LIDAR OBSERVATION OF MESOSPHERIC CLOUDS ABOVE BEIJING: A CASE STUDY

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ABSTRACT

We report on the first observation of mesospheric cloud (MC) at the altitude range of 50-65 km with lidars at Yanqing (40.5°N, 116°E) and Pingquan (41°N, 118.7°E) on 30 October 2018. The MC occurred at the 51-56 km altitude range during the hours of dawn. It had an obvious double-layer structure, but the cloud layer was sparse. The MC was re-observed at the 56-62 km altitude range in the twilight, and the double-layer structure was still obvious. However, the cloud layer became thicker with a maximum volume backscatter coefficient (BSC) $3.1 \times 10^{-10} \mathrm{m}^{-1}\mathrm{sr}^{-1}$. Atmospheric temperature structure was derived according to the lidar observations, and it was found that, several hours before the MC occurrence, a temperature anomaly with coldest temperature ~185 K was propagating downward at the altitudes of 50-65 km. This MC layer was simultaneously observed with lidar at Pingquan in the twilight. It could be a regional MC event and possibly formed locally by a transient cooling due to small-scale disturbances in the mesosphere.

1. INTRODUCTION

Mesospheric clouds (MCs) observed at mid-latitudes were accepted as being very unusual atmospheric phenomena. They are possibly related to exceptional dynamical forcing or perhaps are an early indicator of significant long-term changes in the Earth's climate. For a long time, two kinds of typical MCs, i.e., noctilucent clouds and polar mesospheric clouds, have been extensively studied by imaging or lidar observations [1-3]. It was generally agreed that MCs are composed of ice crystals and often occur in summer near polar latitudes in the upper mesosphere between 76 and 86 km [4]. Meanwhile, it was reported that, due to the global climate change, the occurrence frequency of MC has increased and it has been occasionally observed at some mid-latitudes in the last several decades [5-7]. However, for the MC event under the mesopause, it has been seldom reported so far. In this paper, the lidar-observed features of an MC layer in the 50-65 altitude range above Beijing will be introduced. On the basis of the simultaneous lidar observations at different locations, the generation mechanism of this rare atmospheric phenomenon will be discussed.

2.INSTRUMENTATION &METHODOLOGY

The Yanqing (40.5°N, 116°E) lidar station was built in early 2010. Its lidar system works with two laser beams (@532 nm & 589 nm), and their emitted energies are approximately 320 mJ and 60 mJ per shot, respectively [8]. For an individual lidar profile, the photon counts accumulate for every 1000 laser shots in 34 s, and the spatial resolution and temporal resolution are 96 m and 34 s, respectively. The Pingquan (41°N, 118.7°E) lidar station was established in the summer of 2016, and its lidar system currently works with one laser beam at 589 nm. All the parameters of sodium lidar are the same as those at Yanqing. At altitudes between approximately 35 km and 110 km the lidar records the photons backscattered from air molecules, the sodium layer and aerosols.

An MC event is detected as an enhanced signal relative to the background noise and the air molecule signal at the altitude range of 50-80 km. Such enhanced signal can last for more than 30 min and not vary when the laser frequency is detuning. The MC is quantified by determining the volume backscatter coefficient, β_{MC}, which is defined as [9]:

$$\beta_{MC}(z,\lambda) = n(z) \cdot \frac{d\sigma(180^\circ)}{d\Omega} \qquad (1)$$

where n is the number density of MC particles and $\frac{d\sigma(180^\circ)}{d\Omega}$ is the effective cross section for backscatter by an individual MC particle for a specific particle size distribution and the applied wavelength of 589 nm or 532 nm. In practice, β_{MC} was calculated with the following two equations:

$$R(z) = \frac{S_{total}(z)}{S_{mol}(z)} \qquad (2)$$

$$\beta_{MC}(z) = (R\,(z) - 1) \cdot \beta_{mol}(z) \qquad (3)$$

where R is the backscatter ratio of MC, $\beta_{mol}(z)$ is the BSC of atmospheric molecules, S_{mol} is the backscatter signal from molecules, and S_{total} is the total signal after subtraction of the background. At those altitudes where there was no MC, the backscatter signal was normalized to the atmospheric molecular backscatter signal,

$$S_{total} = S_{mol} = c \cdot \beta_{mol} \qquad (4)$$

and it was calculated from the atmospheric densities taken from NRLSISE-00 model. Then, the constant c was used to constrain $\beta_{mol}(z)$ at MC altitudes.

3. RESULTS & DISCUSSION

3.1 Mesospheric cloud observed in the dawn on 30 October 2018.

During the regular lidar observation at Yanqing (40.5°N, 116°E) in the dawn on 30 October 2018, it was found that some obvious enhancement began to occurred in the photon-count profiles at the altitude range of 51-56 km due to the occurrence of MCs. The time variation of the volume backscatter coefficient of this MC was analyzed and plotted in Fig.1. It was shown that, around 04:30 LT, the cloud began to occur near the altitude of 51 km, and it was very sparse. About 15 min later, another cloud layer occurred at the altitude range of 53.5-55.5 km, and a double layer structure was observed during the rest of lidar observations. Unfortunately, this MC observation has been carried out for only ~90 min, and it was terminated around the sunrise (~06:00 LT) because the lidar observation can be performed just in nighttime.

According to the definition in Eq.(1), the volume BSC of cloud layer is directly related to the number density of MC particles. It is presented in Fig.1 that the maximum β_{MC} was only $1.2{\times}10^{-10}\ m^{-1}sr^{-1}$ although the density of cloud particles increased gradually with time. That means the MC layer was very sparse during the hours of dawn, and the number density of MC particles was extremely tiny.

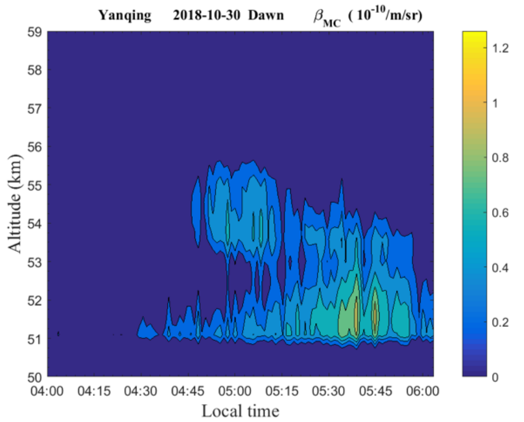

Fig. 1. Contour plot of the volume backscatter coefficient showing the time evolution of MC layer observed at Yanqing (40.5°N, 116°E) in the dawn on 30 October 2018.

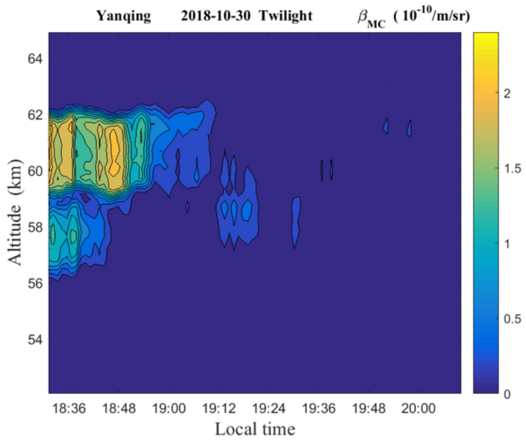

Fig.2. Contour plot of the volume backscatter coefficient showing the time evolution of MC layer observed at Yanqing (40.5°N, 116°E) in the twilight on 30 October 2018.

3.2 Mesospheric cloud observed in the twilight on 30 October 2018.

The lidar observations restarted around 18:30 LT in the twilight, and the MC layers were observed again at the very beginning of the observation. The time-altitude variation of the volume BSC of cloud layer was plotted in Fig.2. It was shown that the MC layer occurred at the altitude range of 56.2-62.3 km, and the double-layer structure was still obvious. However, the number density of MC particles in the upper layer became greater than that in the lower layer, and the maximum β_{MC} occurred in the upper layer around 18:48 LT. The value was $2.8\times10^{-10}\ m^{-1}sr^{-1}$, and it is about twice of the maximum observed in the dawn. Moreover, Fig.2 presents that the volume BSC decreased gradually in 19:00-20:00 LT. It means the number density of MC particles decreased gradually in this time period, and the MC almost totally faded away around 20:00 LT.

At Pingquan (41°N, 118.7°E), this MC event has been simultaneously observed with lidar, and the analysis result about the time variation of the volume BSC was plotted in Fig.3. It is found that the MC was firstly observed by lidar at the altitude range of 52-55 km around 18:45, and a very sparse MC layer existing for only several minutes was observed at the altitude range of 59-62 km. For the layer observed at the altitude range of 52-56 km, the volume BSC firstly increased gradually and then decreased, and the maximum $3.1\times10^{-10}\ m^{-1}sr^{-1}$ occurred around 19:30 LT. This observation result indicates that the MC was very sparse at the very beginning and gradually became thicker till 19:30 LT, and then it gradually diffused and totally fade away around 20:45 LT.

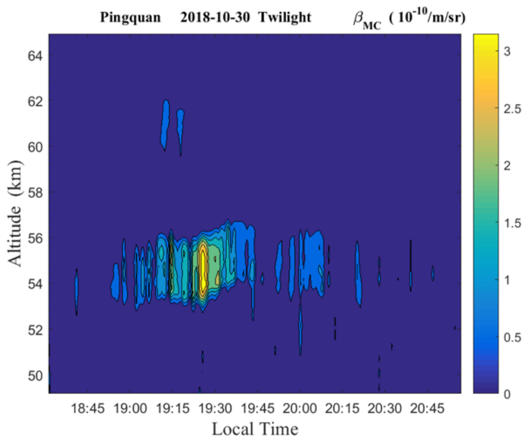

Fig. 3. Contour plot of the volume backscatter coefficient showing the time evolution of MC layer observed at Pingquan (41°N, 118.7°E) in the twilight on 30 October 2018.

3.3 Comparison and discussion

To compare the two simultaneous observation results from lidars at Yanqing (40.5°N, 116°E) and Pingquan (41°N, 118.7°E), although an MC event has been simultaneously observed at both the two locations, the double-layer structure of MC over Pingquan was not such obvious as that observed at Yanqing. In Fig.3, the upper layer was very tiny, and it was visible to lidar for just several minutes around 19:15 LT. Meanwhile, the lower layer mainly located in the altitude range of 53-56 km, and it was ~3 km lower in altitude than that shown in Fig.2. In terms of time, at Pingquan, the maximum concentration of cloud occurred around 19:30 LT, and it was ~40 min earlier than that occurred over Yanqing. Moreover, the MC event disappeared around 20:45 LT at Pingquan, and it was around 20:00 LT at Yanqing. That is, different features of the cloud layer have been observed by lidars at the two locations which are ~230 km far from to each other. This suggests that the MC layer was probably inhomogeneous in horizontal direction.

In additional, at Yanqing, the same MC event was simultaneously observed by the lidar working at 532 nm, and identical features of the MC layer were found. However, at Pingquan, the MC event was observed by lidar in the twilight only, and no clue of MC has been found when the lidar observations in the dawn were checked. This may indicate that a small-scale MC event was observed above Beijing on 30 October 2018.

According to lidar-observed features above, this MC observed above Beijing is likely not a noctilucent cloud or a polar mesospheric cloud which are often occur in summer near polar latitudes in the upper mesosphere between 76 and 86 km. It occurred in the late autumn of Beijing, and the main altitude located near stratopause. However, this lidar-observed MC possibly had similar generation mechanism as them.

By employing the method introduced by Chanin and Hauchecorne [10], the atmospheric temperature structure before the MC occurrence has been retrieved according to the lidar observations at Yanqing. It was found in Fig.4 that, in the time period of 01:00-04:00 LT (i.e., 1~3 hours before the occurrence of MC), a lower temperature structure was transporting downward, and the atmospheric temperature decreased gradually from 210 to 185 K in the 65-50 km altitude range. Moreover, an extremely cold temperature (~140 K) was measured at the altitude of 80 km by SABER/TIMED (footprint@(41.8°N, 119.7°E)) at 23:09 LT on 29 October 2018 (i.e., ~6 hours before the occurrence of MC).

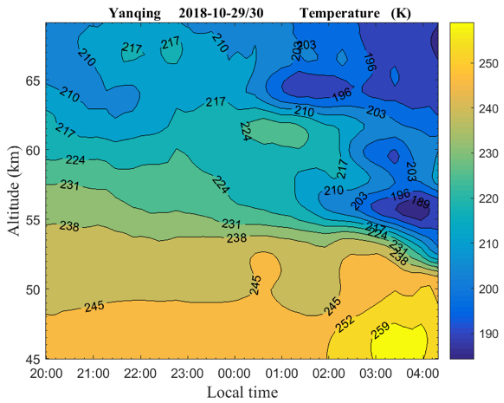

Fig. 4. Time-altitude variation of atmospheric temperature (40-65km) derived from lidar observations at Yanqing (40.5°N, 116°E) before the occurrence of MC.

It is well known that, in the past few decades, greenhouse-gas concentrations in the atmosphere have unequivocally risen, and weather extremes (e.g., extreme temperatures and precipitations) frequently occurred in the Norther Hemisphere mid-latitudes due to the global warming [11]. The mesosphere probably became cooler because of the increasing levels of CO_2 in the atmosphere. Meanwhile, more water vapor occurred in the mesosphere due to the oxidation of elevated levels of methane in the atmosphere.

Therefore, for this lidar-observed MC with a small scale at middle latitudes, it was possibly related to an exceptional dynamical forcing (e.g., gravity wave activities) which was leading to greater adiabatic cooling in a small region and forming a temperature minimum near the altitude range of 50-65 km. When the atmospheric temperature was sufficiently cold, water vapor formed those mesospheric clouds at these altitudes.

4. CONCLUSIONS

At the dawn and twilight on 30 October 2018, an MC event in the 50-65 km altitude range was observed with lidars at Yanqing (40.5°N, 116°E) and Pingquan (41°N, 118.7°E). It is an extremely rare atmospheric phenomenon over Beijing and has not been observed and reported in China so far. Analysis results presented that, this MC layer had a double structure with a small scale, and it was probably inhomogeneous in horizontal direction. Although the composition and the formation mechanism of this MC are still not such clear for us, but this mid-latitude detection is significant because of what it may signify about the global changes of the Earth's climate.

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REFERENCES

[1] T.W. Backhouse, The luminous cirrus cloud of June and July. Meteorol. Mag., 20,133 (1885).
[2] L. Thomas, et al., Lidar observations of ice crystals associated with noctilucent clouds at middle latitudes, Geophys. Res. Lett., 21 (5), 385-388 (1994).
[3] G. von Cossart, et al., Size distributions of NLC particles as determined from 3-color observations of NLC by ground-based lidar. Geophys. Res. Lett., 26 (11), 1513-1516 (1999).
[4] M. Gadsden, The North-West Europe data on noctilucent clouds: a survey. J. Atmos. Sol. Terr. Phys., 60, 1163-1174 (1998).
[5] V.B. Wickwar, et al., Visual and lidar observations of noctilucent clouds above Logan, Utah, at 41.7°N, J. Geophys. Res. 107 (D7), 4054 (2002).
[6] M.J. Taylor, et al., Mesospheric cloud observations at unusually low latitudes. J. Atmos. Sol. Terr. Phys., 64, 991-999 (2002).
[7] H. Suzuki, et al., First imaging and identification of a noctilucent cloud from multiple sites in Hokkaido (43.2-44.4°N), Japan, Earth, Planets and Space, 68, 182 (2016).
[8] S. Gong, et al., Statistical characteristics of atmospheric gravity wave in the mesopause region observed with a sodium lidar at Beijing, China. J. Atmos. Sol. Terr. Phys., 97, 143-151 (2013).
[9] J. Höffner, et al., First observations of noctilucent clouds by lidar at Svalbard, 78° N, Atmos. Chem. Phys., 3, 1101-1111 (2003).
[10] M.L. Chanin, et al., Lidar observation of gravity and tidal waves in the stratosphere and mesosphere. J. Geophys. Res., 86 (C10), 9715– 9721 (1981).
[11] J. Cohen, et al., Recent Arctic amplification and extreme mid-latitude weather, Nature Geosci., 2014, doi: 10.1038/NGEO2234.