Journal of Atmospheric and Solar-Terrestrial Physics 121 (2014) 132–140

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Observational study on melting layer characteristics over Palau in Pacific Ocean

U.V. Murali Krishna[a], K. Krishna Reddy[a,*], R. Mastanaiah[a], Ryuichi Shirooka[b], Chen-Jeih Pan[c]

[a] Department of Physics, Yogi Vemana University, Vemanapuram, Kadapa 516003, Andhra Pradesh, India
[b] Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan
[c] Institute of Space Science, National Central University, Jhongli, Taiwan

ARTICLE INFO

Article history:
Received 1 June 2013
Received in revised form
22 September 2014
Accepted 23 September 2014
Available online 30 September 2014

Keywords:
Bright band
Wind profiler radar
Radar reflectivity
TRMM PR Radar
Radiosonde

ABSTRACT

In this paper, four years (April, 2003–March, 2007) of wind profiler radar (WPR) observations, Tropical Rainfall Measuring Mission measurements, radiosonde and automatic weather station data are utilized to characterize melting layer/bright band (caused due to the melting of hydrometeors when the precipitation has a significant stratiform cloud contribution) variability during easterly and westerly monsoon periods over Palau in Western Pacific Ocean. Four years observational results show that presence of stratiform precipitation is more in Westerly monsoon compared to Easterly monsoon. However, bright band height (BBH) is lower in Westerly monsoon. It is also observed that the BBH during the year 2006 is higher than 2005 possibly due to El Nino effect.

1. Introduction

Lack of knowledge on the detailed physics of the melting layer has some practical consequences in hydrology, microwave communications and numerical weather prediction (Fabry and Zawadzki, 1995). The layer over which the transformation from ice to water occurs defines the melting layer. The top of the melting layer is the melting level, commonly accepted as the altitude of the 0 °C constant-temperature surface (Glickman, 2000). In hydrology, radar measurement of precipitation can be biased by the bright band (Smith, 1986; Joss and Waldvogel, 1990; Fabry et al., 1992; Qi et al., 2013). Bright band height (BBH) is the altitude of maximum radar reflectivity in the melting layer (Austin and Bemis, 1950; Stewart et al., 1984; Klaassen 1988; Willis and Heymsfield, 1989; Fabry and Zawadzki, 1995; Houze, 1997; Gray et al., 2001; White et al., 2003; Zawadzki et al., 2005; Martner et al., 2008; Sharma et al., 2009). Radar observations of melting layer of precipitation has been known and studied for more than three decades (Marshal et al., 1947; Cunningham, 1947; Battan, 1973; Meneghini and Liao, 2000). The radar bright band is associated with the enhancement of radar reflectivity. The enhancement in radar reflectivity is primarily due to increase in dielectric constant of hydrometeors at the top of the melting layer followed by an increase of the fall velocities of melting snowflakes towards the end of the melting process (Battan, 1973; Zawadzki et al., 2005).

In microwave communication, the enhanced reflectivity of the bright band results in enhanced scattering and greater signal extinction. Satellite links operating at frequencies above 10 GHz are often attenuated by hydrometeors such as rain, hail, cloud and the melting layer (Ippolito, 1986; Allnutt, 1989; Crane, 1996; Bryant et al., 2001; Chakravarty and Maitra, 2010; Peters et al., 2010; Badron et al., 2011). The attenuation prediction is usually performed with different meteorological parameters like rain rate, drop size distribution and rain height etc. Among these parameters rain height is the most important because it is very close to 0 °C isotherm height (Hall, 1979; Ajayi and Ofoche, 1984; Romo et al., 2012). Hence, 0 °C is taken into account for the calculation of rain attenuation (International Telecommunication Union Recommendation P 839-3, 2001).

Knowledge of attenuation by the melting layer will be crucial in order to estimate rainfall using short wavelength space borne radars. Hence, characteristics of the melting layer are not only important for understanding the microphysical processes involved in rainfall mechanism but also necessary for rain retrieval algorithms used for present and future space-borne rain radars such as Tropical Rainfall Measuring Mission Precipitating Radar (TRMM-PR) and future Global Precipitation Mission (GPM). With the Tropical Rainfall Measuring

---

[*] Corresponding author. Fax: +91 8562 225419.
E-mail address: krishna.kkreddy@gmail.com (K.K. Reddy).

http://dx.doi.org/10.1016/j.jastp.2014.09.015
1364-6826/

Mission (TRMM) satellite, more data about the melting layer have been available in tropics. Thurai et al. (2003a) shows that there is a significant variation of melting layer height with the latitude. Seasonal variability of zero degree isotherm height for some tropical locations from local Radiosonde data are also reported (Mondal et al., 2001; Mandeep, 2009). Although, TRMM provides a good amount of data, but its resolution is poor both spatially and temporally (Pan et al., 2010). Also measurements of melting layer height from radiosonde are limited to a few hours only. Thus, there is a need of continuous measurement of melting layer to estimate the actual variability of this layer. So, continuous measurements of BBH are required to overcome these limitations. In the present study, BBH measurements are made with a ground based high resolution vertically profiling Wind Profiler Radar (WPR). The advantage of WPR is to measure directly the vertical wind component within a convective environment (Gage et al., 1994). Several researchers (Gage et al., 1994; Atlas et al., 1999; Reddy et al., 2002) have used WPR to reveal details about the vertical structure of precipitating clouds and a few studies on melting layer (Fabry and Zawadzki, 1995; White et al., 2002; Di Girolamo et al., 2012).

Several models (Zawadzki et al., 2005; White et al., 2010) have been proposed to estimate the height/intensity of bright band. Minder and Kingsmill (2013) studied the lowering of snow line over Northern Sierra Nevada using Weather Research and Forecasting model. However, modeling of melting layer/bright band either obtains correct reflectivity enhancement or overestimate the intensity. This is due to the assumption that the bright band enhancement is caused by the melting of low density snowflakes only. The lack of agreement of model results with observations is also exacerbated by the fact that there are no extensive measurement records of the bright band. Most comparisons of models and observations are too often based on one or a few events (Lhermitte and Atlas, 1963; Olson et al., 2001). Given the large number of factors that may influence the bright band (snowflake sizes and shapes, temperature profiles, vertical air velocity), it is not surprising to have so many, often contradictory, explanations of the bright band phenomenon (Russchenberg and Ligthart, 1996; Thurai et al., 2003a,b).

This paper examines the long-term bright band characteristics during different monsoon regimes and its variations during El Nino and non- El Nino (Normal) period over Palau Island in the Pacific Ocean. This paper is organized as follows: Section 2 describes the data and methodology, while Section 3 consists of the result of this study and discussions. Lastly, the conclusions are given in Section 4.

2. Location, data and methodology

Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is carrying out research at Palau Islands (7° 20′ N, 134° 28′ E) focusing on the **P**acific **A**rea **L**ong-term **A**tmospheric observation for **U**nderstanding of climate change (PALAU) project to elucidate cloud-precipitation processes and air-sea interactions over the warm water pool, focusing on seasonal and intra-seasonal variations (Kubota et al., 2005; Ushiyama et al., 2009). JAMSTEC installed ground based sensors viz., a Lower Atmospheric Wind Profiler (LAWP), Micro Rain Radar, Ceilometer, Microwave Radiometer, Joss-Waldvogel Disdrometer (JWD) and Automatic Weather Station (AWS) at Aimeliik observatory (7.3°N, 134.3°E). However, for the present study, WPR, JWD and AWS data are utilized. Field experiments in Palau provided long-term high-temporal

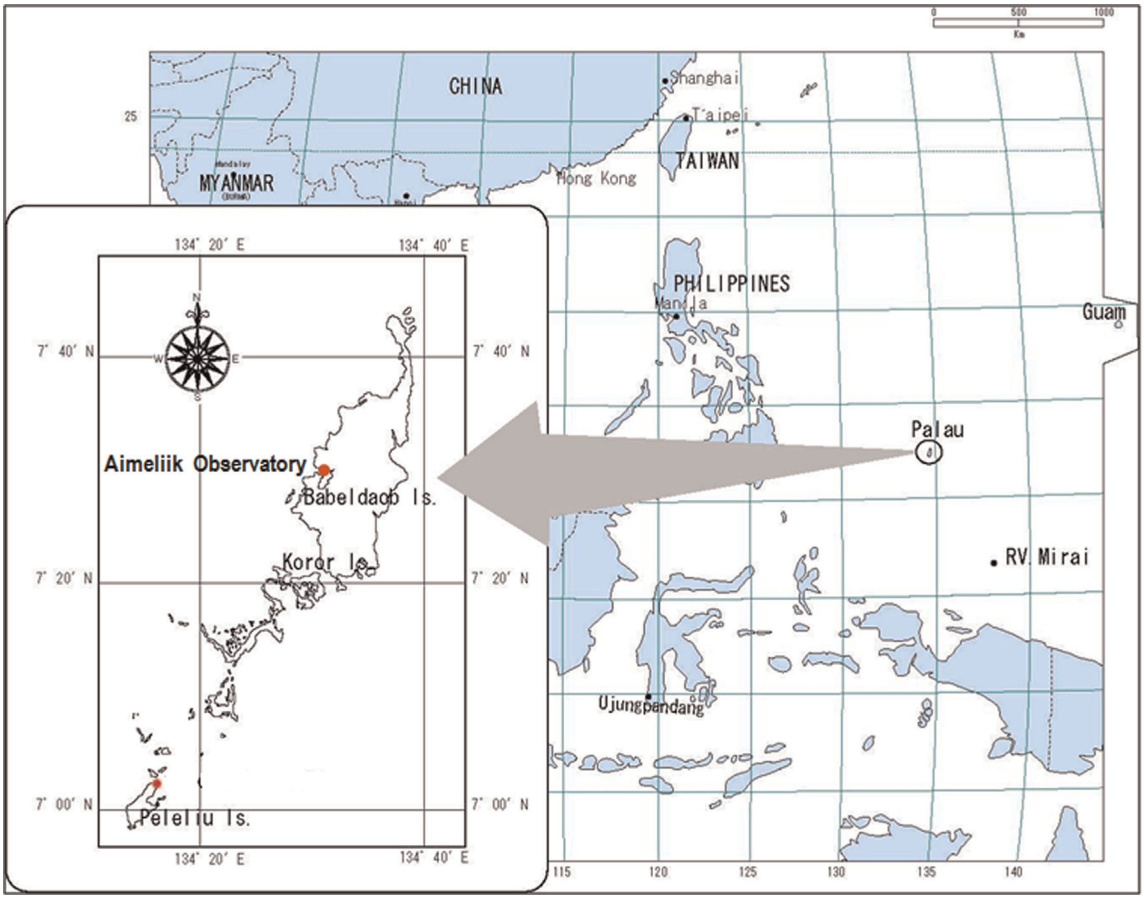

Fig.1. : Map of the western Pacific region. (left) Enlarged map of the Palau area.