Long-term change in characteristics of cloud vertical structures in Padang from radiosonde observations

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Abstract. The characteristics of clouds continue to change with climate change, including changes in cloud-base height (CBH), cloud tops (CT) and the number of layers of clouds. This work investigates cloud vertical structures in Padang using long-term observations of radiosondes (1988-2019). Height of CBH identified based on the relative humidity threshold of 84% following the method proposed by several previous studies. The vertical distribution of cloud tops, cloud base has increased over time in all cloud layers, but cloud thickness has decreased. The most commonly observed cloud layer in Padang is one layer cloud (58.87%), followed by two layer cloud (31.12%). The cloud with more layer is also observed but the number is relatively small (10%).

1. Introduction

Clouds hold the balance of energy on earth by absorbing and reflecting solar radiation entering the Earth's atmosphere and reducing thermal radiation outgoing of the earth [1]. The balance of radiation is very dependent on the vertical structure and distribution of clouds in the atmosphere. In addition, the impact of clouds on the radiation balance of the Earth's atmospheric system also depends on the basic altitude, upper altitude and optical properties of the cloud [2]. Cloud radiative forcing (CRF), which is induced by interactions between aerosols and cloud [3], contributes to uncertainties in weather forecasts and climate predictions [2]. The characteristics of clouds continue to experience changes along with climate warming, cloud parameters have changed including clouds height, cloud cover and cloud morphology [4]. Cloud base height (CBH), cloud top height (CT), and number of cloud layers are important macro cloud parameters, greatly affecting the energy exchange between the ground surface and the cloud layer [5]. Models and observations have been widely used to explain cloud characteristic and their changes over the past several decades, related to annual, seasonal and daily time scales. However, the cloud profile is still poorly understood and remains a major source of uncertainty in studies weather and global climate [6].

The current cloud profile depends largely on satellite data [15] and surface-based observations [7] and surface-based observations [8]. The emergence of cloud radar in space (e.g., CloudSat) has made it possible to better describe the clouds vertical structures on a regional and global scale as well as being one of the most popular sources of data in cloud studies [9]. Cloud profiles and CBH data used from CloudSat and CALIPSO measurements has helped resolve longstanding debates about overly low thermal radiation estimates, which have been updated from previous estimates of 324 Wm\(^{-2}\) [10] to around 345-350 Wm\(^{-2}\) [11]. However, cloud radar installed on CloudSat is not able to identify thin clouds [12]. A new study conducted by Zhang, et al in 2017 shows the uncertainty of CBH values
from CloudSat data and CALIPSO data, which are compared with active cloud-based remote sensing [13]. As with satellites, ground-based cloud observations such as cloud radar, lidar and ceilometer can provide high accuracy in CBH measurements and sustained temporal coverage [14]. The cloud observation system in North America uses a ceilometer, but this ceilometer observes clouds for altitudes of less than 4 km [15]. In some other countries the use of this instrument is very limited. This deficiency can be overcome by radiosonde which can penetrate the cloud layers to provide in-situ measurements such as pressure, temperature and relative humidity. This quantity can be used to estimate the vertical profile of the atmosphere including clouds [16]. More importantly, the radiosonde network makes it possible to take CBH, CT and the number of cloud layers on a large scale because the radiosonde is able to reach layers about 30 km from the earth's surface.

Research on the clouds vertical structure by utilizing old observational data has been carried out in various countries in the world [1]. For example, Wang and Rossow managed to obtain a vertical cloud structure based on relative humidity (RH) data, The results of his study showed that in cloudy conditions, multi-layer cloud occur most frequently (56%) and are dominated by two-layer clouds [17], and Chernykh et al [18] analyze CBH, CT and the number of cloud layers at many points in the world. The results showed a decrease in the height of the cloud base in all seasons around 150 m and the height of the cloud top increased 540 m, the geographical distribution of these changes from the base and peaks is spatially non-uniform and season-dependent [18]. However, research on clouds vertical structure in Indonesia is still very limited. Research on the vertical structure of clouds in Indonesia is still very limited and is mostly related to the spatial distribution of clouds from satellite imagery related to the spatial distribution of rainfall [19]. Research on the vertical distribution of clouds and aerosols for two years of observation has been conducted in Jakarta using Lidar scattering Mie by Sugiotto et a. The results showed the maximum CBH height in the area at 5 km, especially during the rainy season, but the study had not been able to reach the peak height of the clouds [20]. Therefore we analyze the characteristics of the initial vertical structure in relation to climate change in West Sumatra especially in the Padang region.

2. Data and Methods

2.1. Data
Radiosonde observation data used in this study was managed by the University of Wyoming. Observation data for 31 years (1988-2019) at the Padang regional station (0.88 ° S, 100.35 ° E) Radiosonde launch was held twice a day, ie 00.00 UTC (07.00 WIB) and 12.00 UTC (19.00 WIB) with the code observation station_ID code 96163 WIMG.

Figure 1: Distribution of observation data based on the number of cloud layer.
2.2. Methods
The method used in this study, follows the method proposed by Wang and Rossow [19]. This method estimates the vertical structure of the cloud including peak height, base height and thickness of the cloud layer. The steps are as follows: (1) cloud base height (CBH) is determined based on; (a) the base of the lowest moist layer is determined as the average height at which a minimum RH greater than 84% is achieved for at least four consecutive valid measurements; (b) at least 3% of jumps in RH can be seen from adjacent lower levels. (2) next height above the base height is checked and is temporarily considered as part of the humid layer if RH ≥ 84% to an altitude with RH below 84%. (3) The peak of the moist layer is considered if it receives one of three conditions namely; (a) RH ≥ 87% ;(b) if this height is not the peak of the profile, RH is at least 84% but must be less than 87% and increased 3% from the previous layer. (c) RH ≥ 84% if this height is the peak of the cloud profile (4) if the top part is not obtained in step 3, the moist layer is not considered a cloud layer. If the peak is obtained, then the maximum RH will be obtained. The moist layer obtained will eventually be considered a cloud layer if the maximum RH is above 87%. Values 84% and 87% are said to be the threshold values of minimum RH and maximum RH.

![Figure 2](image-url)

Figure 2: Time series of cloud-base height and cloud-top heights MSL (km), and layer thicknesses (km) for one layer clouds. Red line indicates least square regression line.
3. Result

Figure 1 shows an observational histogram of the number of cloud layers during 1988-2019. The most common cloud layer (58.87%) is dominated by one-layer cloud, then followed by two-layer cloud (31.12%). Three-layer, four-layer and other layers are also observed but the numbers are relatively small.

Figure 2 shows the time series of statistical measurements of cloud altitude above mean sea level (MSL) for single layer clouds. Cloud top height (Figure 2a) has increased from year to year, a similar pattern was also observed for cloud base height (Figure 2b). However, cloud thickness (Figure 2c) decreased during the observation.

![Figure 3](image-url)

**Figure 3:** The time series of cloud base height, cloud top height MSL (km), and layer thickness (km) for the two cloud layers. The red line shows the least squares regression line.

Figure 3 shows the time series of the height and thickness of the layer cloud for first-layer and second-layer clouds of two layer cloud. Cloud tops and cloud base height for first-layer clouds (Figure 3a and Figure 3b) appear to have increased significantly from year to year, but the thickness of the cloud actually decreased (Figure 3c). Cloud tops and cloud base height for the second-layer cloud (Figure 3d and Figure 3e) also seems to have increased but not significantly (slightly increased) from year to year, but cloud thickness has decreased slightly (Figure 3f). The same conditions occur at the height of the peak and base for three-layer clouds such as first-layer and second-layer clouds. Similar
pattern is observed for other cloud with more cloud layer. The linear regression line of cloud top, cloud base and cloud thickness for the first layer of the cloud with three layers is \( y = 0.0067x - 11 \), \( y = 0.026x - 52 \), and \( y = -0.02x + 41 \), respectively. For the second layer, the equations are \( y = 0.026x - 47 \), \( y = 0.026x - 49 \), and \( y = -0.0008x + 2.5 \), respectively. Furthermore, for the third layer, the equations are \( y = 0.019x - 31 \), \( y = 0.021x - 36 \), and \( y = -0.0022x + 5.2 \), correspondingly.

4. Conclusion
This study shows that one-layer cloud was the most dominant cloud observed in Padang. Cloud-base and cloud-top heights show an increase with increasing time. This pattern is observed for all cloud layers. However, cloud thickness shows a decrease with increasing time. This result reinforces the influence of climate change on the characteristics of clouds in Padang.

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