Interactions between aerosols and PBL and implication for air quality

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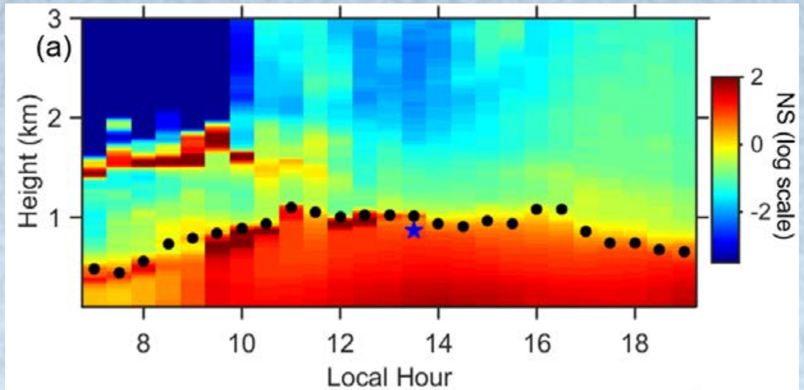
Previous method and Challenge

Previous identification methods for backscatter lidar

References	Method
Boers et al., 1984	Visual inspection
Melfi et al., 1985	Signal threshold
Hooper and Eloranta, 1986	Identifying maximum signal variance
Steyn et al., 1999	Fitting to idealized profile method
Cohn and Angevine, 2000; Davis et al., 2000	Wavelet transform
Flamant et al., 1997	First gradient method
Senff et al., 1996	Logarithmic gradient method
Lewis et al., 2013	Combination of the wavelet technique and image processing
Yang et al., 2017	Cubic root gradient methods
Bravo-Aranda et al., 2017	Change in depolarization ratio
Poltera et al., 2017; Bruine et al., 2017	Pathfinder method



A temperature inversion often exists at the top of PBL that traps moisture and aerosols, which leads to a sharp decrease in aerosol backscatter signals at the upper boundary of the PBL.

Limitation and Challenge

Lidar retrievals can achieve overall good performance

The accuracy of lidar retrievals can vary considerably under different environment conditions

Under what environmental conditions will lidar accurately identify PBLH?

How to achieve good performance under various aerosol loadings and stability conditions?

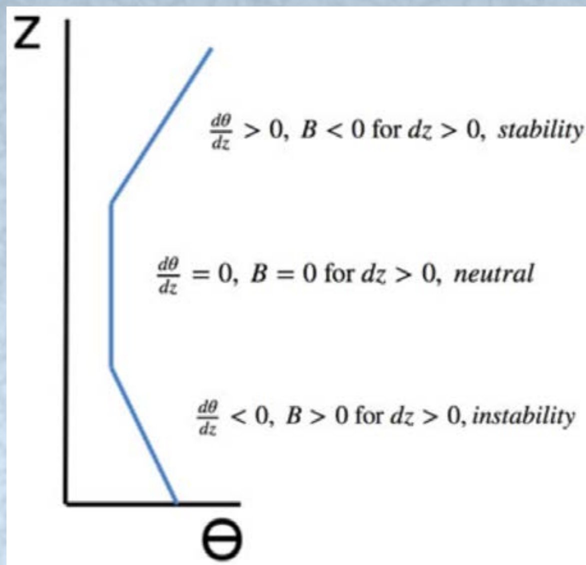
Site and Instruments

This study uses an MPL backscatter and radiosonde time series collected at the SGP site near Ponca City, Oklahoma. The dataset spans June 2010 through June 2018 with high continuity.

https://www.flickr.com/photos/armgov/6310185472

Image from Jensen et al, 2016

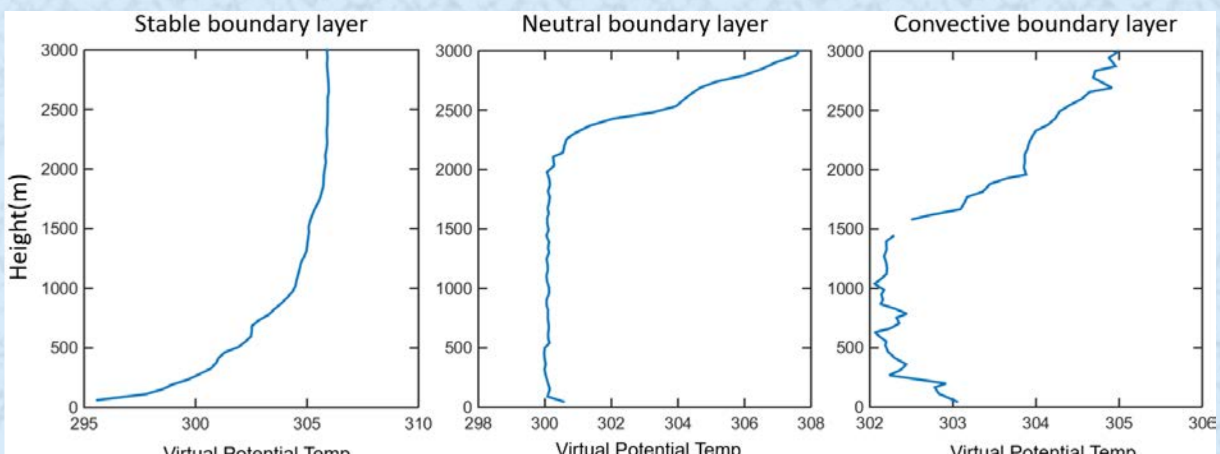
Stability and PBL types



Buoyancy:

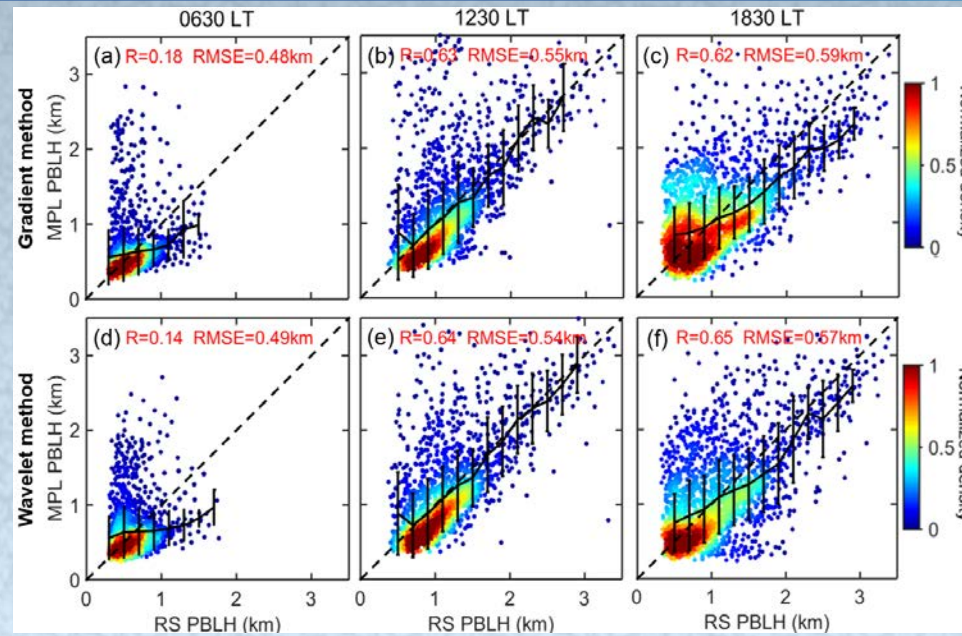
$$B = -g\,\Delta z\,\frac{1}{\theta}\,\frac{d\theta}{dz}$$

Following Liu and Liang. (2011), the PBL types can be determined by the near-surface potential temperature difference in low atmosphere.



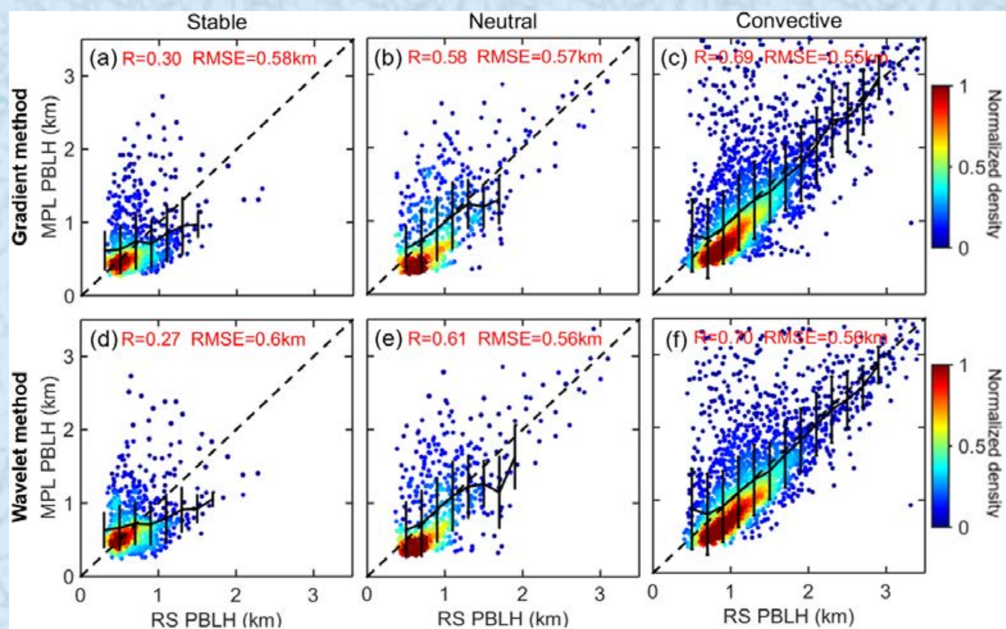
Evaluation of existing algorithms

During morning time, the PBLH retrievals have very poor performance, partly duet to interference of residual layer.



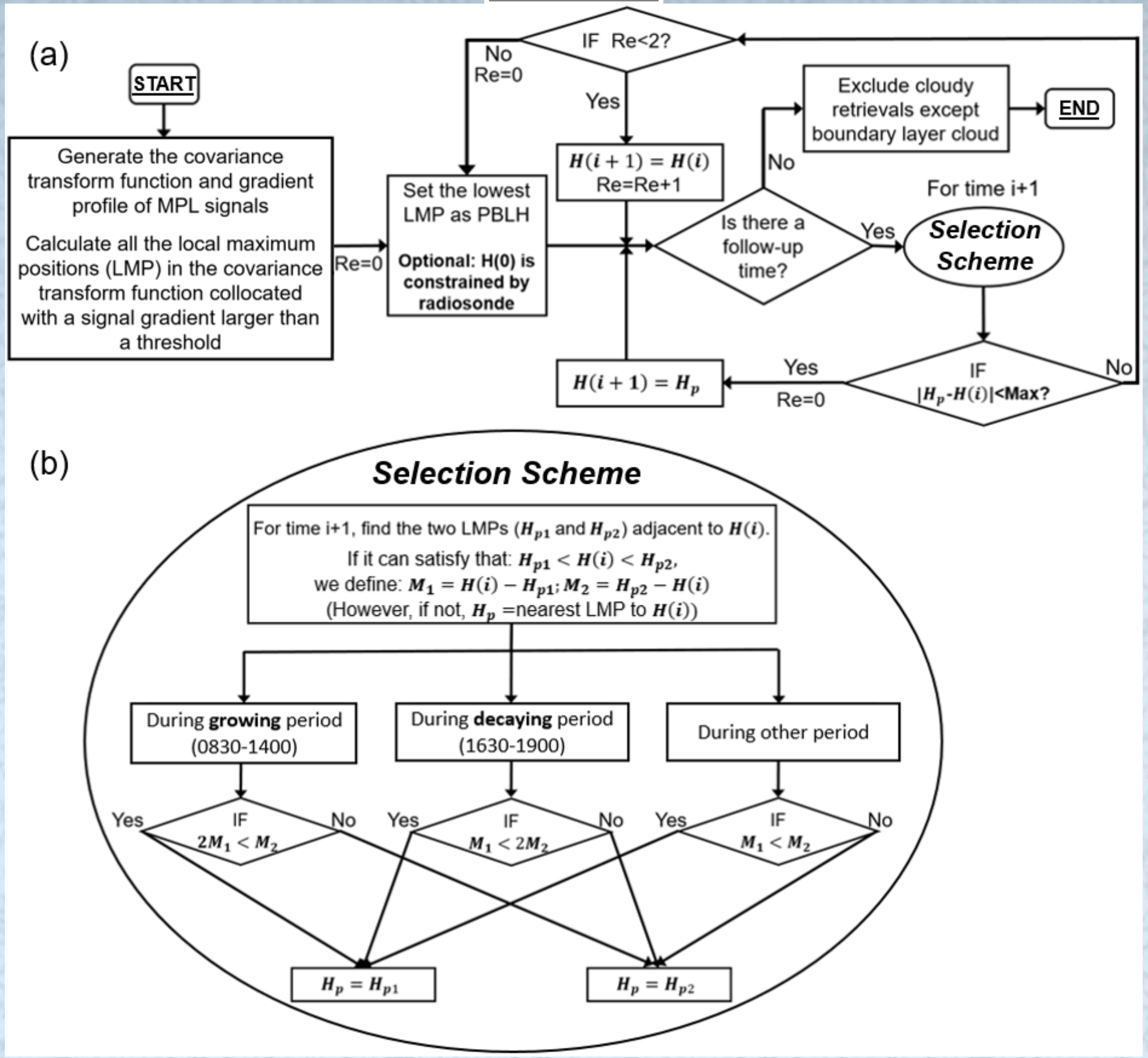
Only afternoon retrievals (1200-1900LT)

The retrievals are strongly affected by different PBL types (i.e. thermodynamic conditions).



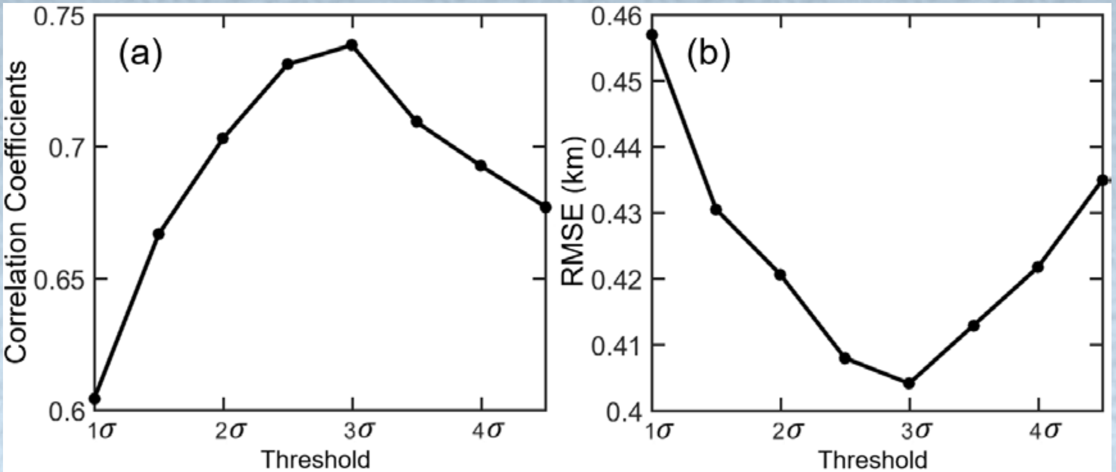
Development of new method

DTDS

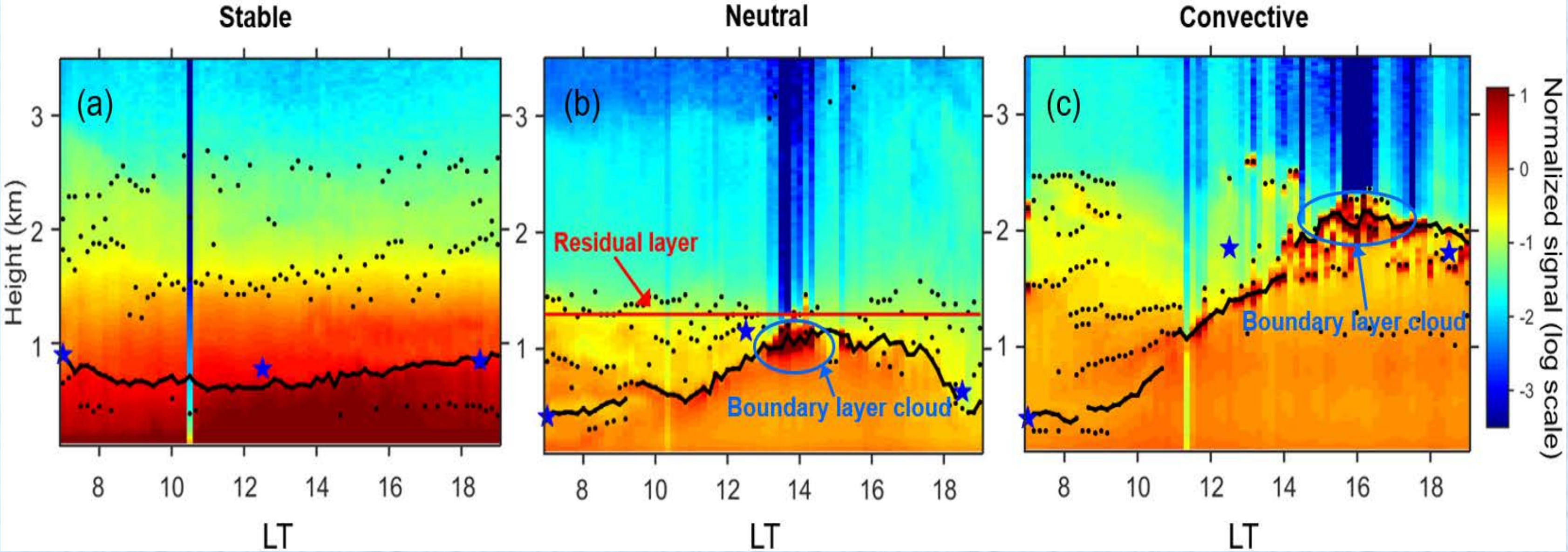


Development of new method

- **Sensitivity test for threshold**

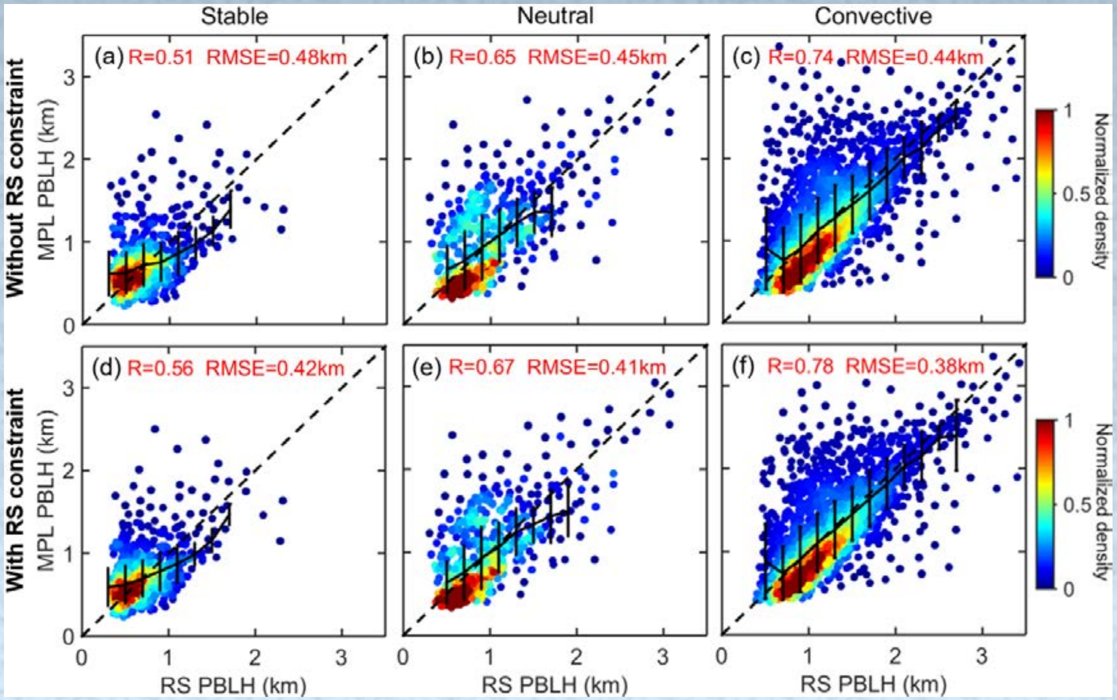


- **Examples for different thermodynamic stability**

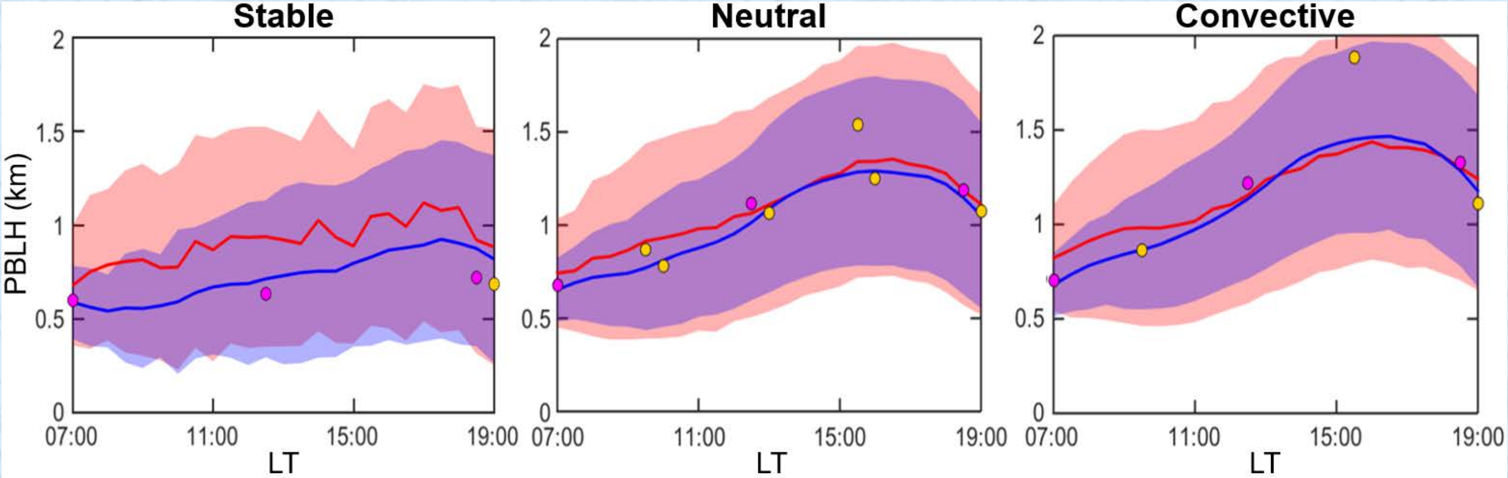


Evaluation of DTDS

Validation against radiosonde for afternoon retrievals

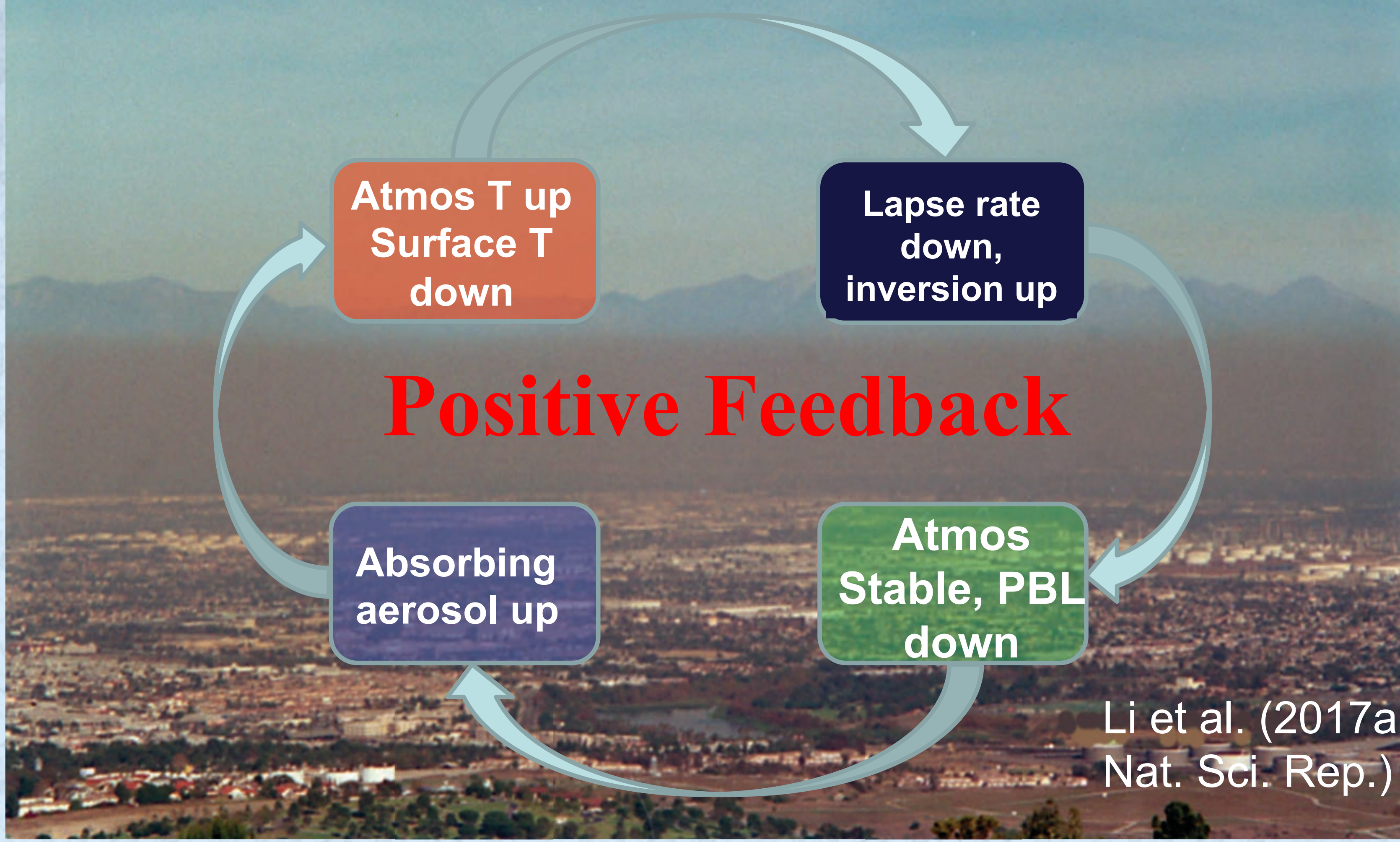


- **Diurnal variations**

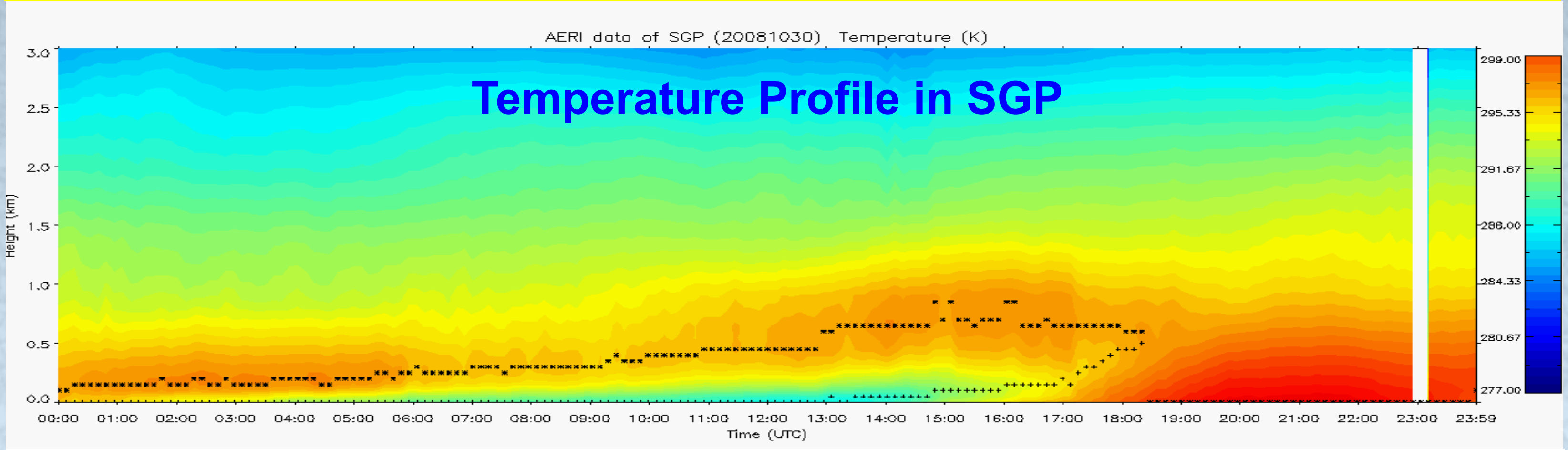


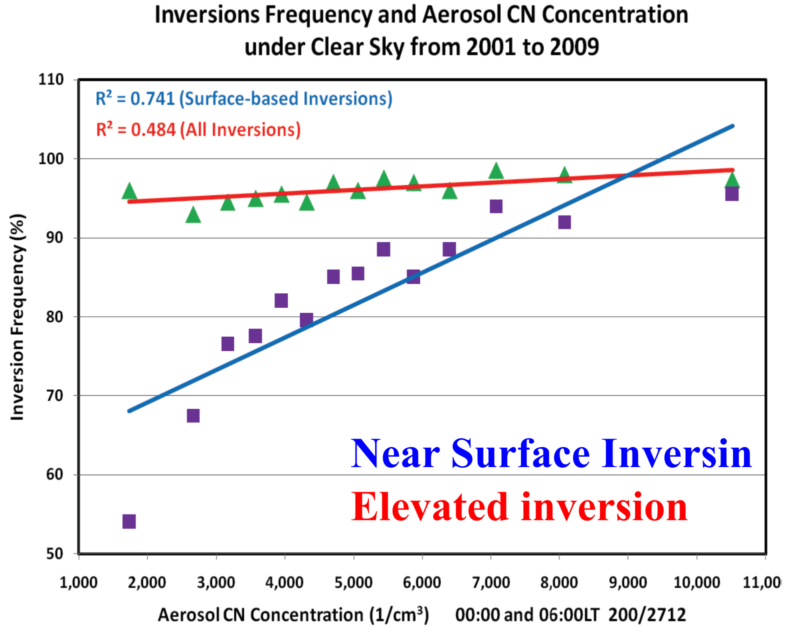
Aerosol-PBL Interaction Mechanisms

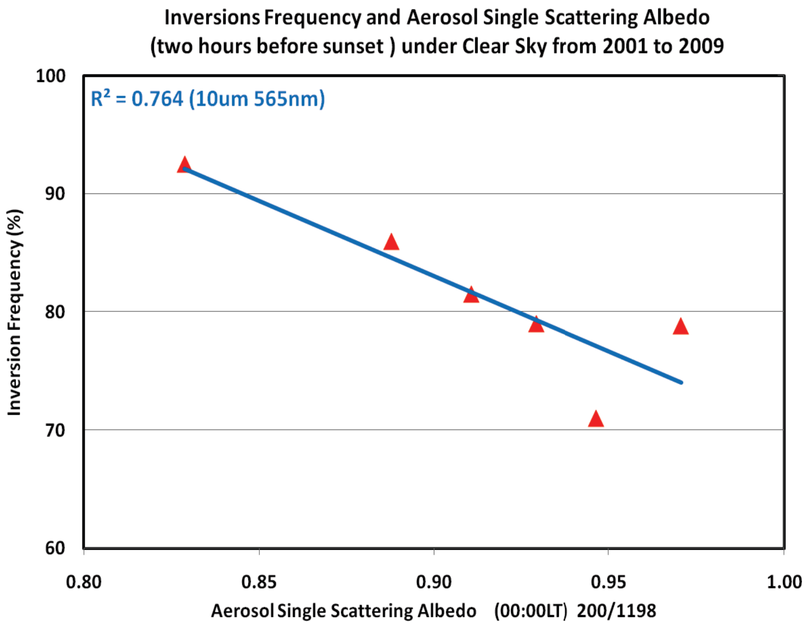
- Aerosol reduces surface heat fluxes, thus convective energy
- Aerosol-induced atmospheric warming, stabilizing atmosphere
- Enhance stability, suppress pollution dispersion



Impact of Aerosol on Temperature Profiles and Inversion in South Great Plains

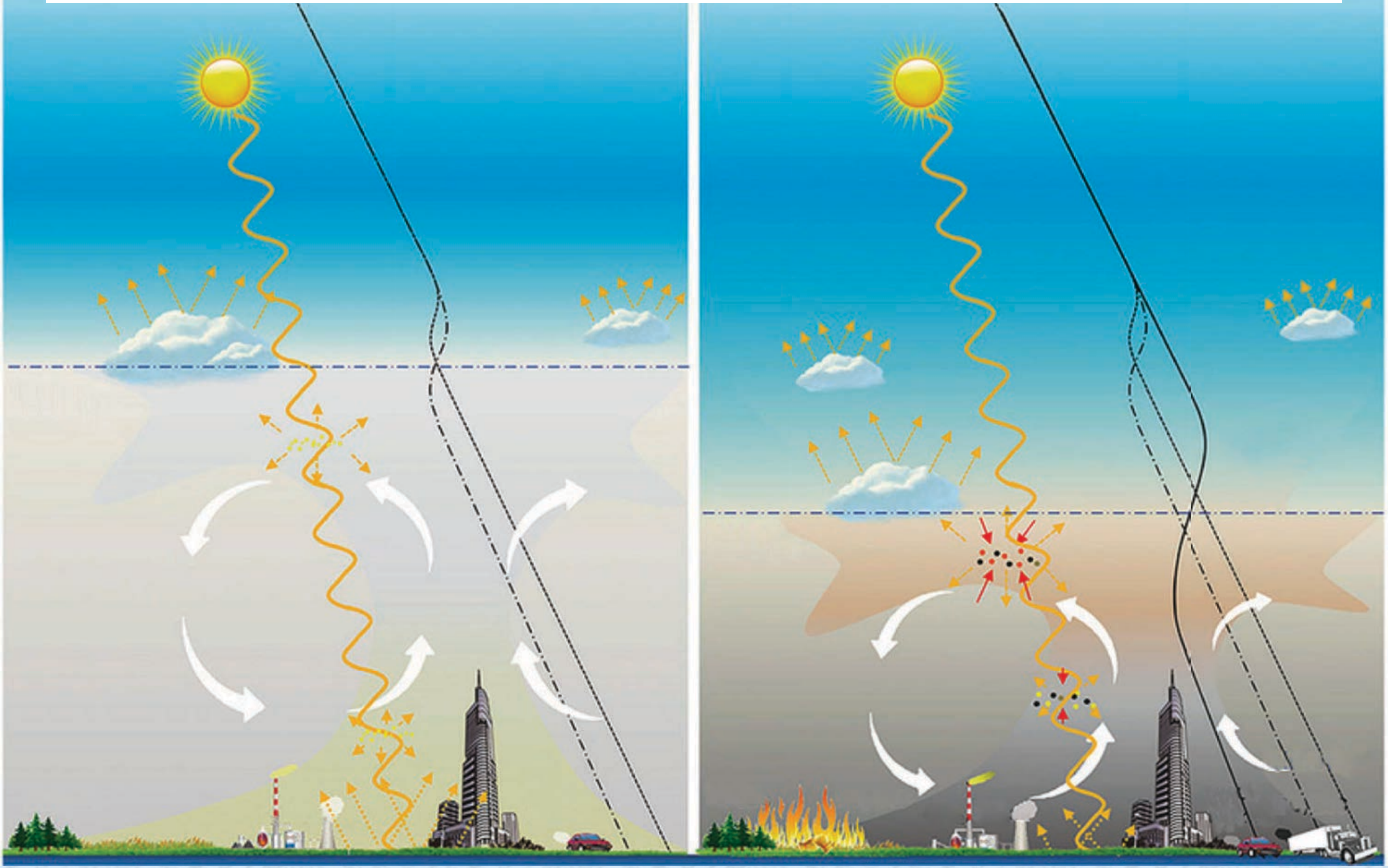






Li et al. (2017, Nat. Sci. Rev.)

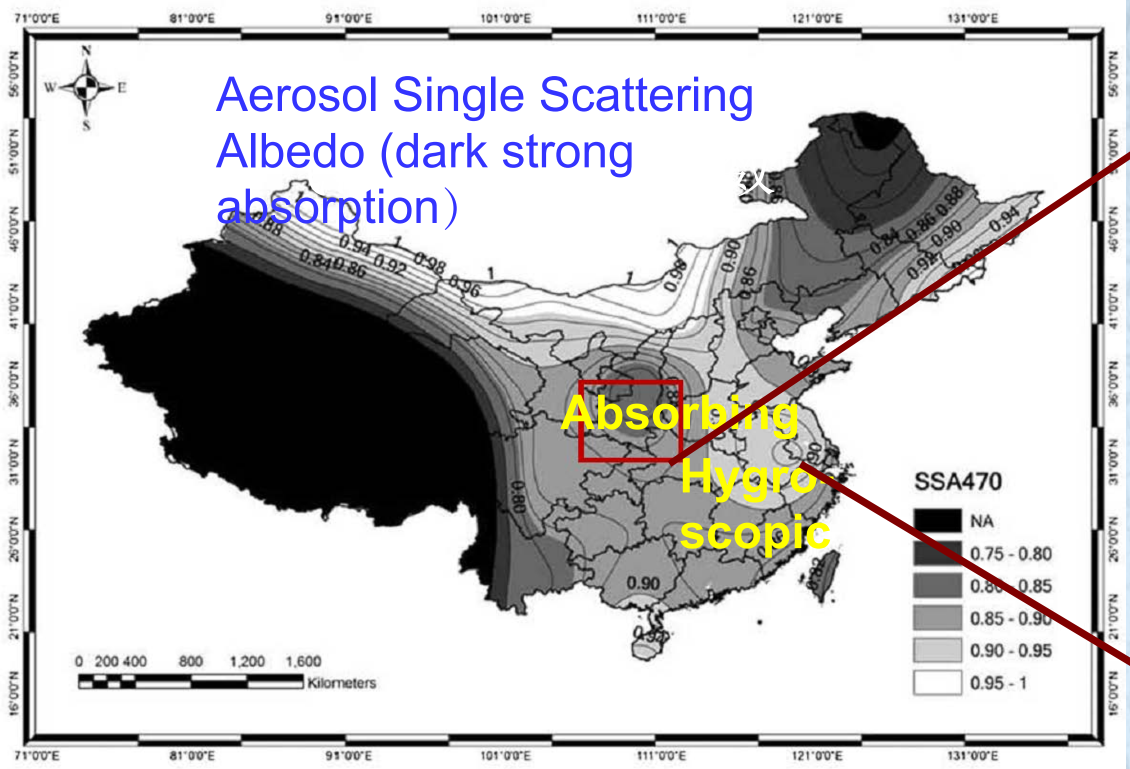
Aerosol-PBL Feedback Lowers the PBL



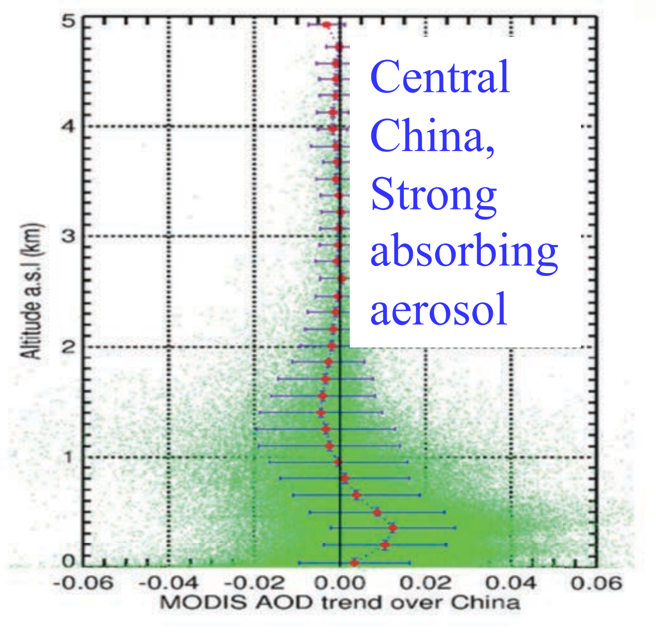
Ding et al. (2016, GRL)

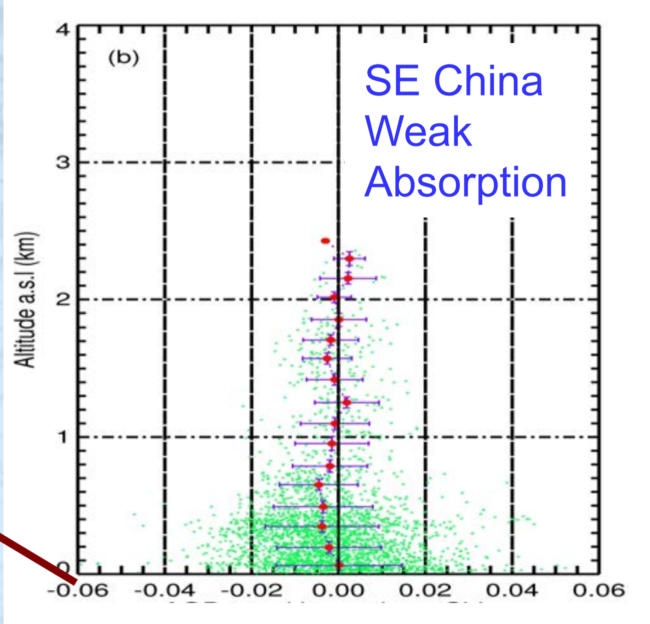
Evidence of the feedback on PBL

Use passive AOD to probe profile of aerosol changes at different altitudes



Lee, Li, et al. (2007)

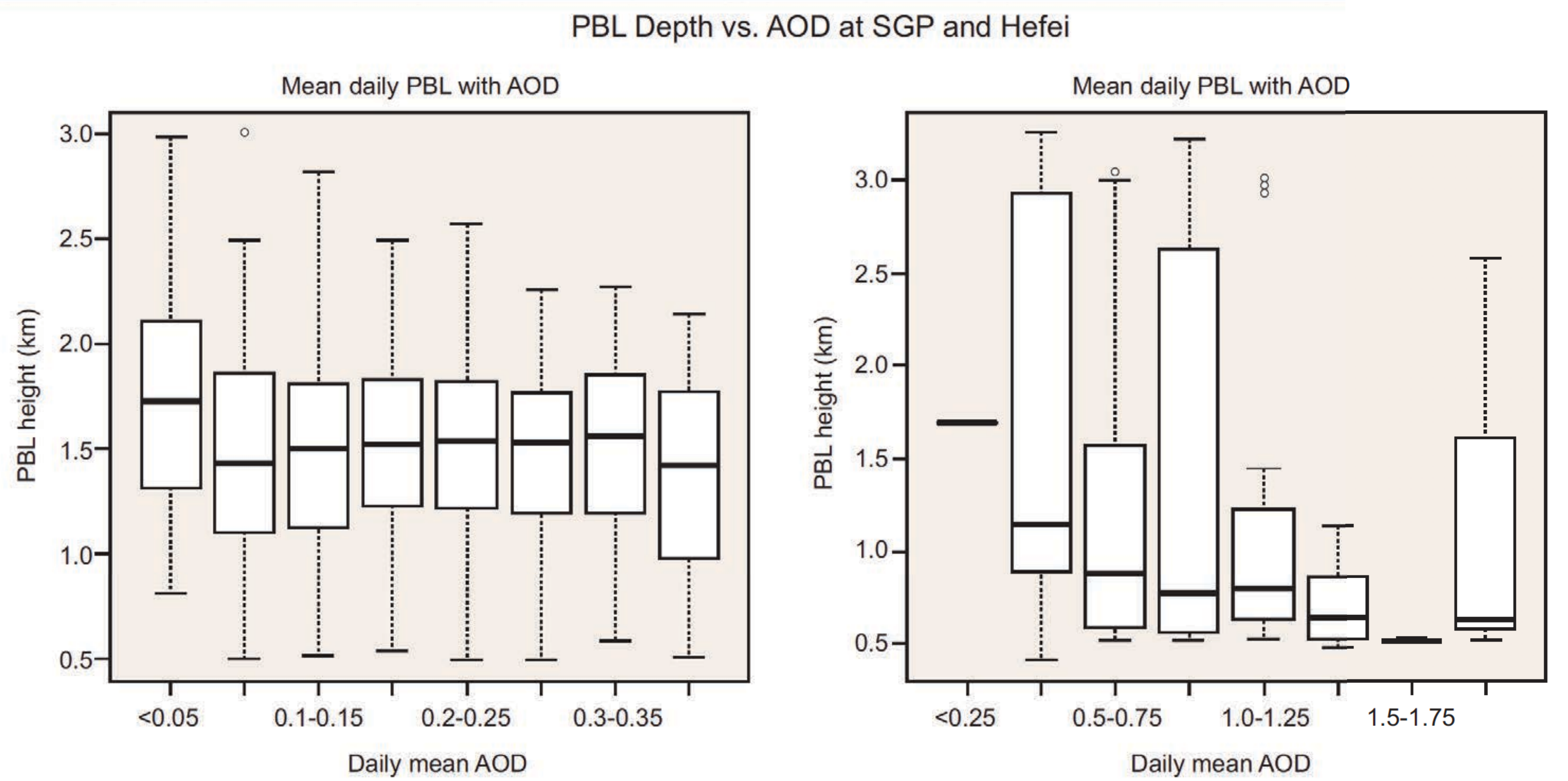




Trend of AOD Change

Dong, Li, et al. (2017， ACP)

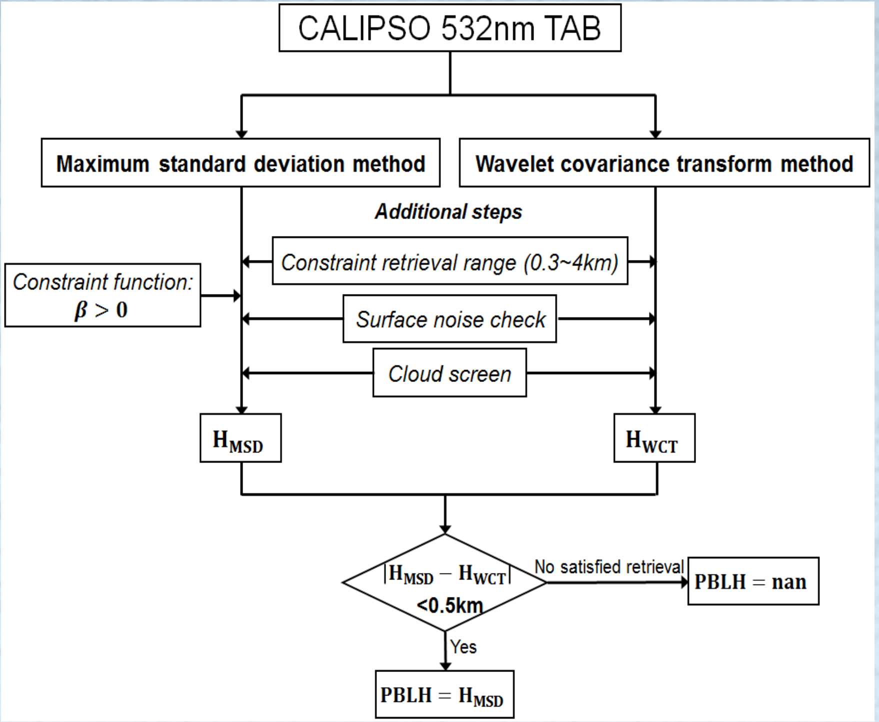
Comparison of PBL Climatological Height between US (SGP) and China (SE China Plain) Derived from Lidar Measurements



Li et al. (2017a, Nat. Sci. Rev.)

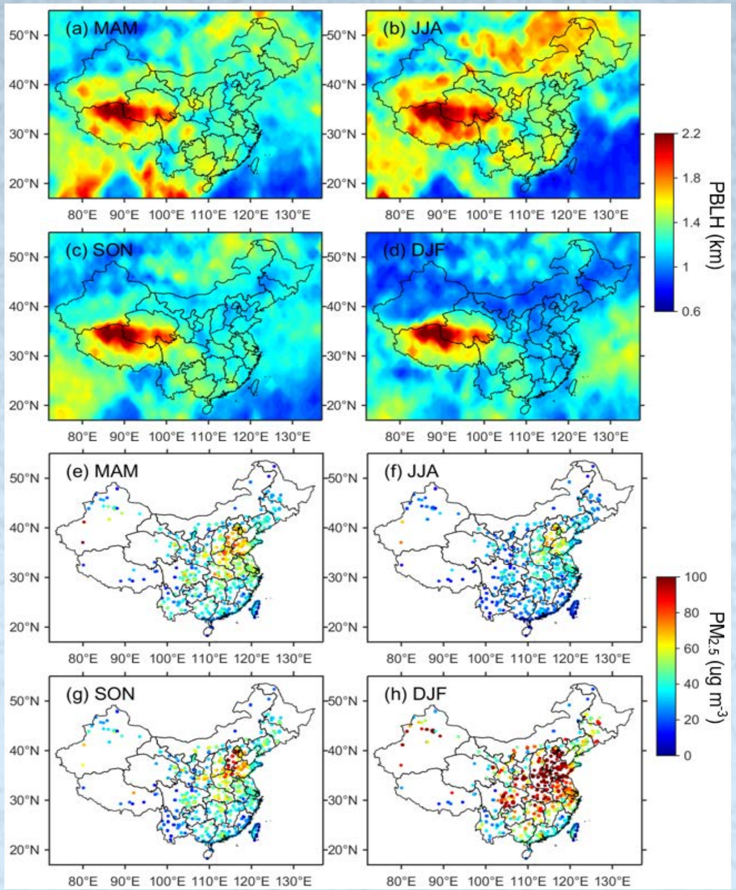
Relationships between PBLH and surface pollutants derived from lidar observations over China

Retrieve PBLH from CALIPSO



- We combine maximum standard deviation and wavelet covariance transform, this method show good agreements with PBLH retrievals derived from MPL. (Su et al., 2017)

Climatology of PM2.5 and PBLH

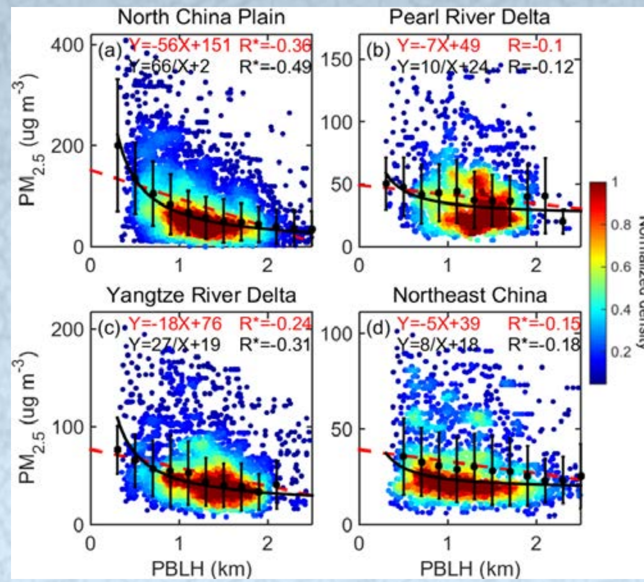


- There is coupling between the seasonal climatology of PBLH and PM2.5.
- The low PBLH during winter could be an important reason for the severe polluted episodes.

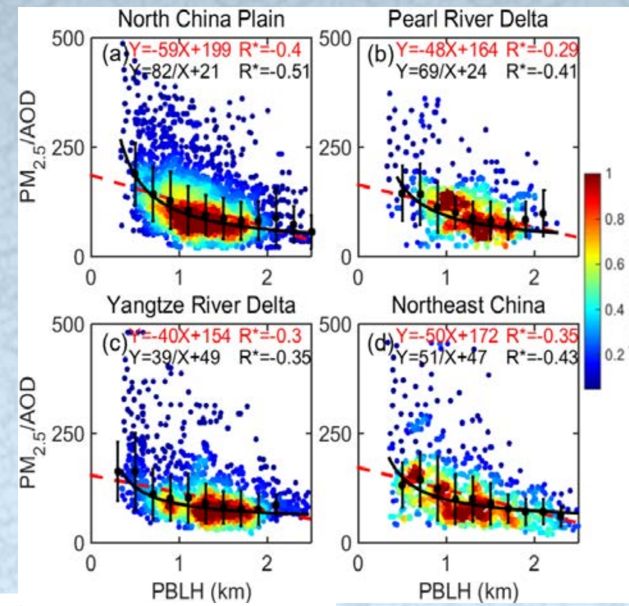
Regional Pattern

Region of Interests

Relationships between PBLH and PM2.5 over 4 ROIs



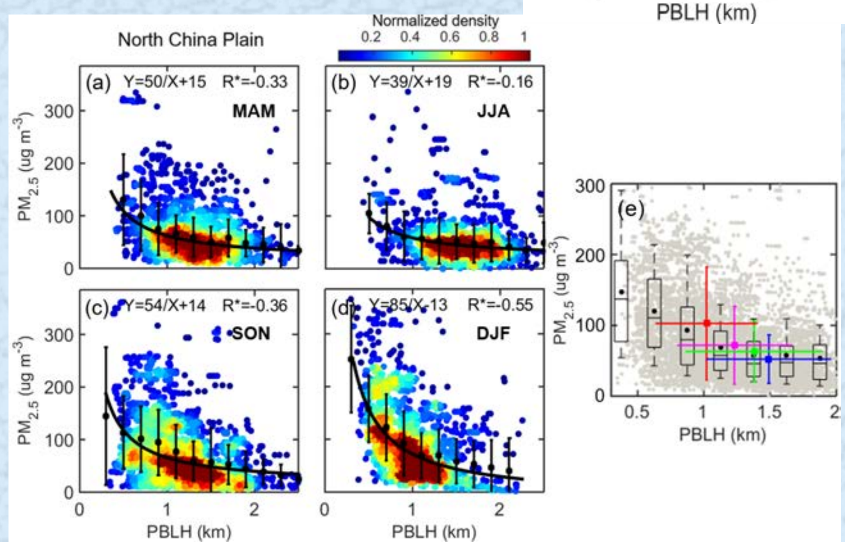
After normalizing, the relationships between PBLH and normalized PM2.5.



- **Found significant negative correlations over NCP, a major polluted region.**
- **There is a weak correlation between PBLH and PM2.5 over Pearl River Delta.**
- **Nonlinear responses of PM2:5 to PBLH evolution are found, especially for the NCP.**
- **Compared to PBLH–PM2.5 correlations, the correlations between PBLH and normalized PM2.5 increased significantly for clean regions, resulting in smaller regional differences overall.**

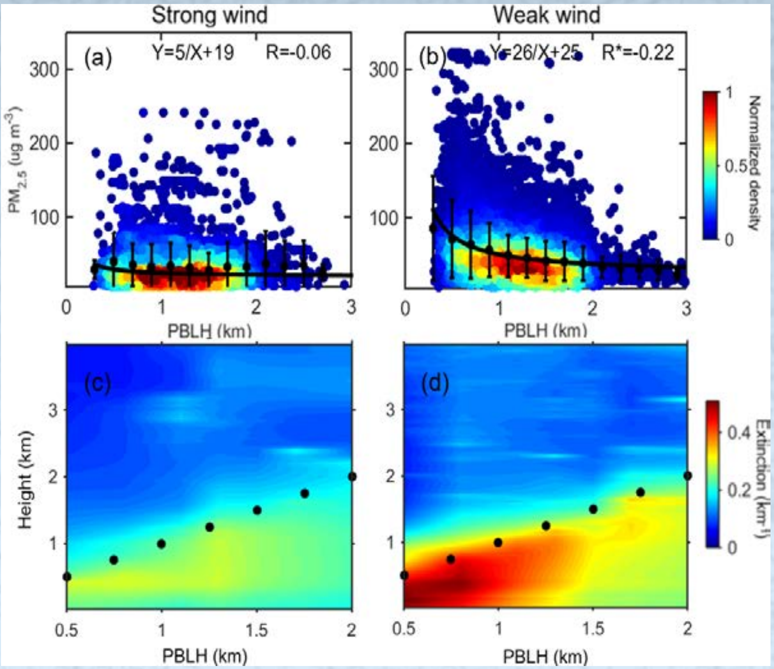
Prominent seasonality over NCP

- **The nonlinear relationship between PBLH and PM2:5 shows stronger interaction when the PBLH is shallow and PM2:5 concentration is high, which typically corresponds to the wintertime cases.**



Influential Factors

Horizontal transport

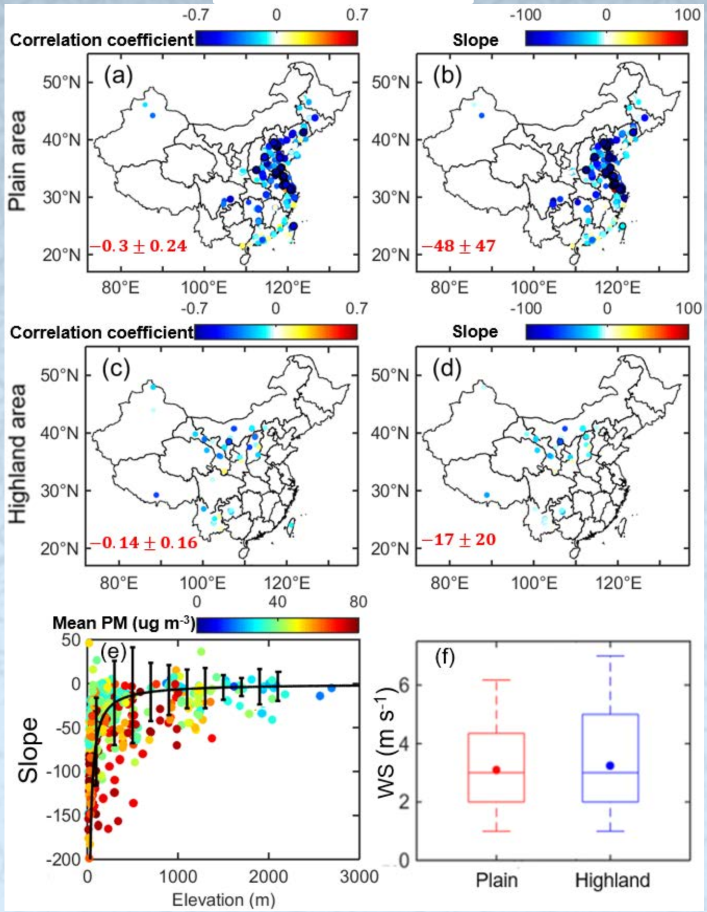


➢ **Strong wind with clean upwind air plays a dominant role in removing pollutants, and leads to obscure PBLH–PM relationships.**

Potential factor: Absorbing aerosol (feedback)

Su et al., 2018

Topography



➢ **The PBLH-$PM_{2.5}$ correlations are found to be more significant in plains.**

➢ **This is related to the more frequent air stagnation and strong local emission over China's plains, as well as a greater concentration of emission sources.**

➢ **The mountain breezes and a larger fraction of transported aerosol above the PBL contribute to weakening of the PBLH–$PM_{2.5}$ correlation over highland areas.**

Summary

– Aerosol-PBL feedback plays a key role in modulating surface air quality

– A new method is developed to retrieve PBL from lidar that can account for better the diurnal variation of PBL

– Aerosol lower PBL height, less room for hosting pollutants

– Absorbing aerosols induce inversion to stabilize PBL whose frequency of occurrence is strongly affected by aerosol absorption.

Overview of PBL-Aerosol-Air Quality Interactions

REVIEW

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ENVIRONMENT/ECOLOGY

Special Topic: Air Pollution and Control

Aerosol and boundary-layer interactions and impact on air quality

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ABSTRACT

Air quality is concerned with pollutants in both the gas phase and solid or liquid phases. The latter are referred to as aerosols, which are multifaceted agents affecting air quality, weather and climate through many mechanisms. Unlike gas pollutants, aerosols interact strongly with meteorological variables with the strongest interactions taking place in the planetary boundary layer (PBL). The PBL hosting the bulk of aerosols in the lower atmosphere is affected by aerosol radiative effects. Both aerosol scattering and absorption reduce the amount of solar radiation reaching the ground and thus reduce the sensible heat fluxes that drive the diurnal evolution of the PBL. Moreover, aerosols can increase atmospheric stability by inducing a temperature inversion as a result of both scattering and absorption of solar radiation, which suppresses dispersion of pollutants and leads to further increases in aerosol concentration in the lower PBL. Such positive feedback is especially strong during severe pollution events. Knowledge of the PBL is thus crucial for understanding the interactions between air pollution and meteorology. A key question is how the