eff} for larger τ_c, and vice versa; this suggests that the cloud was, as a whole, in a developing stage. However, the opposite correlations between τ_c and r_{eff} were also noticed in some places, where there might be dominated by drizzle and precipitation formation or ship-track clouds [6]. The cloud distribution features and the τ_c vs r_{eff} correlations changed in time and location during the *Yamase* event.

From the five days' remote sensing during 23 June to 27 June, the occurrence probability of the retrieved τ_c, r_{eff} and *LWP* were analyzed for the low-level clouds in a wide area of about 400 km×400km, east off the Sanriku district. Figure 3 shows the frequency histograms of the retrieved τ_c, r_{eff} and *LWP*. It is shown that most clouds were fairly thin with optical thicknesses between 4 and 20

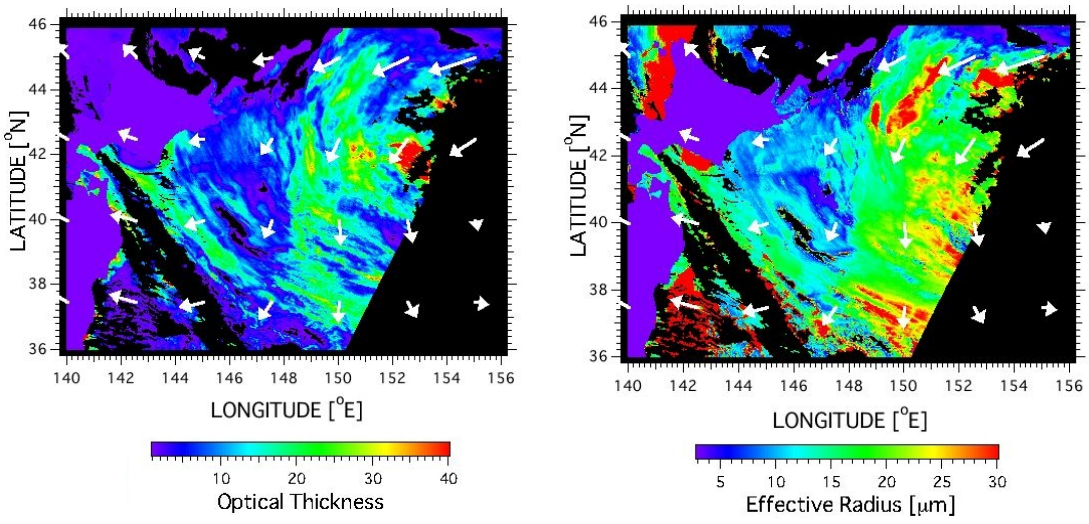

Fig.2. Optical thickness (*left*) and effective radius (*right*) retrieved from the AVHRR data of NOAA-17 for the low-level clouds on 24 June 2003. The black areas indicate the areas of no data and/or covered by higher clouds. The white arrows indicate wind velocity at 1000 hPa from the NCEP/NCAR reanalysis data.

(mean nalue of 12) and with rather uniform particle radii between 8 and 16 μm (13 μm). The mean value of *LWP* averaged over the area was about 110 gm^{-2}.

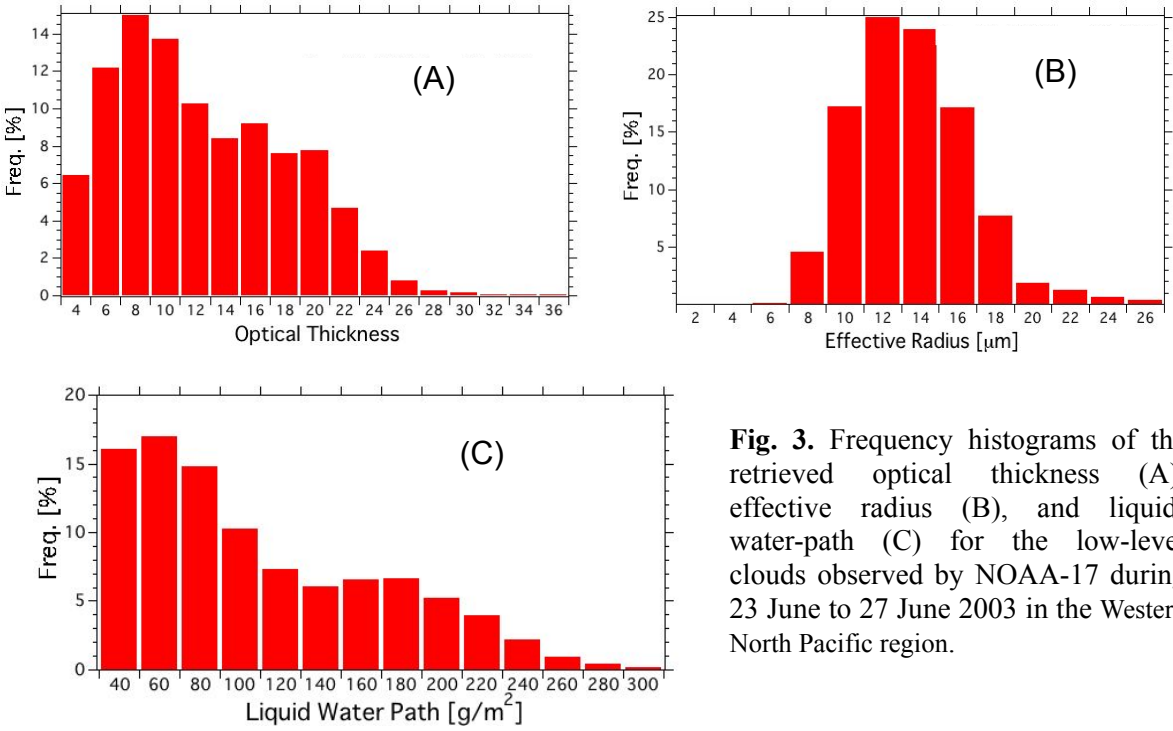

Fig. 3. Frequency histograms of the retrieved optical thickness (A), effective radius (B), and liquid-water-path (C) for the low-level clouds observed by NOAA-17 during 23 June to 27 June 2003 in the Western North Pacific region.

4. Concluding remarks

We have investigated the optical and microphysical properties of *Yamase* clouds in June 2003 by means of the shipboard observation on *Koufu-maru* and remote sensing using the contemporary AVHRR data from NOAA-17 satellite. For the first time, we could observe the evolution features of maritime low-level clouds in *Yamase* event from their formation to decade. The present results can be used to validate numerical simulations of the 2003 *Yamas*e event by using non-hydrostatic cloud-resolving models. The shipboard experiment should be continued to accumulate more observational data usable to validate and improve the performance of numerical models and satellite remote sensing of low-level clouds for different weather conditions and different places.

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