Spatiotemporal Distribution Characteristics of Cloud Liquid Water in the Three Major Mountainous Regions of Xinjiang (Postprint)

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Abstract

Using the AIRS/Aqua L2 Standard Physical Retrieval (AIRS+AMSU) V006 (AIRX2RET) cloud dataset released by the National Aeronautics and Space Administration (NASA) from 2003 to 2015, this study selected the Xinjiang region, particularly its three major mountainous areas with abundant cloud water content, as the research area to investigate the spatiotemporal distribution characteristics of cloud liquid water. The results indicate that, in terms of spatial distribution, cloud water content in Northern Xinjiang is higher than that in Southern Xinjiang, with mountainous regions exhibiting greater abundance than desert basins, and windward mountain slopes showing even higher concentrations, reaching up to 500×10 kg · m ^{2}, and displaying a pattern of greater abundance in the west and less in the east. Influenced by atmospheric circulation, cloud water content is relatively abundant in spring across the entire study area, the Tianshan Mountains, and the Altai Mountains, all exceeding 350×10 kg · m ^{2}, while the Kunlun Mountains show greater abundance in summer; conversely, cloud water content is generally low across the entire study area in autumn, falling below 20×10 kg · m ^{2}. Over the 13-year study period, the annual mean cloud water content in the study area ranged from 42.47×10 kg · m ^{2} to 455.32×10 kg · m ^{2}, with overall stability across the entire study area but a declining trend observed in the three major mountainous areas; during 2009-2010, cloud water content across the study area showed an overall upward trend, with particularly pronounced changes in the Tianshan Mountains. The annual variation of cloud water content in the three major mountainous areas exhibits a "single-peak" pattern, with the highest periods for the Altai Mountains, Tianshan Mountains, and Kunlun Mountains occurring in February-April, March-May, and April-August, respectively, with peak values of 822.30×10 kg · m ^{2}, 869.75×10 kg · m ^{2}, and 742.82×10 kg · m ^{2}.

Full Text

Spatial and Temporal Distribution for the Cloud Liquid Water over Three Major Mountains in Xinjiang

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Abstract

Using the cloud dataset distributed by NASA (AIRS/AMSU) and selecting the Xinjiang region, especially the three mountainous areas with abundant cloud liquid water, this study investigates the temporal and spatial distribution of cloud liquid water. The results show that the cloud water volume in the northwestern region is higher than that in the southeastern region, with the lowest values in the desert basin. The mountainous areas are richer, reaching up to 500×10 kg · m ^{2}, and the upwind direction shows higher values in the mountainous region. Affected by the general circulation of the atmosphere, the total research areas, Tianshan Mountains and Kunlun Mountains have abundant cloud liquid water in spring, which is greater than 350×10 kg · m ^{2}. Kunlun Mountains are more abundant in summer, while the total research areas are lower in autumn, below 20×10 kg · m ^{2}. The average annual cloud water volume fluctuated between 42.47×10 kg · m ^{2} and 455.32×10 kg · m ^{2} in recent 13 years. The cloud liquid water was generally stable in the total research areas, and the three mountainous regions showed a decreasing trend. The cloud liquid water volume showed an upward trend in the general region from 2009 to 2010, and Tianshan Mountains has obvious changes. The annual variation of cloud water in the three major mountain areas showed "single peak," and the highest period of cloud liquid water in Altai, Tianshan and Kunlun Mountains occurred from February to April, March to May and April to August respectively, with peak values of 822.30×10 kg · m ^{2}, 869.75×10 kg · m ^{2}, and 742.82×10 kg · m ^{2}.

Keywords: cloud liquid water; atmospheric circulation; temporal and spatial distribution; Xinjiang region; the three mountain ranges

1. Introduction

1.1 Data and Study Area

The study area (73°-97°E, 34°-49°N) encompasses Xinjiang, characterized by its typical arid climate with scarce precipitation, abundant evaporation, and sparse vegetation coverage below 40% [3]. The region features a complex terrain distribution with three major mountain systems: the Altai Mountains (85°-95°E, 45°-50°N) with a length of approximately 500 km and elevations of 1000-3000 m; the Tianshan Mountains (75°-95°E, 40°-45°N) stretching about 2500 km with a width of approximately 1700 km and elevations of 3500-4500 m, with peaks exceeding 5000 m (as shown in Figure 1); and the Kunlun Mountains (73°-82°E, 34°-40°N) with elevations above 4000 m.

Meteorological data were obtained from the NCAR/NCEP reanalysis dataset with a spatial resolution of 2.5°×2.5°. The cloud liquid water data were derived from NASA' s AIRS/AMSU satellite remote sensing products. The study period covers 2001-2015, with specific focus on the three mountainous regions: Altai Mountains ($_{P}Q$ 2010@ 2006@ (cid : 129)(cid : 130)(cid : 131)X(cid : 133)(cid : 134)GS(cid : 192)T(cid : 157)i(cid : 128)(cid : 157)¥@_PQ: 2010, 2015), Tianshan Mountains ($_{P}Q$ 2012@ 2014@ (cid : 136)(cid : 137)X(cid : 138)(cid : 134)GS(cid : 192)T(cid : 157)i(cid : 128)(cid : 157)¥@_PQ: 2005, 2013), and Kunlun Mountains.

1.2 Data Sources

The primary dataset used is the AIRS/AMSU L2 Standard Physical Retrieval (AIRS+AMSU) V006 (AIRX2RET) distributed by NASA' s Goddard Earth Sciences Data and Information Services Center. The cloud liquid water path (CLWP) data have a spatial resolution of 0.5°×0.5° and cover the period 2003-2015.

1.3 Methods

The spatial and temporal distribution characteristics of cloud liquid water were analyzed using GIS and IDL programming. Composite analysis was employed to investigate the relationship between atmospheric circulation and cloud water distribution. The study examined seasonal variations, interannual trends, and the influence of large-scale circulation patterns on cloud liquid water content over the three mountain ranges.

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2. Results

2.1 Spatial Distribution Characteristics

2.1.1 Multi-year Average Seasonal Distribution Figure 3 shows the spatial distribution of seasonal mean cloud liquid water from 2003 to 2015. The cloud water content exhibits significant spatial heterogeneity, with higher values in the northwestern region compared to the southeastern region. The mountainous areas show substantially higher cloud liquid water content than the desert basins, with maximum values reaching 500×10 kg · m ^{2} in the windward slopes of the Tianshan and Altai Mountains.

The Altai Mountains display the highest cloud liquid water content, particularly in spring, with values exceeding 800×10 kg · m ^{2}. The Tianshan Mountains show a banded distribution pattern, with higher values on the northern slopes (400–500×10 kg · m ^{2}) and lower values on the southern slopes (200–300×10 kg · m ^{2}). The Kunlun Mountains exhibit moderate values ranging from 300-400×10 kg · m ^{2} during summer months.

2.2 Temporal Variation Characteristics

2.2.1 Interannual Variations Figure 4 illustrates the interannual variation of cloud liquid water in the three mountainous regions from 2003 to 2015. The annual mean cloud liquid water content ranged from 42.47×10 to 455.32×10 kg · m ^{2}. The Tianshan Mountains showed the highest interannual variability, with a maximum of 525.37×10 kg · m ^{2} in 2004 and a minimum of 42.54×10 kg · m ^{2} in 2014.

Notable anomalies occurred during 2009/2010, when all three mountain ranges experienced above-average cloud water content. This period coincided with a strong atmospheric circulation pattern that enhanced moisture transport from the west and northwest [26]. The Altai Mountains showed a decreasing trend overall, while the Kunlun Mountains exhibited slight increases after 2012.

2.2.2 Seasonal Variations The seasonal distribution of cloud liquid water (Figure 5) reveals distinct patterns among the three mountain ranges. The Altai and Tianshan Mountains peak in spring (March–May), with mean values of 444.30×10 and 347.73×10 kg · m ^{2} respectively. The Kunlun Mountains peak in summer (June–August), reaching 440.68×10 kg · m ^{2}.

Autumn (September–November) shows the lowest cloud water content across all regions, with values dropping below 20×10 kg · m ^{2} in some areas. Winter (December–February) shows moderate values, particularly in the Altai Mountains where orographic lifting maintains cloud formation.

Table 1 shows the seasonal mean values of cloud liquid water for the three mountain ranges from 2003 to 2015.

Mountain Range	Spring	Summer	Autumn	Winter
Altai	444.30	184.08	18.92	347.73
Tianshan	368.77	440.68	114.26	25.05
Kunlun	436.46	15.49	42.11	394.97

Note: Units are ×10 kg · m ^{2}

2.2.3 Monthly Variations Monthly analysis reveals that the peak cloud liquid water occurs in March for the Altai Mountains (822.30×10 kg · m ^{2}), April–May for the Tianshan Mountains (869.75×10 kg · m ^{2}), and July for the Kunlun Mountains (742.82×10 kg · m ^{2}). The minimum values occur in September–October across all regions.

3. Influence of Atmospheric Circulation

Composite analysis of 500 hPa geopotential height and wind fields (Figure 6) shows that high cloud liquid water years are associated with anomalous low-pressure systems over Central Asia and enhanced westerly flow. During spring, the interaction between mid-latitude westerlies and orographic forcing over the Tianshan Mountains creates favorable conditions for cloud formation, with moisture transport exceeding 2×10 kg · m ^{2}.

In summer, the southward shift of the subtropical jet and the development of the South Asian monsoon circulation enhance moisture transport toward the Kunlun Mountains. The anomalous circulation pattern during 2009/2010 featured a persistent trough over the Caspian Sea region, directing moisture-laden air masses toward Xinjiang [26].

The spatial distribution of cloud liquid water correlates significantly with windward/leeward effects. The northern slopes of the Tianshan Mountains receive more moisture due to prevailing westerly and northwesterly flows, while the southern slopes are in the rain shadow. Similarly, the western sections of the Altai Mountains show higher cloud water content than eastern sections due to orographic uplift of moist air masses.

4. Conclusion

The analysis of 13 years of AIRS/AMSU data reveals significant spatial and temporal variability in cloud liquid water over Xinjiang’ s three major mountain ranges. The mountainous regions, particularly the windward slopes, exhibit substantially higher cloud water content than desert basins, with peak values exceeding 800×10 kg · m ^{2}. Seasonal variations show spring maxima for the Altai and Tianshan Mountains and summer maxima for the Kunlun Mountains. Interannual variability is strongly influenced by large-scale atmospheric circulation patterns, with anomalous years such as 2009/2010 showing enhanced moisture transport and cloud formation across all three ranges. These findings provide important insights for water resource management and weather modification operations in this arid region.

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