College of Atmospheric Sciences, Lanzhou University
Key Laboratory for Semi-Arid Climate Change, Ministry of Education

Dust aerosol vertical profile in the hinterland of Taklimakhan Desert

Jianrong Bi[1], Z. Li[1], D. Zuo[1], F. Yang[2], Z. Huang[1], and J. Huang[1]

1. College of Atmospheric Sciences of Lanzhou University, China
2. Institute of Desert Meteorology, Chinese Academy of Science, China

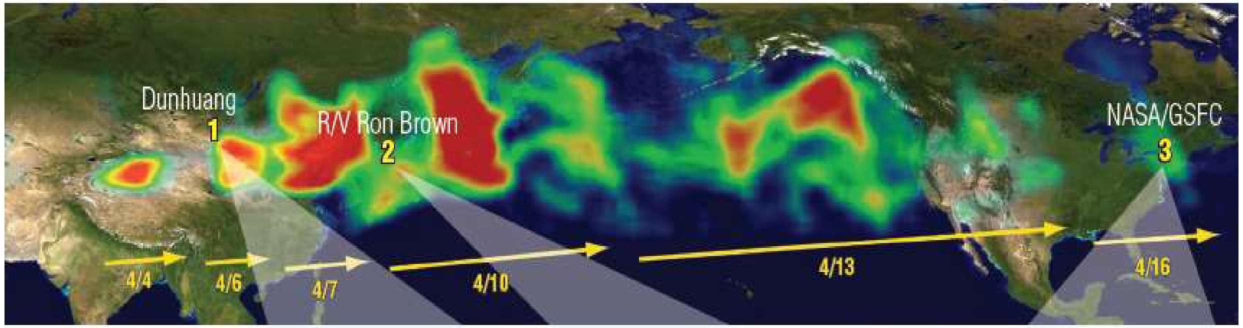
6th International SKYNET Workshop 2021
November 11, Japan (online)

http://climate.lzu.edu.cn/bijr/

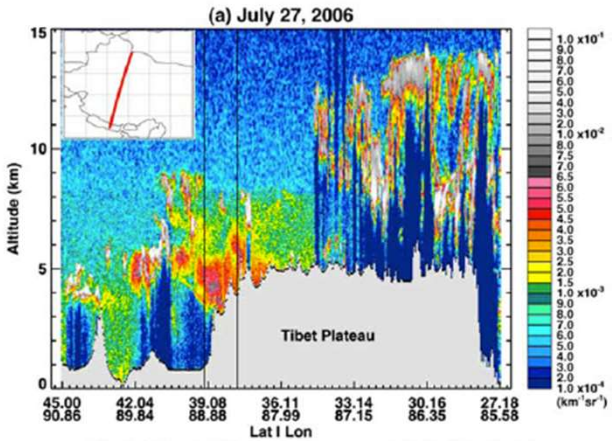
Outline

- Field Campaigns
- Retrievals Method
- Results Analysis
- Summary

Long distance transport and impact of dust aerosol

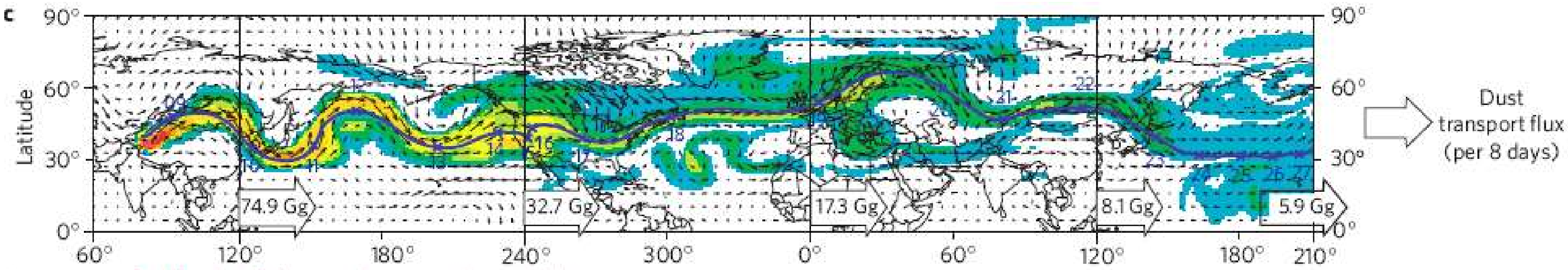


Dust aerosols travel long distances during a heavy dust storm in April 2001 for ACE-Asia Intensive Period [Husar et al., JGR 2001]



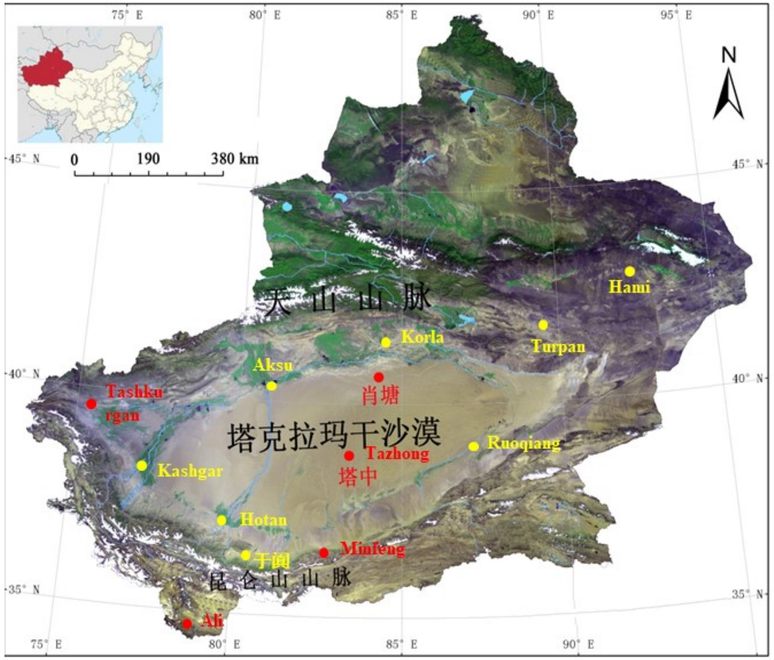
[Huang et al., GRL, 2007]

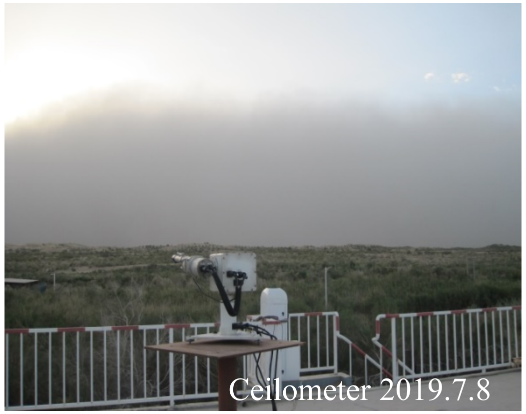
[Uno et al., Nature Geosci. 2009]



Dust aerosol can travel over thousands of kilometers, even across the Pacific Ocean and reach western coast of North America with prevailing westerly wind, and thus exert profound impacts on climate and environment over extensive area of Asia-Pacific rim.

Field experiment for dust during summer 2019




Ceilometer 2019.7.8


Sun/sky radiometer 2019.7.20


Polarization lidar 2019.7.20


Radiosonde in Tibet2019.7.18

IOP： July 1th to Sep. 30th, 2019

Sites： Xinjiang Tazhong, Minfeng, Kashgar, and ALi in Tibet

Aims at： 1. Vertical structures of dust and cloud layers in hinterland Desert

2. Whether the summer dust aerosols can be transported to downstream?

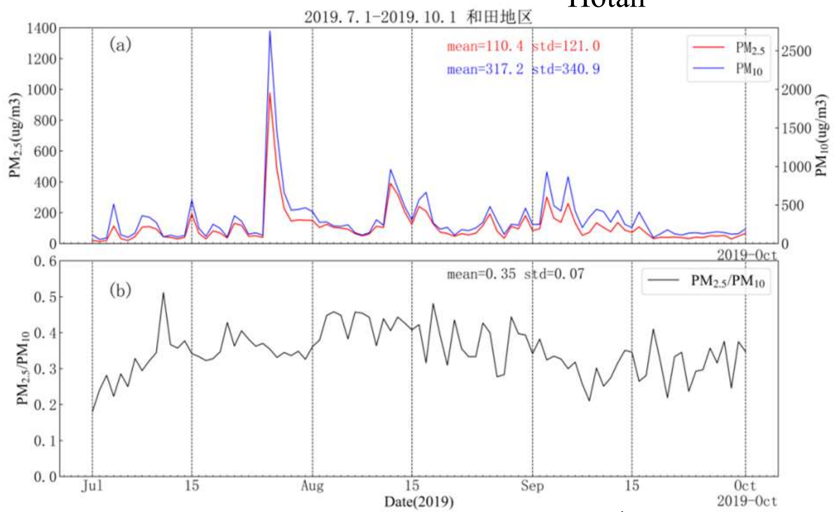
3. Interaction among the dust-cloud-precipitation in Taklimakan Desert

Dust storms occur frequently in TD during summer

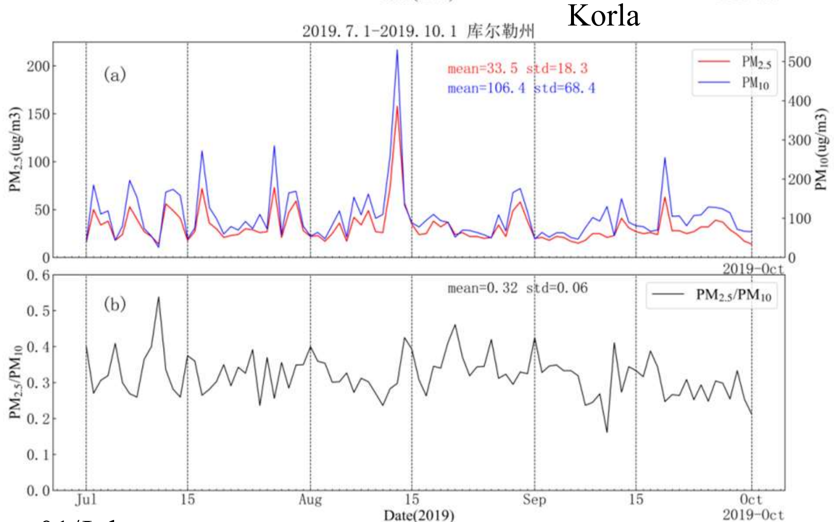
Only desolate desert, no desolate life!!

There is an obvious dust layer hanging over Tarim Basin during summer 2019, which is called **dust stagnation layer**

Hotan



Korla



01/July

01/Oct

The ratios of $PM_{2.5}/PM_{10}$ are less than 0.50, indicating coarse-mode particles are dominated

CHM15k Ceilometer--A single wavelength backscattering lidar

CHM15k Ceilometer, German Lufft

Item	Specifications
Laser	Nd:YAG, 1064nm, ~8 μJ per pulse, 6500Hz, Pulse width 1~5 ns
Measured range	5 m~15 km
Range resolution	5m, 10m, 15m (optional)
Time resolution	2s~600s (optional)
Detected profiles	Cloud and aerosol layers
Quantities	Backscattering $\beta(z)$、extinction $\sigma(z)$、aerosol layer height、Vertical optical range VOR、Cloud base height, cloud penetration depth, cloud coverage
Measured Principle	Laser Detection and Ranging (LiDAR)

CHM15k is unattended, continuous observation, and widely used in detection of haze and clouds, e.g. cloud height DWD in German, KNMI weather network in Netherlands.

Solution of Mie scattering Lidar equation

Main issue:

Two unknown variables in one equation, extinction coef. (σ) and backscattreing coef. (β)

$$X(z) = P(z)z^2 = EC\beta(z)\exp[-2\int_0^z \sigma(z')dz']$$

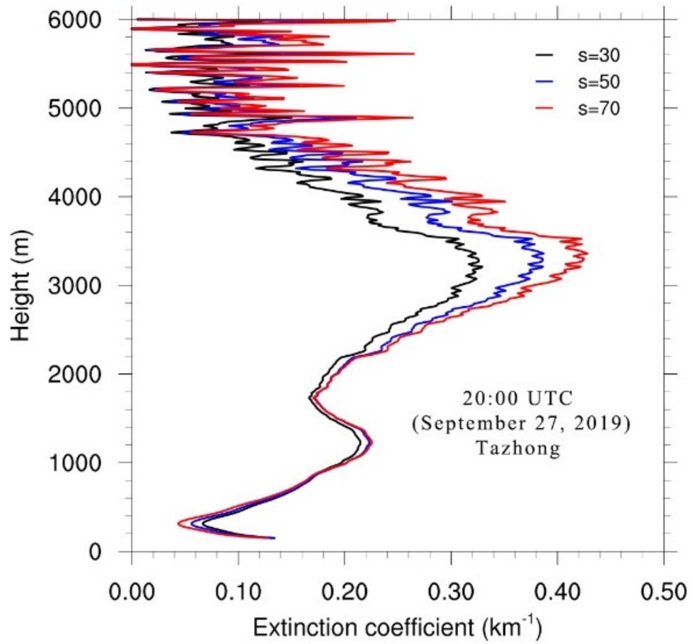
X(z): normalized range corrected signal (background noise, afterpulse, overlap)
P(z): the energy of backscatter signal at altitude z
E: Lidar emitted energy, C: Lidar system constant
β(z) : backscattering coefficient at z
σ(z) : total extinction coefficient at z

Fernald method (1984): $S_a = \dfrac{\sigma_a(z)}{\beta_a(z)}$

(S_a: 10～150 sr)

$$S_m = \frac{\sigma_m(z)}{\beta_m(z)} = 8\pi/3$$

Lidar ratio of dust aerosol:
46.5±10.5 sr
(42～55 sr)



[Liu et al., 2001; Murayama et al., 2002, Ansmann et al., 2005; Sugimoto et al., 2006; Noh et al., 2017; Kim et al., 2021]

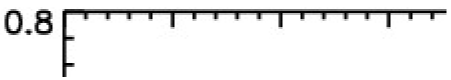
Aerosol optical property in Tazhong

AOD_{500}=0.73±0.50

α=0.28±0.12

WVC=1.43±0.36cm

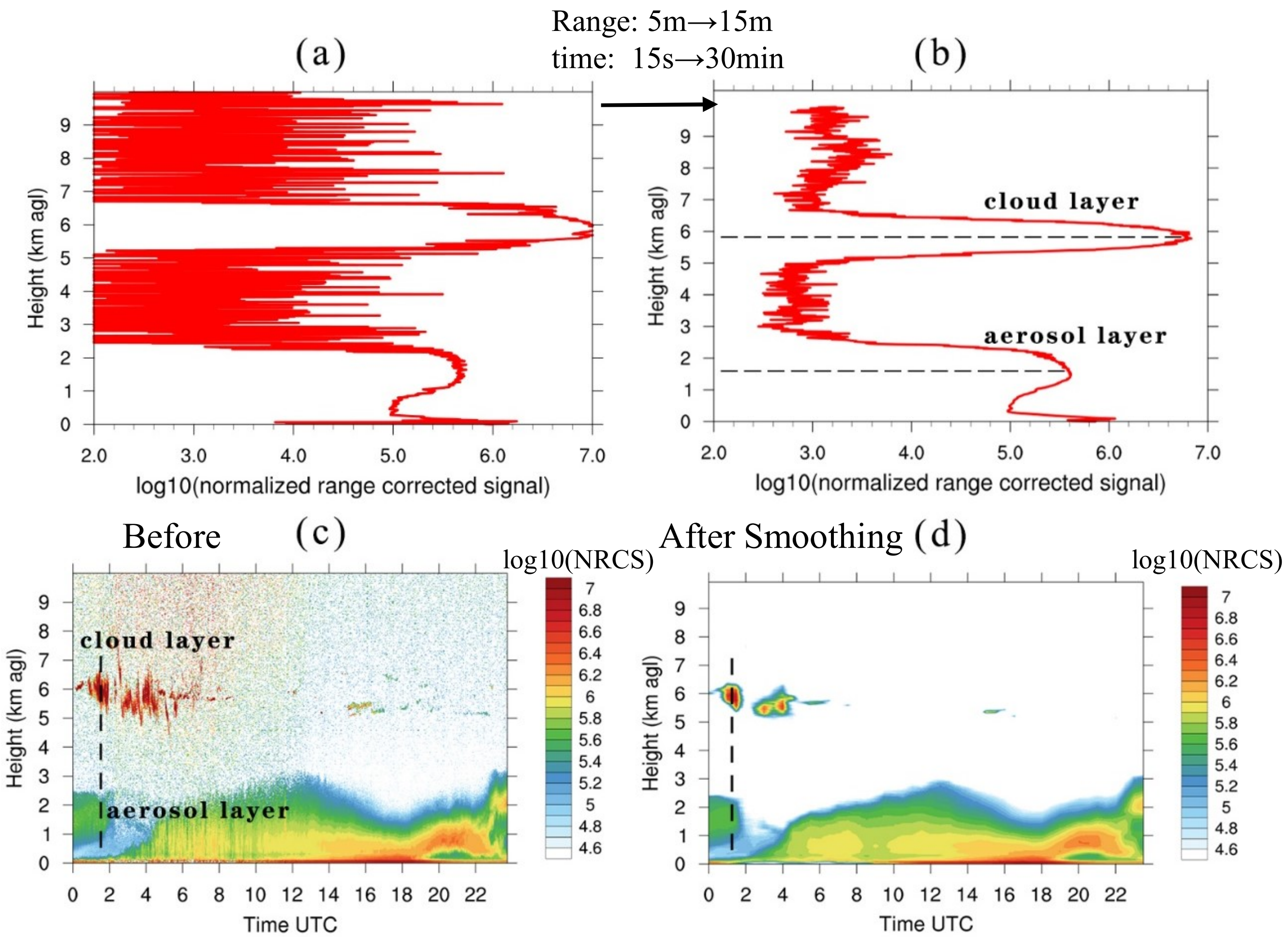
α<0.6, coarse particles are dominant!



The dominant aerosol in hinterland TD is dust particles, with little impacts by human activities!!

Lidar signal smoothing method

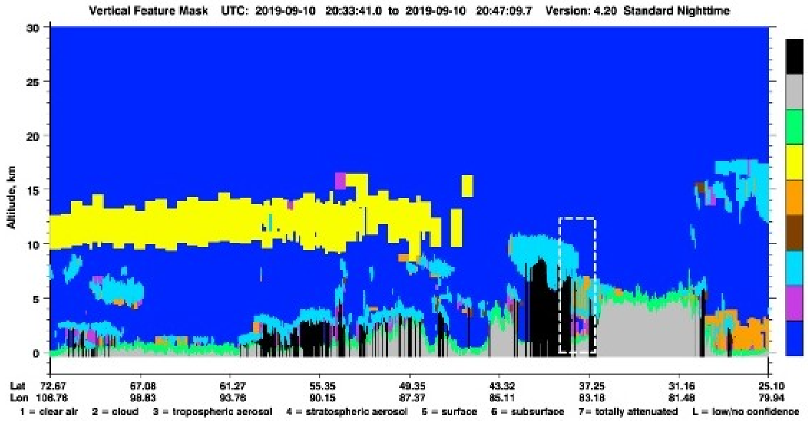
SNR: ratio of signal to noise



The emitted laser energy is low (~8μJ), SNR=1 at 4km height, and drops seriously above 4km. Smoothing the signal can suppress the noise, and aerosol or cloud layers could be detected more clearly!!

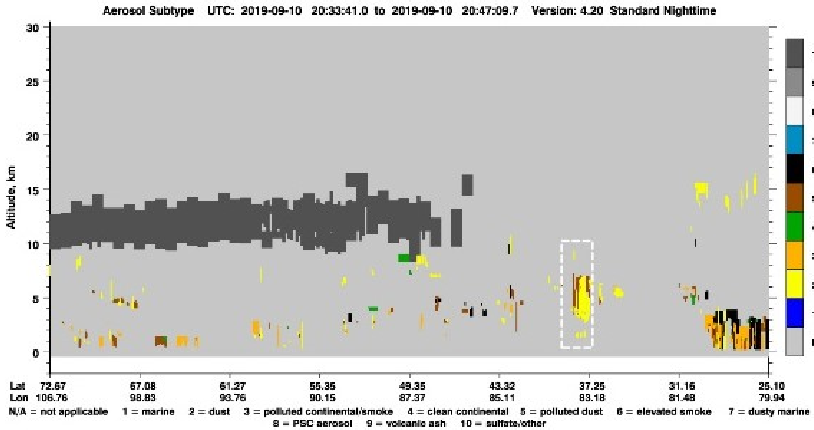
Vertical structure of dust aerosol

CALIPSO (a)



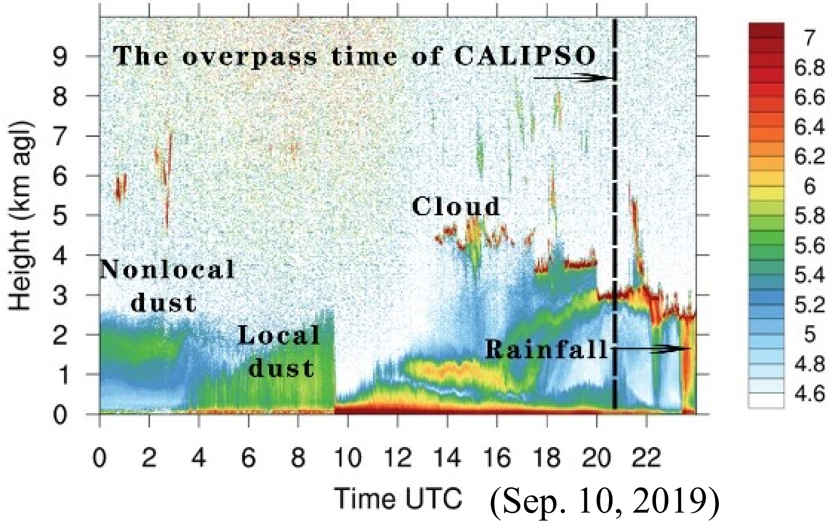
1=clear air 2=cloud 3=tropospheric aerosol

(b)



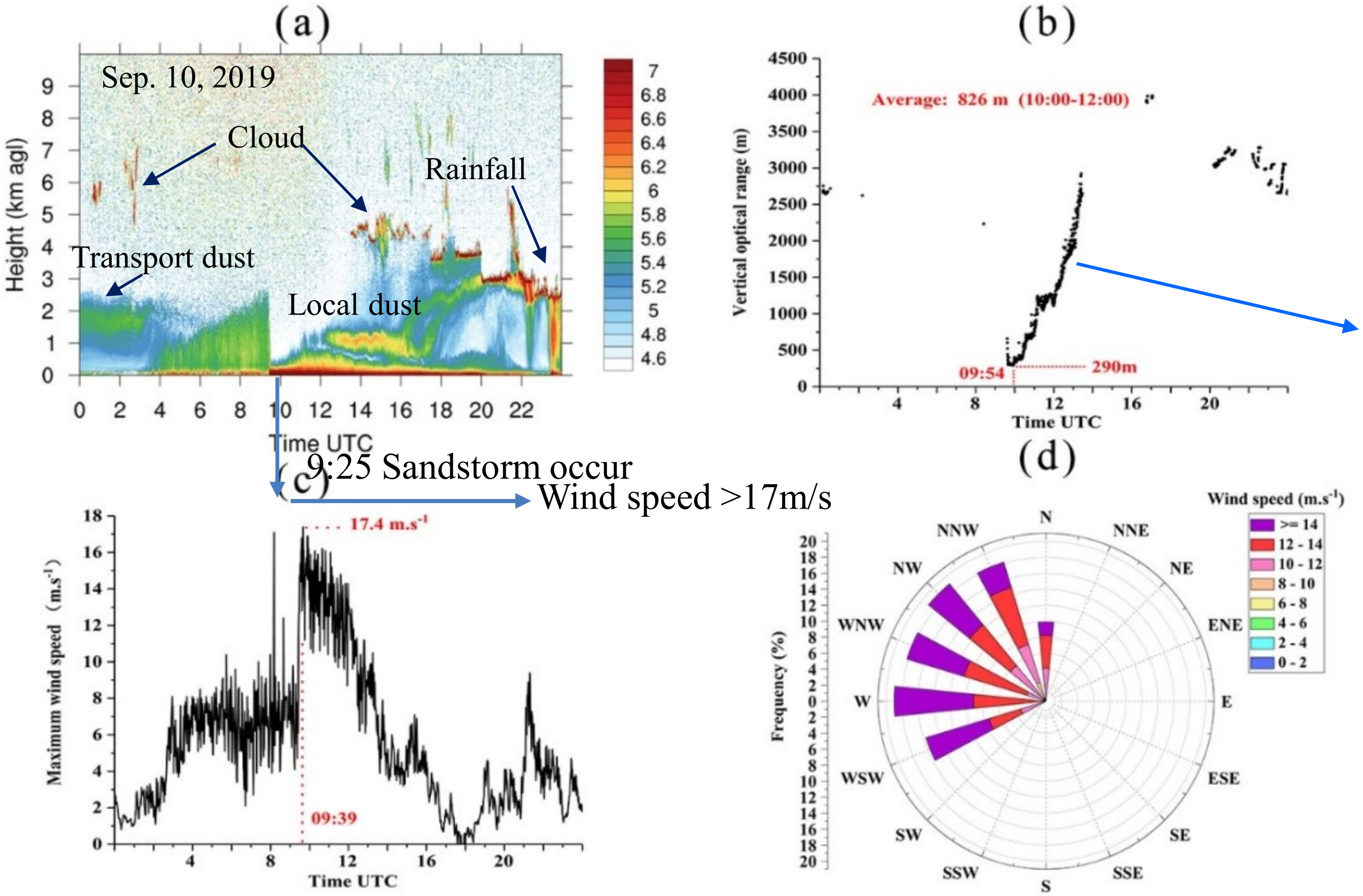
1=marine 2=dust 3=polluted continental smoke
4=clean continental 5=polluted dust

Ceilometer (c)



Both Ceilometer and CALIPSO clearly detect the cloud layer (purple and light blue in (a)) and dust layer (yellow and brown in (b)).

Vertical structure of dust aerosol



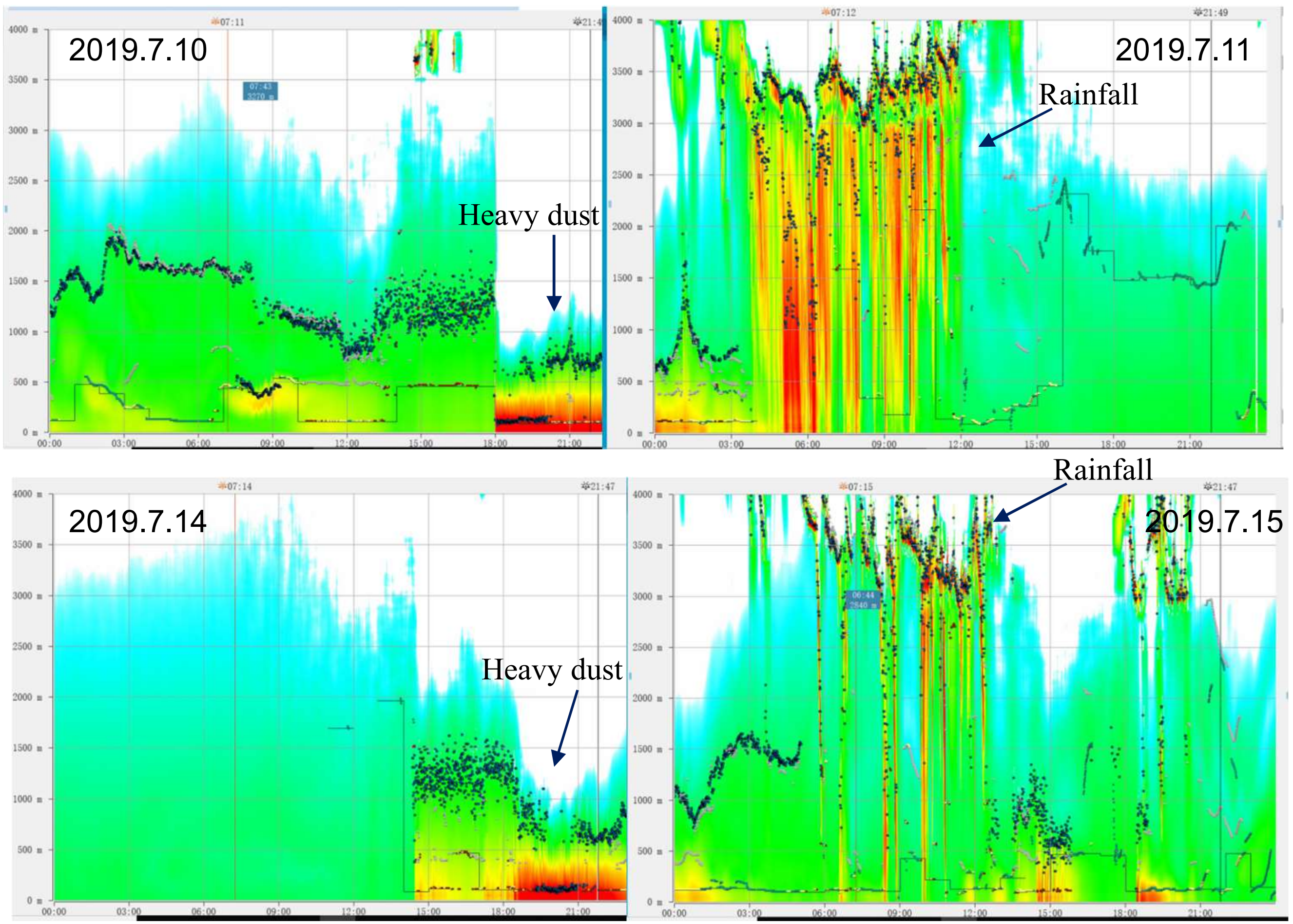
VOR: Vertical Optical Range

$$\int_0^{VOR} \alpha(z)dz = 3$$

When dust aerosols travel upward, VOR gradually increase with height

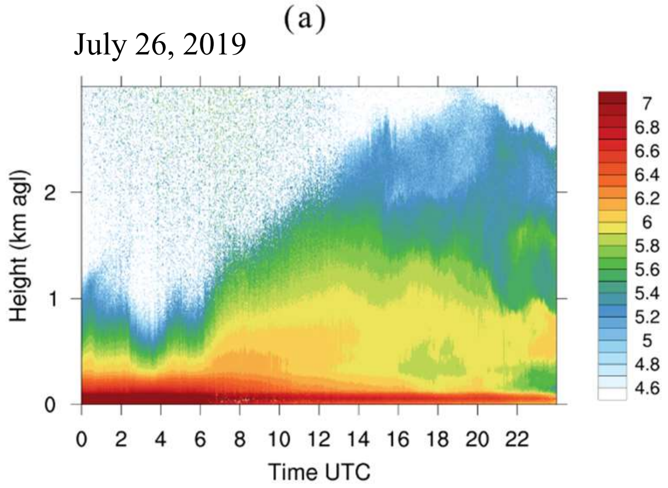
Ceilometer can detect the vertical structures of aerosol layer and cloud layer

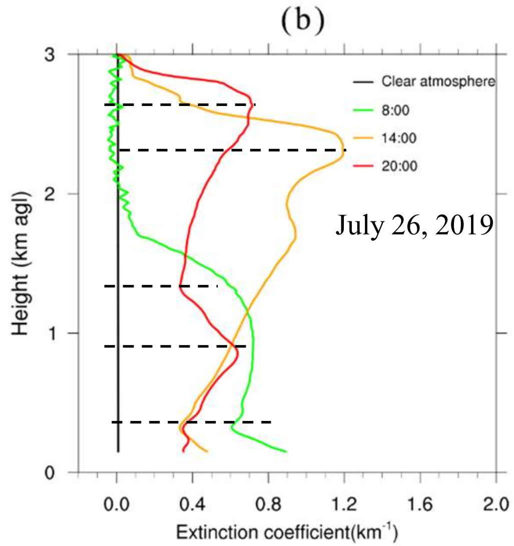
Vertical structure of dust and cloud layers



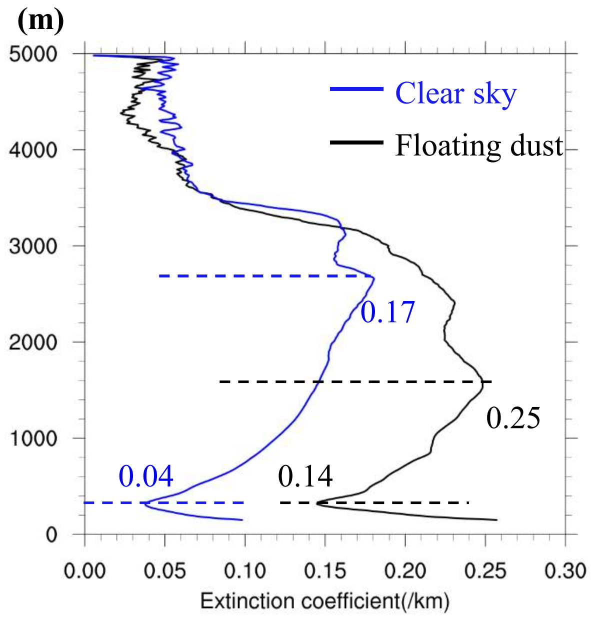
Ceilometer can successfully detect the several strong dust storm and rainfall processes during the experiment

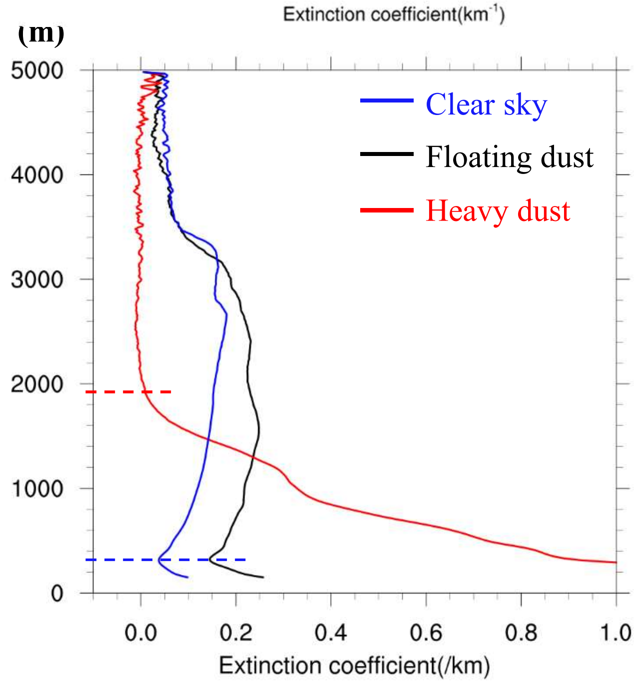
Vertical profile of dust aerosol extinction coefficient





In a dust event, the dust layers gradually travel upward and rise over times (08, 14 and 20), and the profiles of extinction coefficient vary significantly.

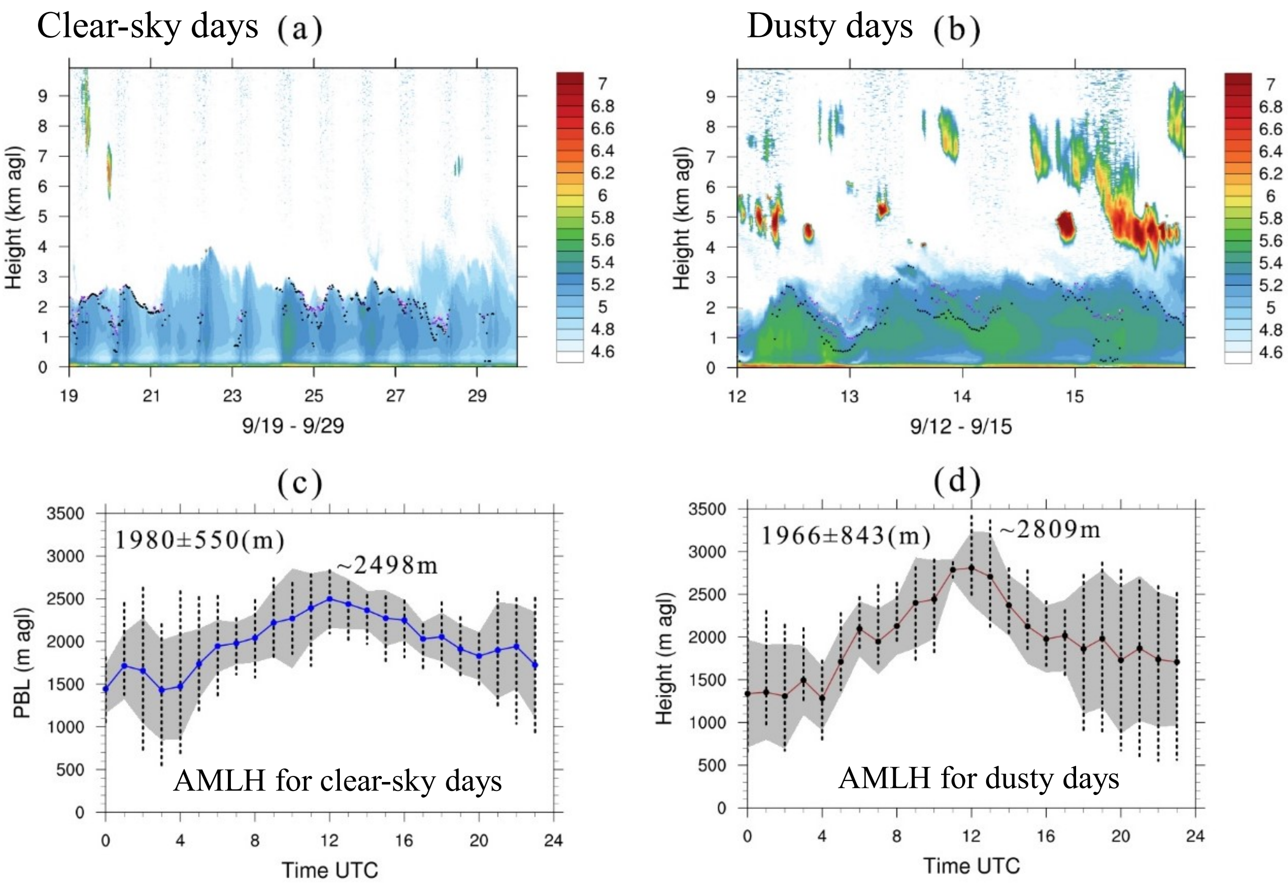




Extinction profile:

A obvious dust layer at 1.5~3km, dust extinction coefficients are 2~3 times of those in clear sky

AMLH--Gradient and wavelet covariance method



There is a deep aerosol mixing layer height (~3 km) and an obvious dust stagnation layer (1.5~3km) over the hinterland TD, which is consistent with the PBL height (2~4km) from radiosonde data

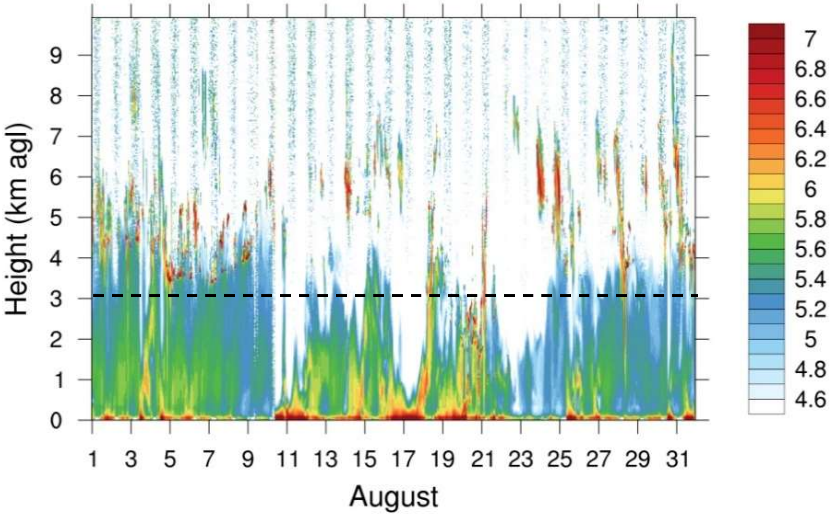
Deep aerosol mixing layer: ~3km

An obvious dust stagnation layer: 1.5~3km

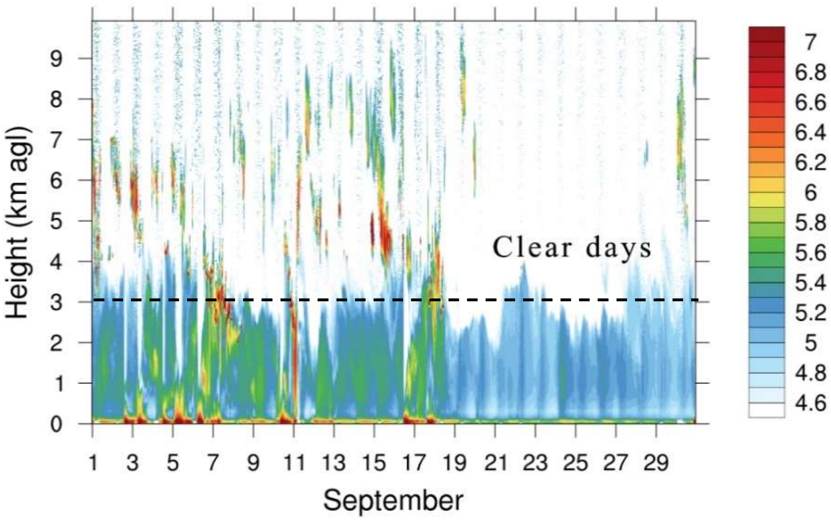
Abundant solar radiation and strong sensible flux heating

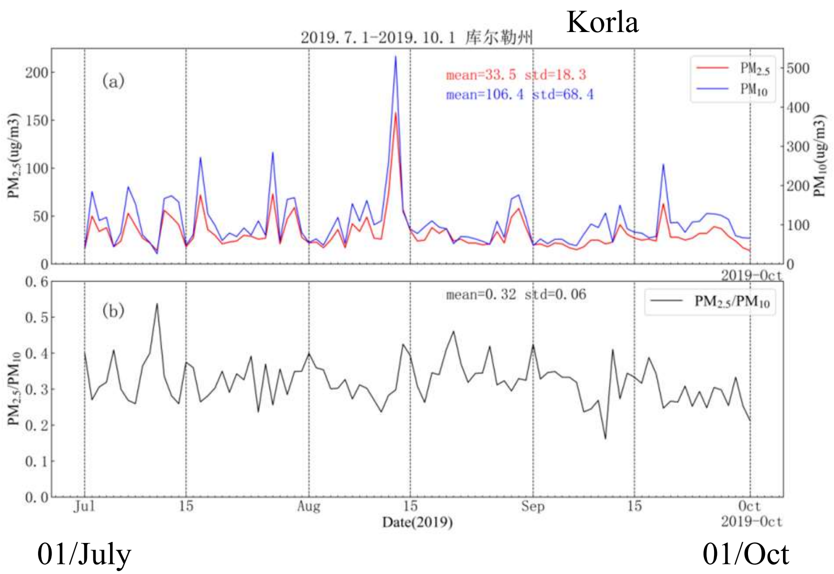
Vertical structure of dust aerosol

(a)



(b)





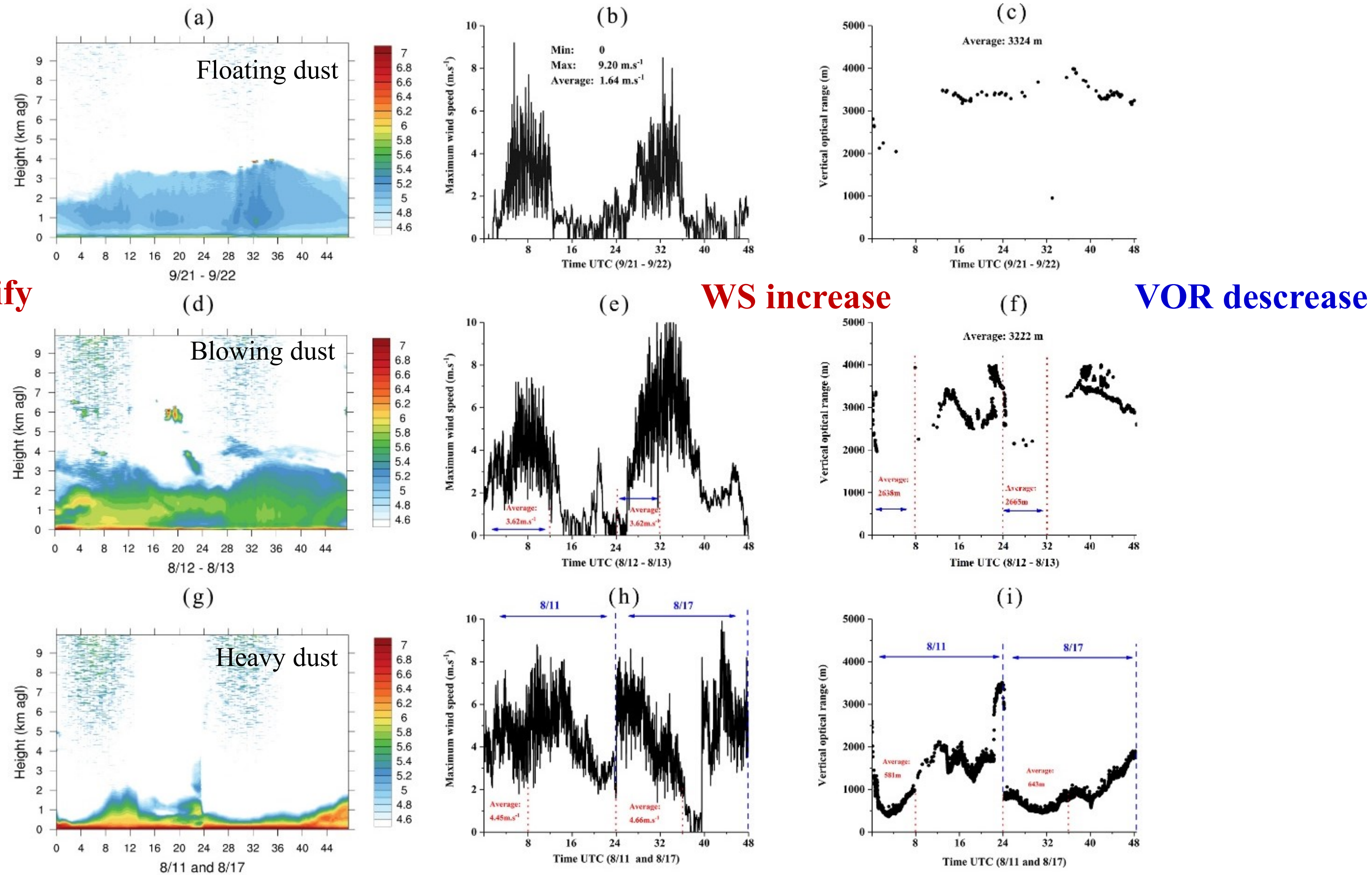
1.Dust storms occur frequently in the hinterland TD during summer, the intensity and frequency of dust in August are significantly higher than those in September,

2.The numbers of dusty days account for 77%, the dust layer height is less than 3km;

3.Whether the dust aerosol can be transported downstream for a long distance depends on the uplifted height (4~5km) and the intensity of mid-latitude westerlies.

Threshold of diverse dust aerosol intensities

Dust intensify



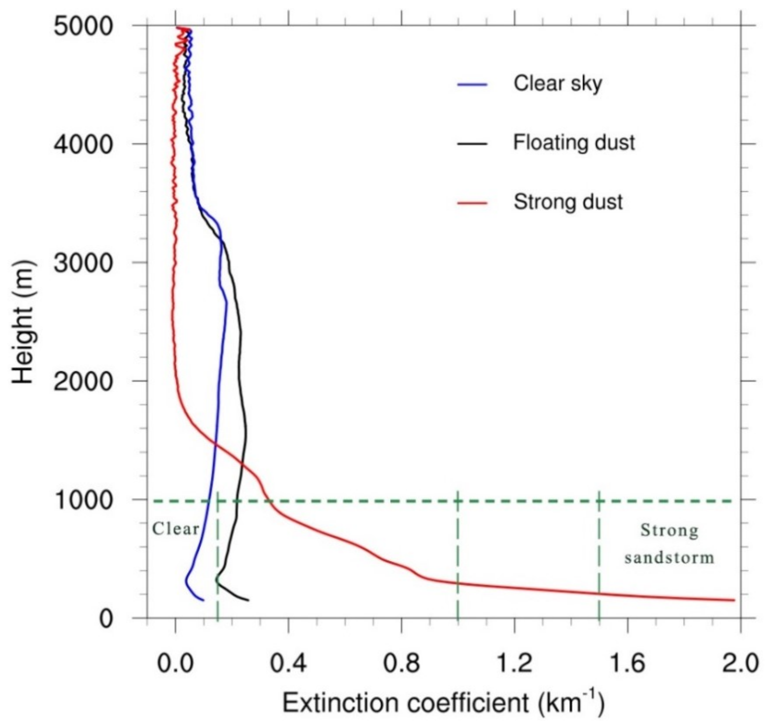
Normalized range corrected signal (NRCS)

Surface wind speed

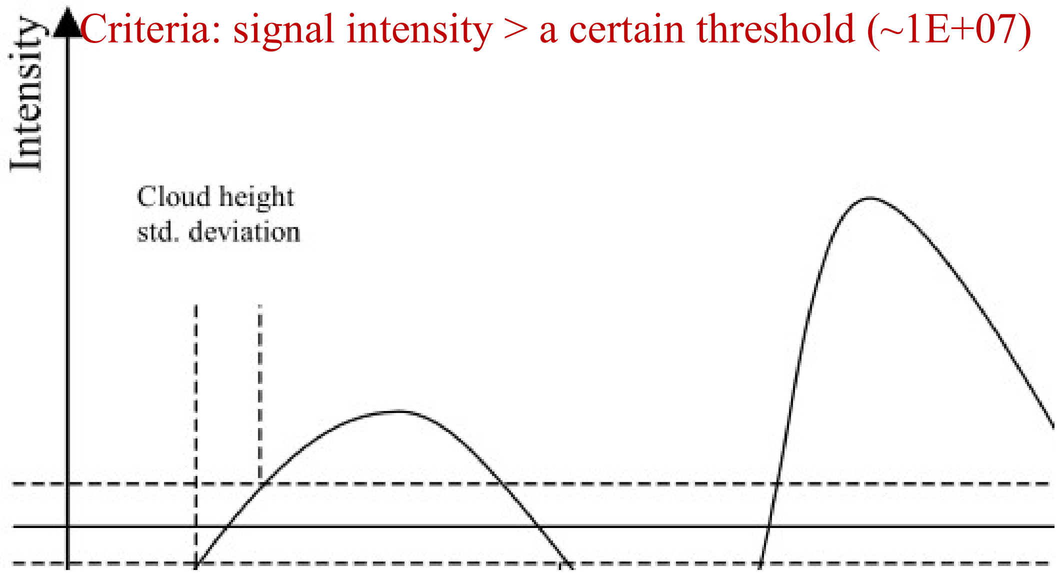
Vertical optical range (VOR)

Thresholds of different dust intensities

Dust level	Log(NRCS) (0-1km)	Wind speed ($m.s^{-1}$)	VOR (km)	α (km^{-1})（0-1km）	β ($km^{-1}sr^{-1}$)（0-1km）
Heavy dust	>5.6	>10	<1	>1.5	>0.03
Blowing dust	5.3~5.6	4-10	<1	1.0~1.5	0.02~0.03
Flowing dust	5.1~5.3	2~4	1~3	0.15-1	0.003~0.02
Clear sky	<5.1	<2	>3	<0.15	<0.003



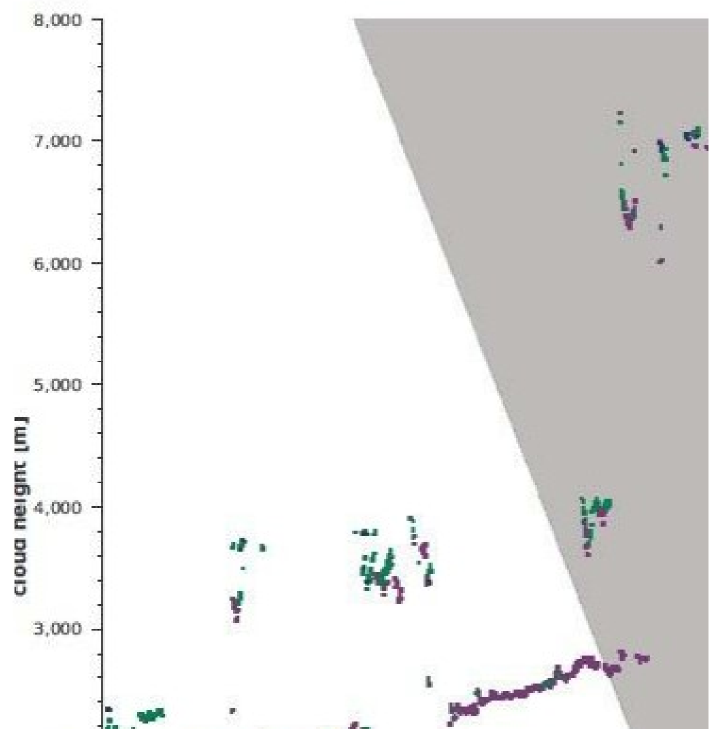
Retrieval of cloud macroscopic parameters



Schematic diagram of inversion of **cloud base/top height** and **thickness** for CHM15k

Cloud layer thickness is calculated by the cloud base and cloud top height. The heights between ±20% of the threshold are the standard deviation of cloud base height, representing the confidences of inversion

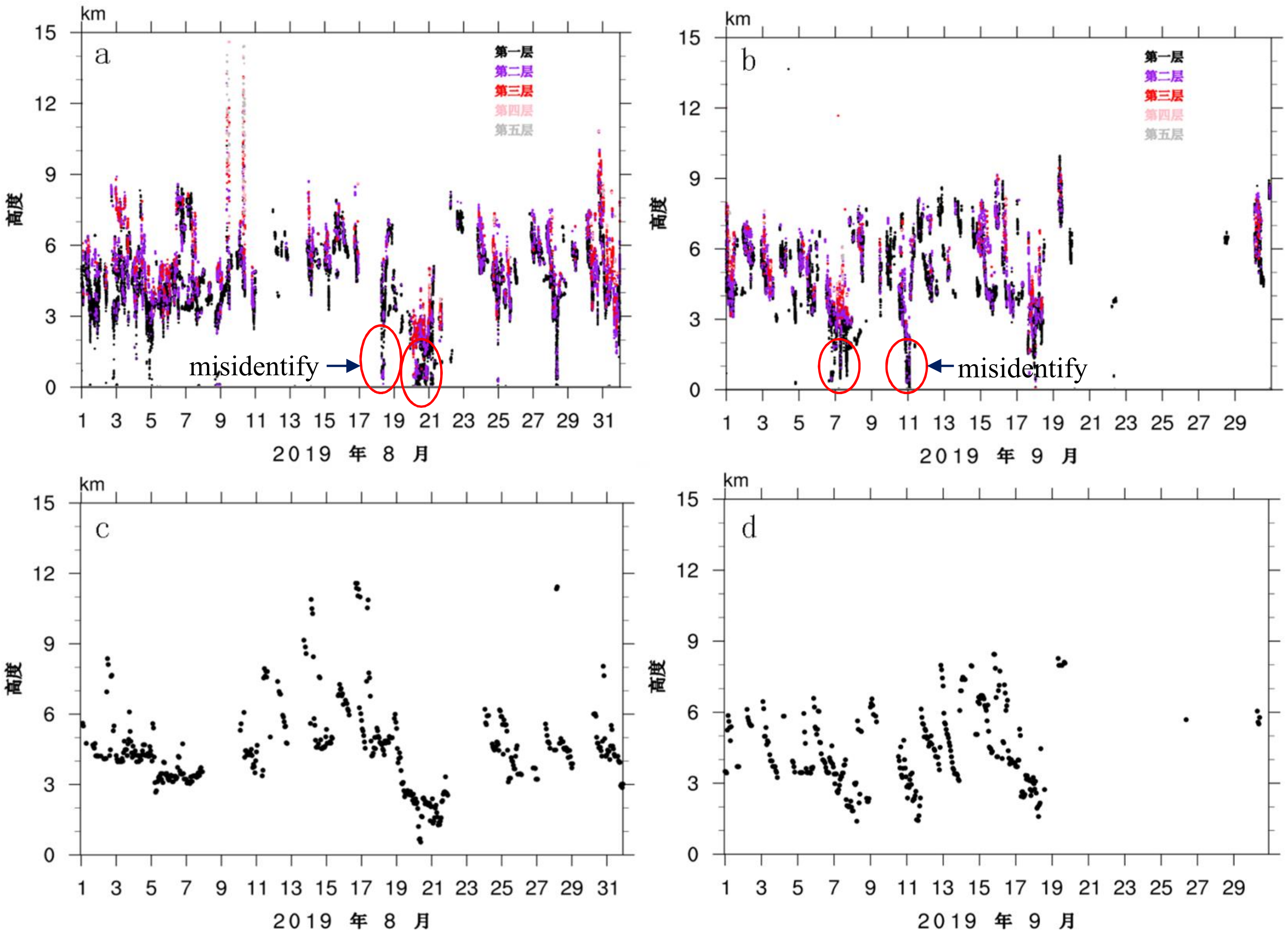
Cloud coverage: the probability of cloud occurrence



Schematic diagram of inversion of **cloud coverage** for CHM15k, different colors denote the detected cloud base height

Cloud coverage: the ratio of the number of detected cloud occurrences to the total number of detected records in the selected time interval

Cloud base height

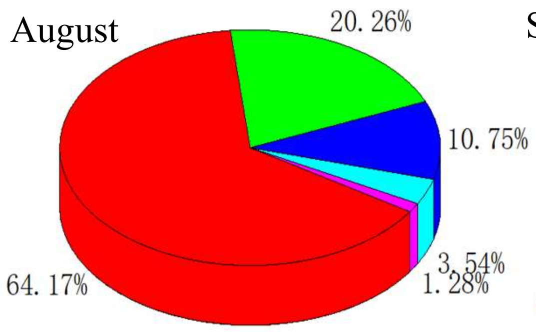


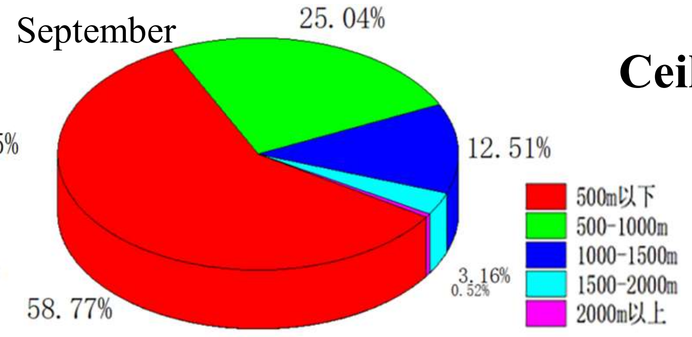
Ceilometer: ~4.6 km

ERA5 data : ~4.5 km

Two datasets show a similar variations of cloud height!

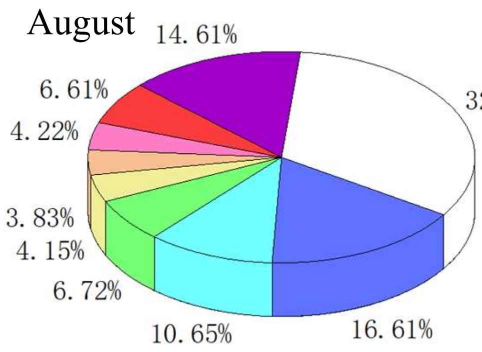
Cloud thickness and total cloud coverage

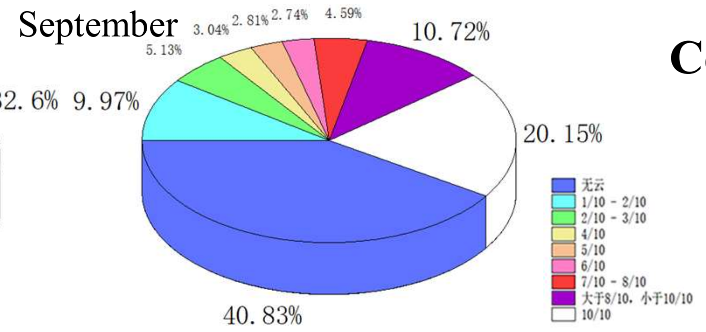




Ceilometer: cloud thickness

Thin clouds are dominated, the average thickness of first cloud layer is 467m

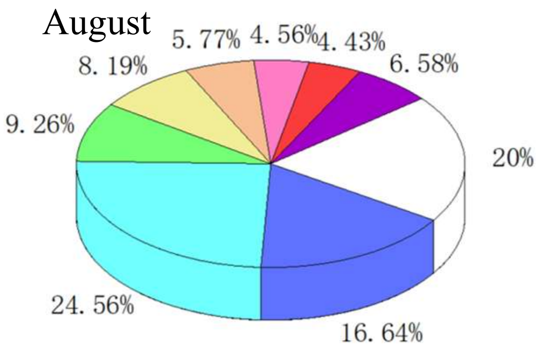


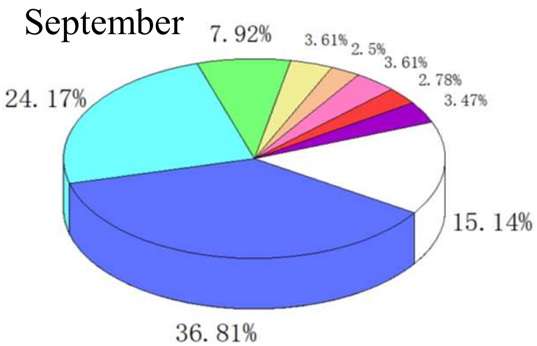


Ceilometer: total cloud coverage

Overcast days in August: 32.6%

Clear-sky days in September: 40.8%





ERA5 data

Overcast and clear-sky days are reasonable!

Summary

1.Ceilometer can detect the cloud and dust layer in TD, recommending that simultaneously measured with sky radiometer

2. Dust aerosols and thin clouds are dominant in TD during summer

3.There is a deep aerosol mixing layer height (~3 km) and an obvious dust stagnation layer (1.5~3km) over the hinterland TD

4.Whether the dust aerosol can be transported downstream for long distance depends on the uplifted height (4~5km) and the intensity of mid-latitude westerlies

Thank you for your attention!