

**Study on Marine Boundary Layer Clouds
and Their Environment
for Cloud Parameterizations in Global Climate Models**

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Chapter 1. Introduction

Marine boundary layer clouds (MBLCs) are low-level clouds prevailing over the ocean. Optically thick MBLCs typically prevail over oceans with low sea surface temperature (SST) and high lower tropospheric stability. Although they do not bring heavy rain or strong wind, MBLCs are important for the global radiation budget because of their large shortwave radiative effects. Recent research shows that uncertainties in predicted temperature increases in global warming simulations can be mainly attributed to representation of MBLCs in global climate models (GCMs). MBLCs formed and maintained by a subtle balance of complicated physical processes can never be represented by GCMs having coarse horizontal and vertical resolutions. The purpose of this thesis is to reveal relationships between MBLCs and their environment, and to contribute to the improvement of the parameterization of MBLCs in GCMs.

Chapter 2. A Simple Parameterization Scheme for Subtropical Marine Stratocumulus

A simple scheme is implemented in the global spectral model at the Japan Meteorological Agency to represent marine stratocumulus clouds off the west coast of continents. The parameterization is based on diagnostic cloud schemes where cloud fraction is determined mainly as a function of inversion strength with consideration of other parameters. This resulted in a remarkable improvement in representation of the

global distribution of marine stratocumulus clouds off the west coast of continents. Low-level cloud amount showed reasonable agreement with satellite-based observation data. Further, a comparison with observed radiation flux data shows that, with improved cloud amount, the radiation fields were also improved. Seasonal and diurnal variations of marine stratocumulus cloud amount off the west coast of continents also showed reasonable agreement with surface-based observation data.

Chapter 3. Probability Density Functions of Liquid Water Path and Cloud Amount of MBLCs: Geographical and Seasonal Variations and Controlling Meteorological Factors

The representation of stratocumulus was dramatically improved by the introduction of the simple scheme described in Chapter 2, but the diagnostic scheme can be too simple to represent the detailed behaviors of MBLCs or to simulate the reliable future changes. Subgrid-scale fluctuations of physical values, including humidity, are intrinsically important for cloud parameterization and are required for sophisticated cloud parameterizations. The probability density functions (PDFs) of the liquid water path (LWP) in MBLCs in areas that correspond to a typical grid size of large-scale (global climate and weather prediction) atmospheric models (200×200 km) are investigated using geostationary satellite visible data. Geographical and seasonal variations in homogeneity, skewness, and kurtosis of LWP PDFs are discussed in addition to cloud amount. It is clear that not only cloud amount but also these subgrid-scale statistics have well-defined geographical patterns and seasonal variations.

Furthermore, meteorological factors that control subgrid-scale statistics of the LWP related to boundary layer clouds are investigated using reanalysis data and PDFs of LWP data from satellites. Meteorological factors related to stability between 850 and 1000 hPa, including the corrected gap of low-level moist static energy developed here, show higher correlations with the homogeneity, skewness, and kurtosis of PDFs of the LWP of MBLCs than those with cloud amount examined by the previous studies.

Chapter 4. Probability Density Functions of Liquid Water Path and Total Water Content of MBLCs: Implications for Cloud Parameterization

For the use in cloud parameterizations, PDFs of total water content (and cloud water content) are obtained from those of LWP, which is a vertically integrated value derived from geostationary satellite visible data in Chapter 3. It is shown that, under some realistic assumptions, different atmospheric stabilities have different PDF shapes for total water content: in general, triangular PDFs are realistic approximations of PDFs of total water content in MBLCs for strongly stable atmospheric boundary layers (ABLs), and Gaussian PDFs are reasonable approximations for moderately stable ABLs. This result implies that liquid water content PDFs for moderately stable ABLs, where stratocumulus tends to be dominant, have longer tails due to its convective activity than those for strongly stable ABLs, where stratus tends to be dominant. The correction ratio for the autoconversion rate of cloud water content to precipitation and the reduction factor for shortwave reflectance were also obtained as functions of cloud amount. These values are used in precipitation and radiation processes in models to take inhomogeneity effects into account. The information can have practical implications for cloud parameterizations.

Chapter 5. Conclusions

Subgrid-scale PDFs of water vapor and cloud water are critical for cloud parameterizations. The shapes of the PDFs, however, have been assumed just as given in many of the studies concerning PDF-based cloud parameterizations, and investigations related to PDF forms that are based on observational data which cover large area and various seasons have been quite limited. In this thesis, subgrid-scale PDFs of MBLCs were studied based on satellite observation data, which have large observational area coverage with high frequency and long period. The major subgrid fluctuations in large-scale models are not caused by turbulence associated with MBLCs, but by their meso-scale morphological types. Therefore, the characteristics of the subgrid statistics which cover large area must be revealed, and subgrid PDFs were investigated using a lot of observed snapshot with the size of 200×200 km in this study. This size of snapshots can capture different meso-scale morphological types occurring in MBLCs because the size of open cells and closed cells are several tens of kilometers.

The most important contribution of research described in this thesis is that meteorological factors that control subgrid-scale PDFs of LWP related to MBLCs were revealed for the first time. Relationships between cloud amount and meteorological factors have been extensively studied and they are well-known. However, relationships

between shapes of PDFs of cloud water and meteorological factors have never been investigated statistically before this study. Furthermore, mathematical forms of PDFs of total water content were estimated also for the first time depending on the ABL stabilities from the observation data. In addition, inhomogeneity factors have not previously been provided as a function of cloud amount for different cloud regimes. Therefore, we conclude that this research significantly contributed to and promoted research related to subgrid-scale PDFs associated with MBLCs, and provided useful information for cloud parameterization in GCMs and global numerical weather prediction models.