PREFACE

Clouds over ocean play an important role in the energy balance of the atmosphere by way of radiation feedback. The radiation characteristics of a cloud are closely related to marine boundary layer (MBL) and microphysical structures; therefore the observation and analyses of the MBL and Precipitating cloud microphysical structure are essential for the study of climate and climate change. *The main objective of the Ph.D., thesis is to understand the mechanism of cloud-precipitation processes over the warm water pool, focusing on vertical structure of marine boundary layer, precipitating clouds and microphysical (rain integral parameters or Rain drop size distribution and melting layer or bright band) characteristics.*

Institute of Observational Research for Global Change/Japan Agency for Marine-Earth Science and Technology Center (IORGC/JAMSTEC), Yokosuka, Japan has been conducted the observational project PALAU (Pacific Area Long-term Atmospheric observat for the Understanding of climate change) over Aimeliik state of Babeldaob Island (7.45° N; 134.47° E) of Republic of Palau. The above mentioned field study can advances our knowledge of marine stratocumulus by providing information on the boundary layer and cloud structure, as well as their diurnal cycle. This field experiment is useful to understand stratocumulus clouds that can be formed under a diverse range of conditions, in both deep and shallow marine boundary layers (MBL), and under a wide range of aerosol conditions. These clouds radiative and precipitation properties are sensitive to aerosols, liquid content, cloud depth, and insolation.

The experimental site, Aimeliik is located in the high island of Babeldaob [in the Palau (508 Sq. km) archipelago], which is one of the largest islands in the Western Pacific Ocean. Babeldaob Island is partly elevated limestone and partly volcanic. The vegetation in this island varies from the mangrove swamps of the coast, with trees often
from 10–16 meters high; to the savannah type grasslands of the near interior which support palms and pandanus, and the densely forested valleys further inland.

At Aimeliik Observatory, instead of a single instrument, several ground-based instruments (Wind Profiler Radar (WPR), Ceilometer, Micro Rain radar, Impact Disdrometer and Automatic Weather Station) are deployed to cover more than one aspect of the atmosphere at the same time. National weather service (NWS) which is confided by National Oceanic and Atmospheric Administration (NOAA) is located at Koror (7.33°N; 134.48°E) the capital of Palau.

For the present study, four-years of data collected during April 2003 to March 2007 from Wind Profiler Radar (WPR), Ceilometer, Joss-Woldvogel Disdrometer (JWD), Micro Rain Radar (MRR), and Automatic Weather Station data have been utilized. Upper air sounding is carried out by Koror National Weather Service (NWS) which is located about 10 km south of Aimeliik observatory. Balloons are launched twice a day i.e. around 0000 and 1200 UTC [Local Time (LT) = UTC +0900 hours where UTC is universal coordinated time].

We defined the monsoon season using 850 hPa zonal wind sounding and low-mode WPR (1500 m to 2000 m) data over Palau as the wind speed exceeds more than 5 m/s. In general, Westerly monsoon (WM) onset appears around May to July and withdrawal around September to December.

Over the past three decades, wind profiling technology has proved valuable in both research and operational applications, including severe weather analysis and forecasting, numerical modeling, pollution monitoring and space launch support. Individual profilers and networks of Wind Profiler Radars provide continuous measurements, economically and automatically, with high space and time resolutions which are necessary in defining smaller scale as well as synoptic scale phenomena.
Wind profiler radar (WPR) operating near 1 GHz has been used in boundary layer dynamics and precipitation research by the several researchers. The WPR have been used extensively in numerous field campaigns. The WPR system is capable of observing the lower part of atmosphere from 120 m to 3000-5000 m in clear air conditions with height resolution of 60 m and up to ~ 12000 m in the precipitation conditions with a height resolution of 200 m. WPR observations during clear air conditions are used to obtain the background wind fields, turbulence parameters and marine boundary layer evolution. WPR observations yield time height cross sections of equivalent reflectivity, Doppler velocity and spectral width that illustrate the evolution of marine boundary layer and precipitating clouds. In the presence of precipitating clouds backscattering from hydrometeors is dominant and the Doppler velocity provides a measure of the fall velocity of hydrometeors. The vertical structure of these parameters has been used to classify marine boundary layer and precipitating cloud systems into several different categories. The observations over Palau-WPR document the prevalence of shallow and deep convective cloud systems over the Pacific warm pool region. They also show the relative abundance of rainfall from stratiform and convective components of precipitating cloud systems and the continuous observations reveal the diurnal evolution of the precipitating clouds over Palau in the Pacific Ocean.

Raindrop size distributions (DSD) are crucial for understanding rain formation processes. Joss-Woldvogel Disdrometer (JWD) is the one of the reliable instruments for measuring DSD on the ground. The JWD is capable of estimating the rain DSD in the range of 0.3-5.0 mm with time resolution of one minute and it provides accurate rain drop size distribution parameters on the ground. The MRR estimates the vertical profiles of DSD and the type of rain (snow or rain) for every minute. These
systems/sensors thus make an ideal combination for the studies on precipitation over Palau in the Pacific Ocean.

Other important objective of the present study is to evaluate characteristics of melting layer, it is first necessary to have long term measurements of the bright band. These measurements will allow us to derive the dependence of bright band characteristics on precipitation type and intensity that will help in quantifying the contribution of the various causes to the bright signature over Pacific Oceanic region. Data collected from Aimeliik- wind profiler radar were used to compute average profiles of radar reflectivity in and surrounding the melting layer to quantify various phenomena causing the bright band signature. The possibilities of intensive observations in these areas and availability of number of co-located facilities at Aimeliik can be used for ground validation of the proposed Global Precipitation Mission (GPM).

This thesis consists of SEVEN chapters. The contents of each chapter are as follows:

Chapter I, present a general introduction to the lower atmospheric/ tropospheric processes and monsoon precipitation over Pacific Oceanic regions. It is well known that the local geographical and climatic conditions play dominant role in the marine boundary layer futures as well as precipitation characteristics. The orographic features around Palau and predominant weather conditions are described. Finally, the motivation and objectives of the present study are described.

Chapter II describes radar remote-sensing techniques used for probing the Earth’s atmosphere to understand monsoon precipitating cloud systems. The scattering mechanisms relevant to the radar remote sensing of the atmosphere in general and specifically to this study are described. It also describes the techniques related to the
wind profiler radar used for the present study. In addition experimental techniques used for the measurements are also covered in Chapter. II. The details of the hardware and software of the instruments/sensors WPR, Ceilometer, JWD, MRR, Radiosonde and AWS used for the present study are explained. The signal and data processing techniques applied to the radar systems used for the present study.

Ground-based remote sensing observations of atmospheric variables are collected at Aimellik observatory using a WPR, Ceilometer, JWD, MRR, Radiosonde and AWS. This instrument is sensitive to a limited number of atmospheric variables and thus provides information about one or a few aspects of the atmosphere, with the associated uncertainty and limitations. Hence, major focus of Chapter III is to evaluate the capability of the existing instruments to remotely derive meteorological quantities using sensor synergy. A synergetic approach, relying on the complementary characteristics of different instrumentations, is able to either improve retrieval accuracy, overcome limitations.

In Chapter IV, four-year data-set from Very-high-frequency Wind Profiler Radar (WPR) and Ceilometer to study the vertical structure of marine boundary layer in the Western Pacific warm pool during two distinct (Westerly and Easterly) monsoon seasons. These studies are supported by MRR, Radiosonde, and AWS data to correlate radar reflectivity, thermal buoyancy, and surface rainfall patterns with vertical air-motion structures. A ‘new algorithm’ utilized for understanding of MBL variations during westerly/easterly monsoon periods. The results show a fairly good agreement with the normal peak detection method. It is noticed that multiple forcing mechanisms are primarily responsible for the shallow marine boundary-layer heights observed during westerly monsoon period.
In Chapter V, a four-year dataset from Wind profiler radar, Micro Rain Radar
and Disdrometer are utilized to understand vertical structure of Easterly and Westerly
monsoon Precipitating clouds by partition the cloud fraction into deep convection,
shallow convection, transition (Mixed convection & Stratiform) and stratiform
precipitation. Chapter V also describes research on a new form of gamma drop size
distribution (DSD) model that employs two arbitrary moments as free DSD parameters
to enhance the flexibility in studying the characteristics of gamma DSD model to fit the
spectrum. The validity of a DSD model is evaluated in terms of the stability in solving
non-linear least-squares (NLLS) problem and the accuracy in DSD moment estimates.
The microphysical [i.e., raindrop size distributions (DSD)] parameters are retrieved
during stratiform precipitating clouds over Palau.

Chapter VI investigates microphysical properties (Melting layer / Bright band
characteristics) precipitating clouds observed during easterly and westerly monsoon.
For this study long-term observation of L-band Wind profiler Radar and Micro Rain
Radar, Tropical Rainfall Measuring Mission measurements and radiosonde data is
utilized.

Chapter VII presents summary and scope of the future studies of the subject
presented in the thesis.