Analysis of Cloud Structural Characteristics of Heavy Snowfall Events in Northern Xinjiang Based on CloudSat Data (Postprint)

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Abstract

Using observational data from NASA' s 2008–2015 CloudSat satellite products 2B-CWC-RO, 2B-CLDCLASS, 2C-SNOW-PROFILE and surface meteorological stations, a comparative analysis was conducted on the macro- and microphysical characteristics of clouds during satellite overpasses before and during snowfall for 21 heavy snowfall events in the area along the Tianshan Mountains in northern Xinjiang and its surrounding regions. This study divided the research area into the western and central regions along the Tianshan Mountains in northern Xinjiang. The analysis results indicate: (1) The cloud types before and during snowfall were mainly stratiform clouds, cumulus clouds, altostratus clouds, and deep convective clouds. (2) Before snowfall, the mean ice particle effective radius was distributed between 58.65–67.29 m, the mean ice particle number concentration was between 41.2–76.5 L-1, the mean ice water content was between 25.4–135.1 mg · m-3, the mean snow water content was between 28.0–88.0 mg · m-3, and the mean snowfall intensity was between 0.08–0.36 mm · h-1. (3) The mean values of ice particle effective radius, ice particle number concentration, ice water content, snow water content, and snowfall intensity before snowfall were 2.9%, 6.2%, 34.4%, 36.4%, and 18.7% larger than those during snowfall, respectively, and the high-value areas were mainly concentrated in the western region along the Tianshan Mountains in northern Xinjiang.

Full Text

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Abstract

The CloudSat observational dataset provides an important opportunity to study snowfall, and numerous investigations have made use of CloudSat for snowfall-related research. Based on the data of 2B-CLD-CLASS, 2B-CWC-RVOD and 2C-SNOW-PROFILE and the precipitation data of the ground observation stations, the macro and microphysical properties of the clouds before and during the snowfall were compared and analyzed in 21 heavy snowfall events in the northern Xinjiang, China. In the paper, the northern Xinjiang was divided into the western and the central region along Tianshan Mountains. Firstly, all the sites which had precipitation reached to heavy snowstorm in 24 hours were selected in the northern Xinjiang from 2008 to 2015. Then, according to the specific dates of the snowfall and the latitude and longitude of the sites, those sites which had CloudSat passed their territory were selected as the research object and there were 21 cases obtained. Out of the 21 cases there were 12 cases with the satellite passing their territories while the snowfall was occurring, and 9 cases with the satellite passing their territories before snowfall. The distributions of microphysical properties, which include ice effective radius (IER), ice number concentration (INC), ice water content (IWC), snow water content (SWC) and snow rate (SR), were revealed through analyzing the clouds, cloud types of heavy snowfall and the relationship between cloud microphysical properties and snowfall. Before the heavy snowfall and during the heavy snowfall, the main cloud types were altostratus clouds, cumulus clouds, nimbostratus, stratocumulus clouds, the convective clouds between altostratus clouds and deep stratus. The maximum of IER was 296.5 m and the minimum was 28.4 m. The mean of IER of ice cloud was 64.1 m before the snowfall, and 62.3 m in the snowfall. The IER before the snowfall was 7.1% larger than that in the snowfall. The largest INC is 768.4 L^{-1}, and the values of geometric mean range of INC were 41.2–76.5 L^{-1} before the snowfall, and 28.1–73.0 L^{-1} during the snowfall. The values of geometric mean range of IWC of ice cloud were 25.4–135.1 $mg \cdot m^{-3}$ before the snowfall, and 12.0–77.7 $mg \cdot m^{-3}$ during the snowfall. The largest IWC was 701.8 $mg \cdot m^{-3}$, and the smallest IWC was 1.0 $mg \cdot m^{-3}$. The mean values of SWC and SR were 28.0–88.0 $mg \cdot m^{-3}$ and 0.08–0.36 $mm \cdot h^{-1}$ respectively. The mean values of IER, INC, IWC, SWC and SR before the snowfall were respectively 2.9%, 6.2%, 34.4%, 36.4% and 18.7% higher than those during the snowfall. The areas with larger values of the microphysical cloud properties are mainly concentrated in the western part of northern Xinjiang. This study had presented a comprehensive analysis of cloud vertical structures and regional variations before and during the heavy snowfall. The analysis of

ice effective radius, ice number concentration, ice water content, snow water content and snow rate also helps understand the artificial snow augmentation.

Keywords: CloudSat; heavy snowfall; macro and microphysical properties; northern Xinjiang

Main Text

The CloudSat satellite dataset provides valuable observations for studying snowfall characteristics. Based on 2B-CLD-CLASS cloud classification data, 2B-CWC-RVOD cloud water content data, and 2C-SNOW-PROFILE snow profile data, combined with ground-based precipitation observations, this study analyzed the macroscopic and microscopic physical properties of clouds during 21 heavy snowfall events in northern Xinjiang from 2008 to 2015.

Northern Xinjiang was divided into western and central regions along the Tianshan Mountains. The study first identified all sites that experienced heavy snowstorms (24-hour precipitation reaching heavy snowfall criteria) in northern Xinjiang between 2008 and 2015. Then, based on the specific dates of snowfall events and the geographic coordinates of observation stations, sites that fell within CloudSat' s orbital path were selected as research targets, yielding 21 valid cases. Among these, 12 cases involved satellite overpasses during active snowfall, while 9 cases involved overpasses before snowfall onset.

Analysis of cloud types revealed that before and during heavy snowfall events, the predominant cloud types included altostratus, cumulus, nimbostratus, stratocumulus, and convective clouds transitioning between altostratus and deep stratus. The ice effective radius (IER) exhibited a maximum of 296.5 m and minimum of 28.4 m. The mean IER for ice clouds was 64.1 m before snowfall and 62.3 m during snowfall, representing a 7.1% decrease during precipitation events.

Ice number concentration (INC) reached a maximum of 768.4 L^{-1}, with geometric mean ranges of 41.2–76.5 L^{-1} before snowfall and 28.1–73.0 L^{-1} during snowfall. Ice water content (IWC) showed geometric mean ranges of 25.4–135.1 $mg \cdot m^{-3}$ before snowfall and 12.0–77.7 $mg \cdot m^{-3}$ during snowfall, with absolute extremes of 701.8 $mg \cdot m^{-3}$ (maximum) and 1.0 $mg \cdot m^{-3}$ (minimum). Snow water content (SWC) and snow rate (SR) exhibited mean values ranging from 28.0–88.0 $mg \cdot m^{-3}$ and 0.08–0.36 $mm \cdot h^{-1}$, respectively.

Comparative analysis demonstrated that mean values of IER, INC, IWC, SWC, and SR before snowfall were respectively 2.9%, 6.2%, 34.4%, 36.4%, and 18.7% higher than those observed during snowfall. Regions with elevated microphysical property values were primarily concentrated in western northern Xinjiang.

[Figure 1: see original paper]

[Figure 2: see original paper]

The vertical distribution characteristics of cloud microphysical properties were analyzed through CloudSat observations. The relationship between cloud macrophysical structures and microphysical parameters reveals important information about precipitation mechanisms. The comprehensive analysis of ice effective radius, ice number concentration, ice water content, snow water content, and snow rate contributes to improved understanding of natural snowfall processes and provides a scientific basis for artificial snow enhancement operations.

[Figure 5: see original paper]

The spatial distribution patterns indicate that cloud systems in western northern Xinjiang possess more favorable microphysical conditions for heavy snowfall development. These findings have significant implications for both weather forecasting and cloud seeding operations in the region.

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