Postprint: Macro- and Microphysical Characteristics of Ice Clouds in Summer Heavy Precipitation over the Beijing-Tianjin-Hebei Region

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Date: 2019-01-11T00:00:00+00:00

Abstract

Based on Aqua MODIS Level 2 cloud products and CloudSat Level 2 products, combined with precipitation data and MODIS Level 1B radiance data, this study analyzes the macro- and microphysical characteristics of ice clouds during three heavy precipitation events in the Beijing-Tianjin-Hebei region in summer, and investigates the relationship between these physical parameters and precipitation intensity. The results indicate that: In terms of horizontal distribution, the cloud phase in regions with high precipitation intensity during heavy precipitation events is ice cloud, with ice cloud top heights ranging from 8 to 17 km, and maximum values of ice cloud particle effective radius, ice cloud optical thickness, and ice water path reaching 60 m, 150, and 5000 $g \cdot m^{2}$, respectively; ice cloud optical thickness, ice water path, and ice cloud top height increase with precipitation intensity. Regarding vertical distribution, ice clouds are mainly distributed above 3.5 km, and the ice clouds at stations experiencing heavy precipitation are deep convective clouds, with maximum values of ice cloud particle effective radius, ice water content, and ice cloud particle number concentration reaching 150 m, 3000 $mg \cdot m^{3}$, and 500 L^{1}, respectively; the high-value region of ice cloud particle effective radius is located in the lower-middle portion of the cloud layer and decreases with increasing height, the high-value region of ice cloud particle number concentration is located in the upper-middle portion of the cloud layer and increases with height, while the high-value region of ice water content is located in the middle of the cloud layer; ice cloud particle effective radius, ice water content, and ice cloud particle number concentration increase with precipitation intensity above 9 km.

Full Text

Preamble

DOI: 10.12118/j.issn.1000-6060.2019.01.08
Journal: Arid Land Geography (ChinaXiv Cooperative Journal)

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Abstract:
Heavy rainfall is one of the main weather phenomena in the Beijing-Tianjin-Hebei region during summer. The macrophysical and microphysical properties of ice clouds are of great significance during the precipitation process. This paper selects three heavy rainfall processes that occurred in the Beijing-Tianjin-Hebei region to analyze the horizontal and vertical distribution of macrophysical and microphysical properties of ice clouds and to explore the variation of relationships between these variables and precipitation intensity. The dataset in this paper consists of a merged precipitation product developed by the National Meteorological Information Center of China, Aqua MODIS Level 2 cloud product, CloudSat Level 2 product, and MODIS L1B radiance data. The results show that in the horizontal distribution, clouds with high precipitation intensity during heavy rainfall appear whiter, brighter, and relatively thicker. The cloud phase corresponding to the high precipitation intensity area is ice, but the proportion of ice clouds in the whole Beijing-Tianjin-Hebei region does not change with precipitation intensity. The ice cloud top height ranges from 8 km to 17 km. The maximum values of particle effective radius, optical thickness, and ice water path of ice clouds are up to 60 m, 150, and 5000 $g \cdot m^{2}$ respectively. The optical thickness, ice water path, and cloud top height of ice clouds are positively correlated with precipitation intensity, but the particle effective radius of ice clouds is not correlated with precipitation intensity. In the vertical distribution, ice clouds are mainly located above 3.5 km, and the high precipitation intensity is consistent with the thickness and cloud top height of ice clouds. The ice clouds at the station of heavy rainfall are deep convective clouds. The maximum values of particle effective radius, particle number concentration, and ice water content of ice clouds are up to 150 m, 500 L^{1}, and

3000 mg · m ^{3} respectively. The highest particle effective radius of ice clouds is located in the middle and lower layers of the cloud and decreases with height. The highest particle number concentration of ice clouds is located in the upper layer of the cloud and increases with height. The highest ice water content of ice clouds is located in the middle of the cloud. The particle effective radius, particle number concentration, and ice water content of ice clouds above 9 km are positively correlated with precipitation intensity.

Keywords: Beijing-Tianjin-Hebei; summer; ice clouds; heavy rainfall; macrophysical and microphysical properties

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1. Data and Methods

This study selects three heavy rainfall processes that occurred in the Beijing-Tianjin-Hebei region during summer from 2013 to 2016. Using Aqua MODIS and CloudSat data, we analyze the horizontal and vertical distribution characteristics of macrophysical and microphysical properties of ice clouds during these events. The three cases are: July 1, 2013; July 4, 2014; and August 31, 2015. The analysis focuses on the relationship between cloud properties and precipitation intensity, examining parameters including cloud phase, cloud top height, particle effective radius, optical thickness, and ice water path.

The dataset includes MODIS L1B radiance data (MYD02HKM and MYD02QKM) with spatial resolution of 0.66 m, 0.55 m, and 0.47 m channels, and CloudSat 2B-CWC-RVO and 2B-CLDCLASS products. Precipitation data are derived from hourly precipitation observations during 5:00-6:00 UTC when CloudSat overpasses the region.

2. Results and Analysis

2.1 Horizontal Distribution Characteristics

The horizontal distribution of cloud properties reveals that during heavy rainfall events, areas with high precipitation intensity correspond to brighter, whiter, and thicker clouds in satellite imagery. The cloud phase analysis shows these areas are dominated by ice clouds. The ice cloud top height ranges from 8 km to 17 km across the region.

Figure 1 shows the hourly precipitation distribution and CloudSat orbit path during 5:00-6:00 UTC. Figure 2 presents the Aqua MODIS true-color imagery for the three cases. Figure 3 illustrates the horizontal distribution of cloud phase, while Figure 4 displays the horizontal distribution of cloud top height, particle effective radius, optical thickness, and ice water path.

The maximum values observed for ice cloud properties are: particle effective radius up to 60 m, optical thickness up to 150, and ice water path up to 5000 g · m ^{2}. Statistical analysis indicates positive correlations between precipitation

intensity and optical thickness, ice water path, and cloud top height, but no significant correlation with particle effective radius.

2.2 Vertical Distribution Characteristics

Ice clouds are primarily located above 3.5 km altitude. The vertical structure shows that heavy rainfall stations are associated with deep convective clouds. The maximum particle effective radius reaches 150 m, particle number concentration up to 500 L ^{1}, and ice water content up to 3000 mg $\cdot$ m ^{3}.

The particle effective radius peaks in the middle and lower cloud layers, decreasing with height. Conversely, particle number concentration peaks in the upper cloud layers, increasing with height. Ice water content reaches its maximum in the middle of the cloud layer. For cloud layers above 9 km, particle effective radius, number concentration, and ice water content all show positive correlations with precipitation intensity.

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Note: The original manuscript contained numerous corrupted text segments (evidenced by "cid:" sequences and garbled characters) that could not be reliably interpreted. The translation above preserves all mathematically coherent content, figure/table references, and bibliographic information while omitting irreparable fragments to maintain academic readability.

Note: Figure translations are in progress. See original paper for figures.