Spatial Heterogeneity of Aerosol Effect on Liquid Cloud Microphysical Properties in the Warm Season Over Tibetan Plateau

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Motivation

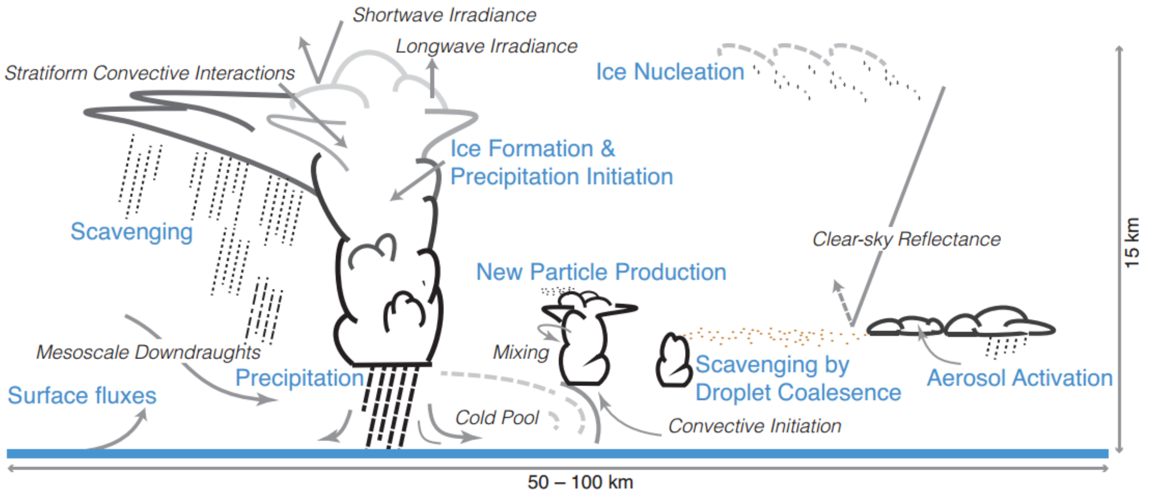


Figure 7.16 | Schematic depicting the myriad aerosol–cloud–precipitation related processes occurring within a typical GCM grid box. The schematic conveys the importance of considering aerosol–cloud–precipitation processes as part of an interactive system encompassing a large range of spatiotemporal scales. Cloud types include low-level stratocumulus and cumulus where research focuses on aerosol activation, mixing between cloudy and environmental air, droplet coalescence and scavenging which results in cloud processing

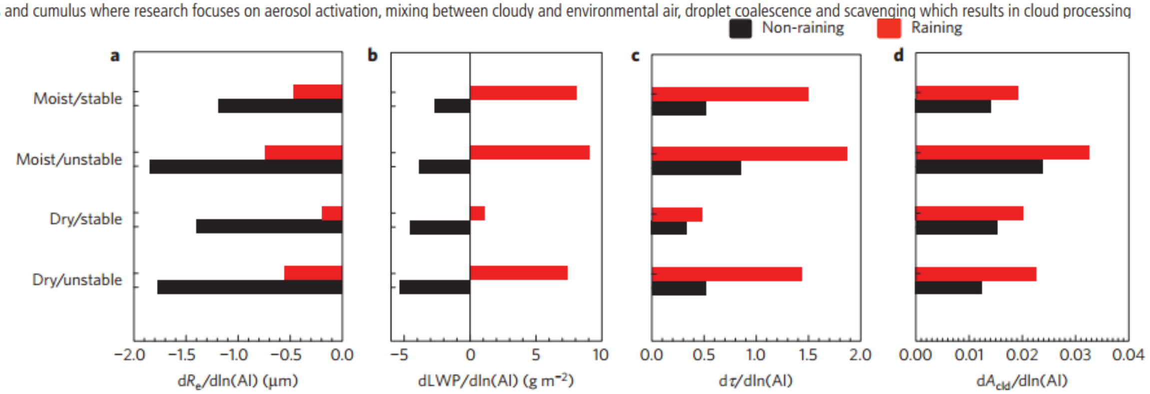
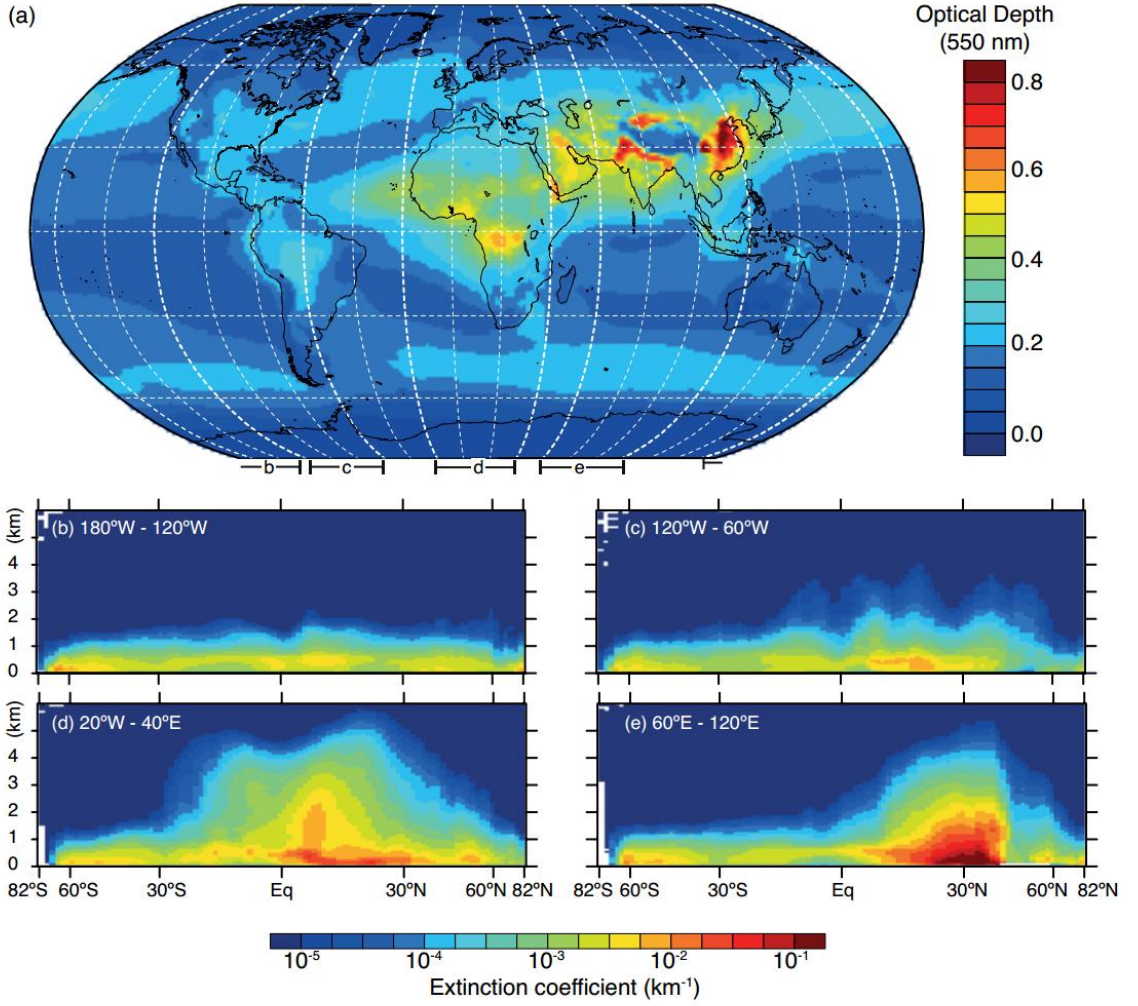


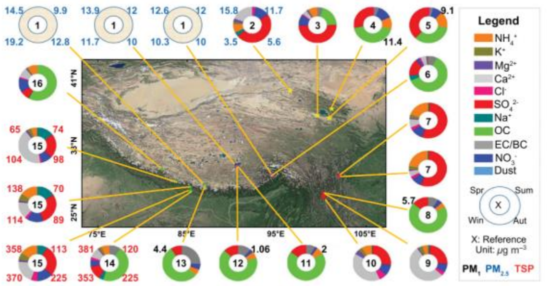
Figure 2 | Cloud property response to varying AI under different environments and non-raining/raining conditions. a–d, The cloud properties include cloud effective radius (R_e; **a**), cloud LWP (**b**), cloud optical depth (τ; **c**), and cloud albedo (A_{cld}; **d**). For the environmental conditions, 'dry' and 'moist' refer to free tropospheric humidity <40% and >40%, respectively; 'unstable' and 'stable' refer to lower tropospheric stability ($\theta_{700\,hPa} - \theta_{surface}$) <17 K and >17 K, respectively. Responses for non-raining/raining clouds are shown in black and red, respectively. The slopes of the linear fit between cloud properties and AI are calculated at the 95% confidence level.



igure 7.14 | (a) Spatial distribution of the 550 nm aerosol optical depth (AOD, unitless) from the European Centre for Medium Range Weather Forecasts (ECMWF) Integrated orecast System model with assimilation of Moderate Resolution Imaging Spectrometer (MODIS) aerosol optical depth (Benedetti et al., 2009; Morcrette et al., 2009) averaged ver the period 2003–2010; (b–e) latitudinal vertical cross sections of the 532 nm aerosol extinction coefficient (km^{-1}) for four longitudinal bands (180°W to 120°W, 120°W to 0°W, 20°W to 40°E, and 60°E to 120°E, respectively) from the Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument for the year 2010 (nighttime all-sky data, ersion 3; Winker et al., 2013).

Li et al., 2011, Nature geoscience; Chen et al., 2014, Nature geoscience

Motivation



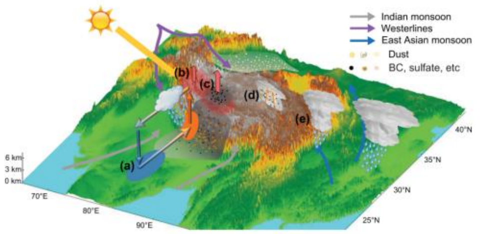
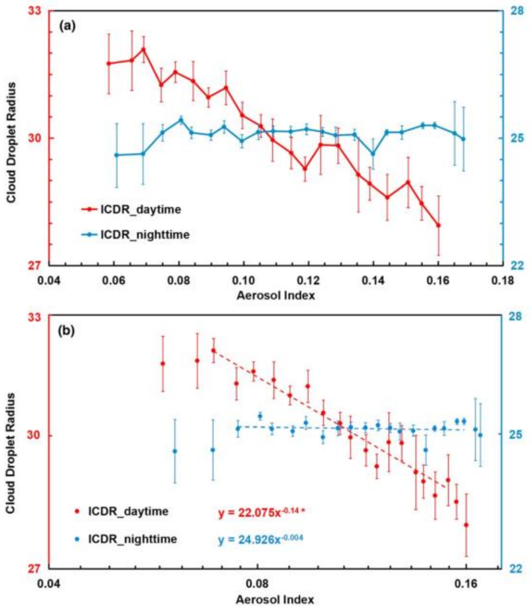
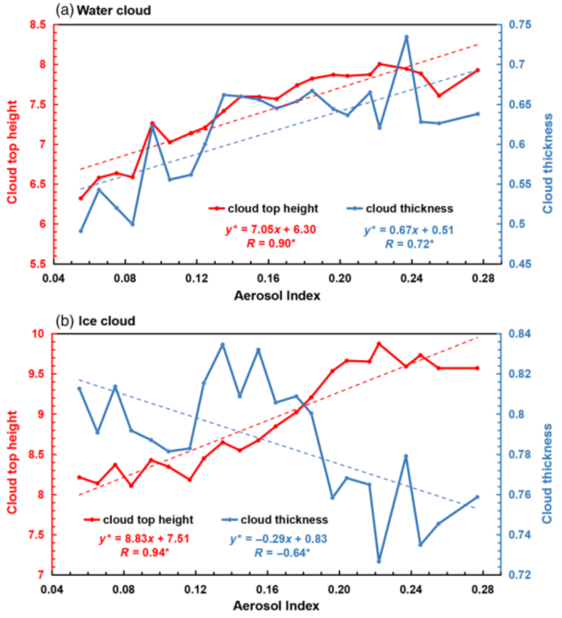


Figure 1. A review of aerosol characteristics at various ground sites or regions over the Tibeta Plateau based on 16 previous studies. Spr, Sum, Aut and Win represent the four seasons of spring summer, autumn and winter, respectively. The black, sky-blue and red numbers around the circle denote PM_1, $PM_{2.5}$ and TSP with unit $\mu g\ m^{-3}$, respectively. OC and EC/BC represent organic carbo and elemental carbon/black carbon, respectively. X indicates the serial number for the previous stud reference, which is also listed in Supplementary Table 1.

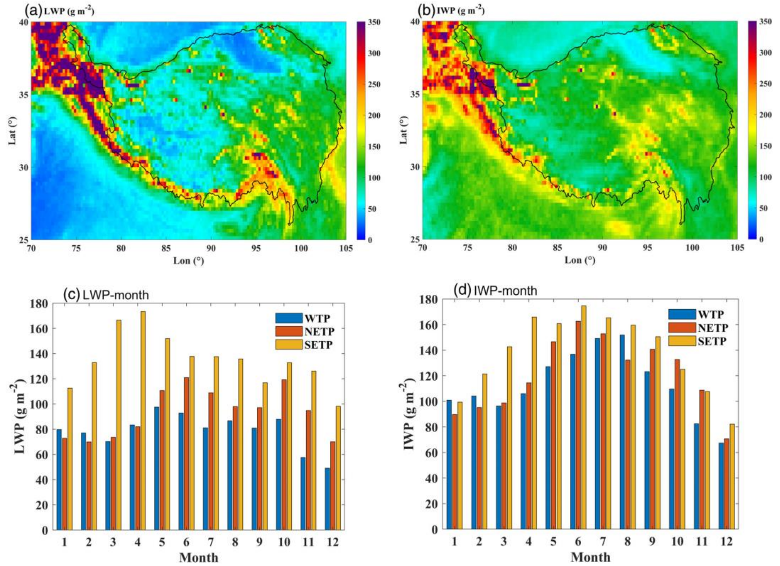
Figure 2. A schematic diagram that demonstrates the potential impacts of aerosols on weather and climate based on literature review: (a) the postponing and strengthening precipitation by aerosols from middle India to south of Himalaya mountains, proposed by [10]; (b) the 'heat-pump' effect proposed by [2]; (c) the enhanced 'heat-pump' effect by absorbing aerosols, proposed by multiple studies including [11]; (d) enhanced convective precipitation by aerosols that serve as cloud-condensation nuclei, which has been indicated by various studies including [14]; (e) enhanced convection could strengthen the precipitation events for downstream regions as shown by [12].

Zhao C. et al., *NSR*., 2019

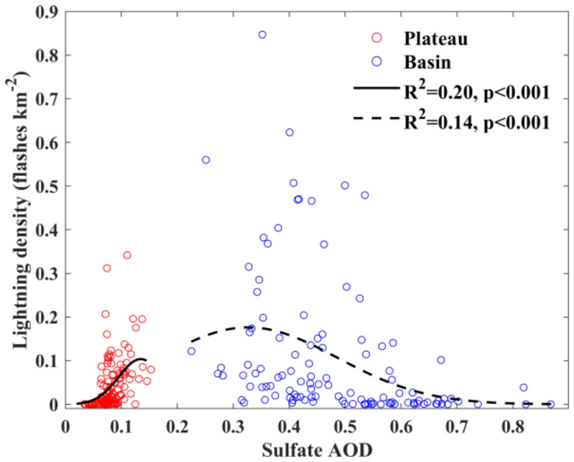




Liu et al., *JGR*., 2020



Zhao et al., *Int J Climatol*., 2021

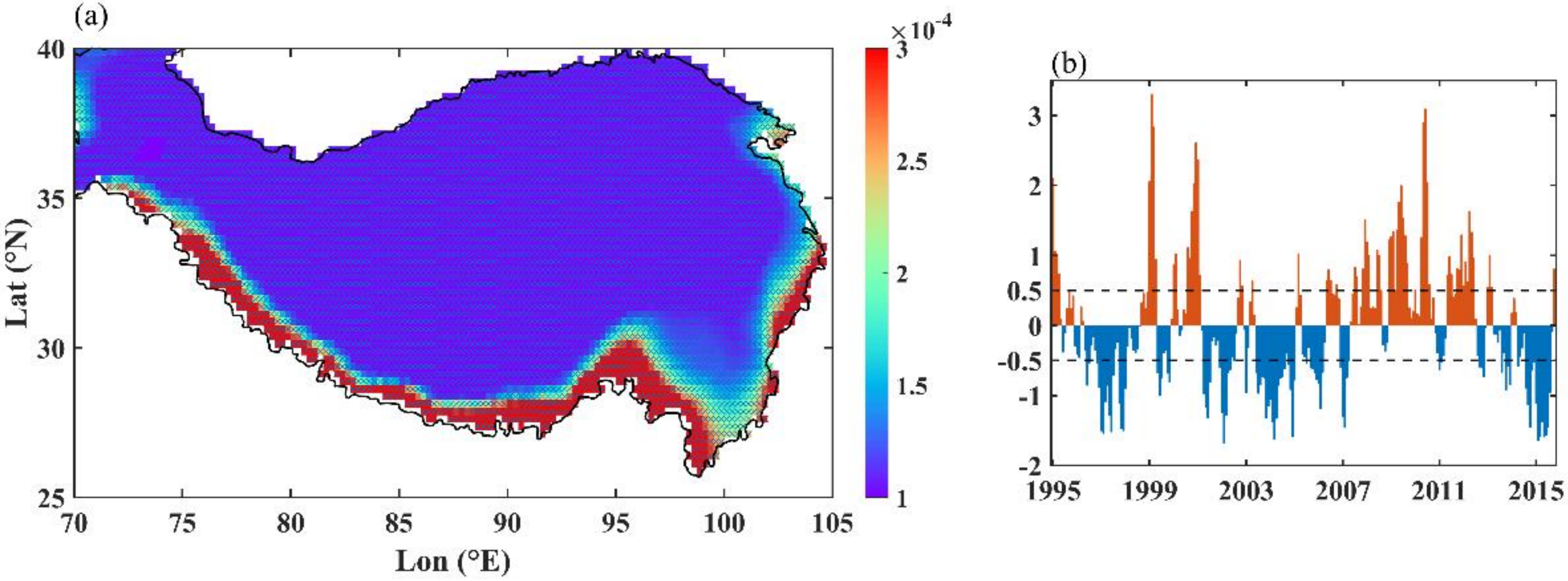


Zhao et al., *ACP*, 2020

Data

- 1995-2015, warm season, 0.25° ×0.25° ;
- Cloud properties: LREF (liquid cloud droplet effective radius), CF (cloud fraction), CTP (cloud top pressure). CM SAF cloud, albedo and surface radiation dataset from the AVHRR data, edition 2 (CLARA-A2)
- Aerosol: Aerosol Index=AOD×AE (Ångström exponent). MERRA-2
- Meteorology: CAPE. ERA-5

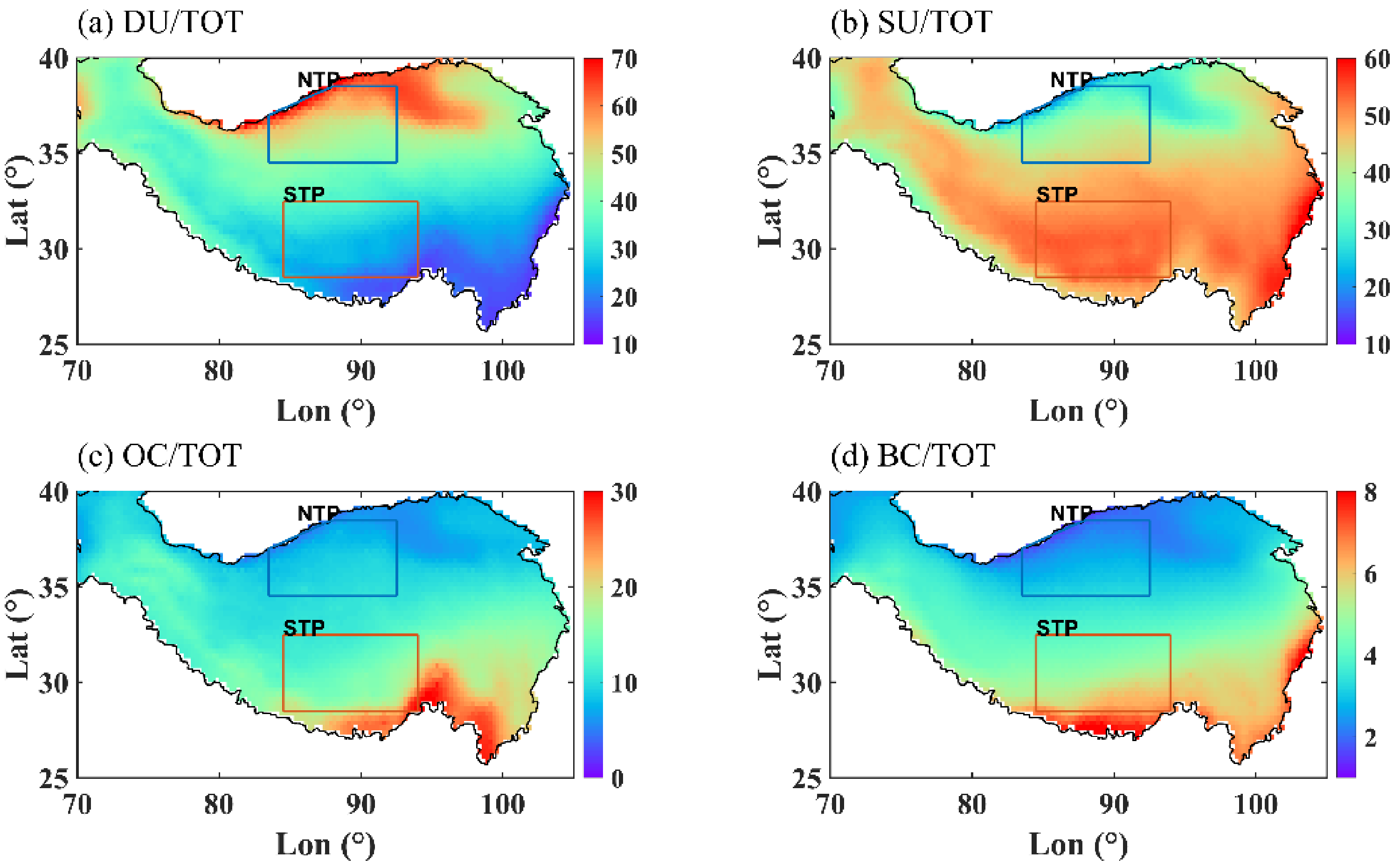
Aerosol Index and Cloud Properties



Trends of AI (month^{-1}) (a), the cross symbols in the figure indicate the grid boxes that have passed the 95% significance test. The time series of AI anomaly from 1995 to 2015 (b), processed by removing the annual cycle and linear trend and standardizing. The dashed lines indicate thresholds for positive and negative AI events.

- In the Tibetan Plateau, the trend of AI change is consistent.
- >0.5 positive events， <-0.5 negative events.

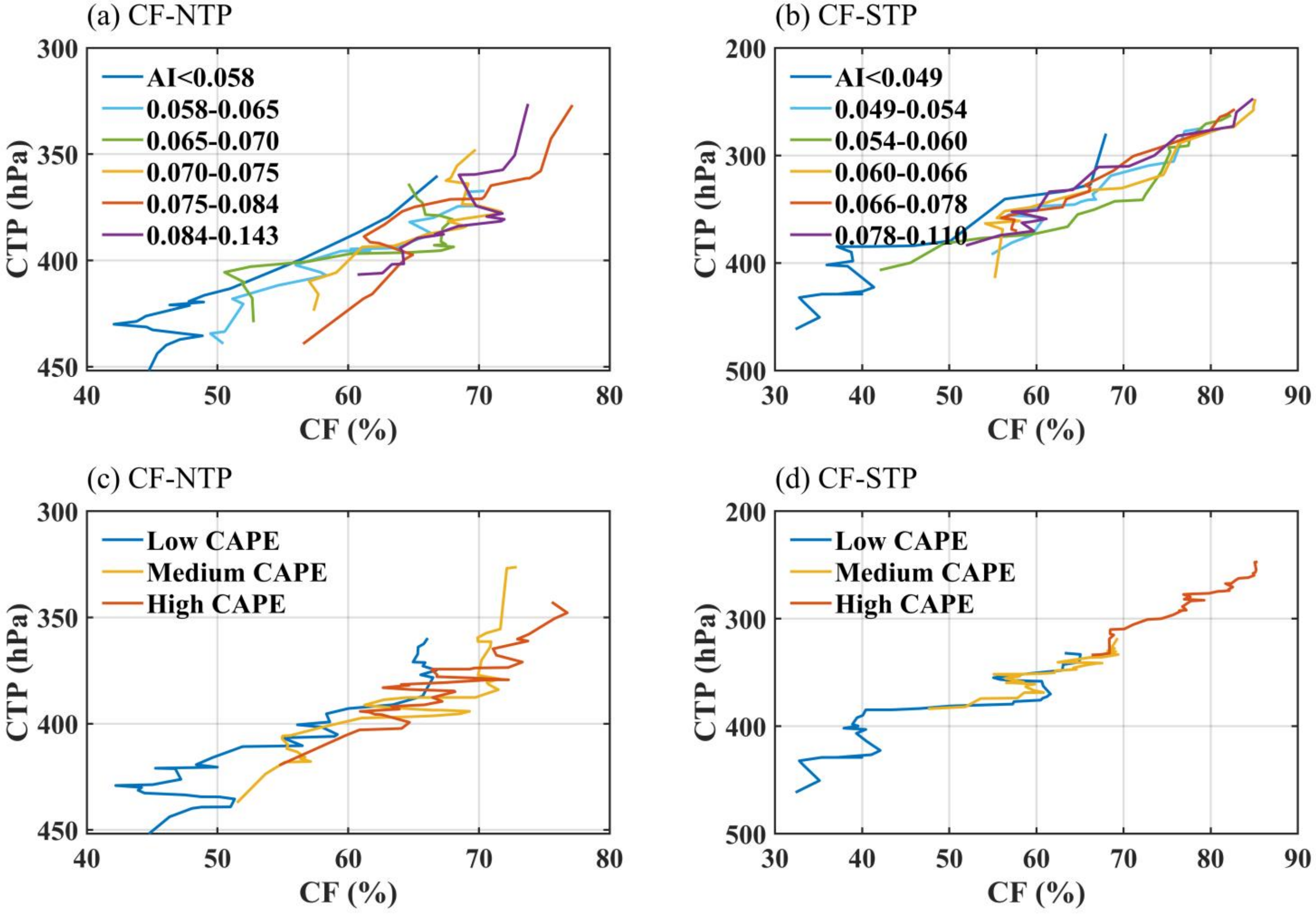
Aerosol Index and Cloud Properties



- The influence of aerosols on the liquid cloud over the TP is obviously different from the north to the south.
- When AI is higher, the LREF in the NTP is larger, in the STP is smaller.

Composite LREF anomalies (μm) for positive (a) and negative (b) AI events, and composite CDNC anomalies (cm^{-3}) for positive (c) and negative (d) AI events in the warm season from 1995 to 2015 over the TP. Dot symbols in the grid indicate that a 95% significance level has been passed according to the Student's t-test. The blue and red boxes represent the NTP and STP, respectively.

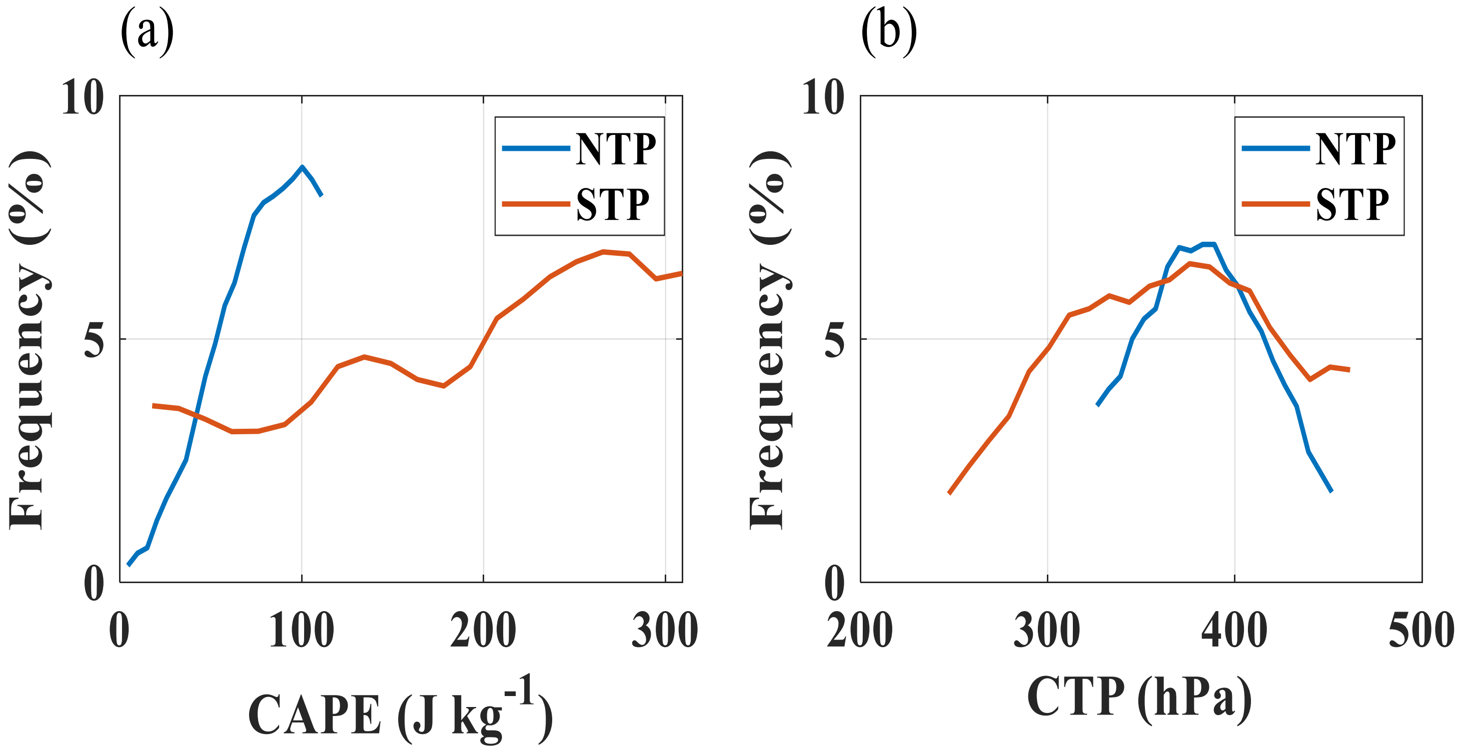
Aerosol Index and Cloud Properties



CF as a function of CTP in the warm season. CFs are grouped into 6 groups according to AI over the NTP (a) and STP (b); and CFs are grouped into 3 classes according to the CAPE over the NTP (c) and STP (d)

- Aerosols promote cloud development over the NTP and STP.
- Frequent convection occurs over the TP.

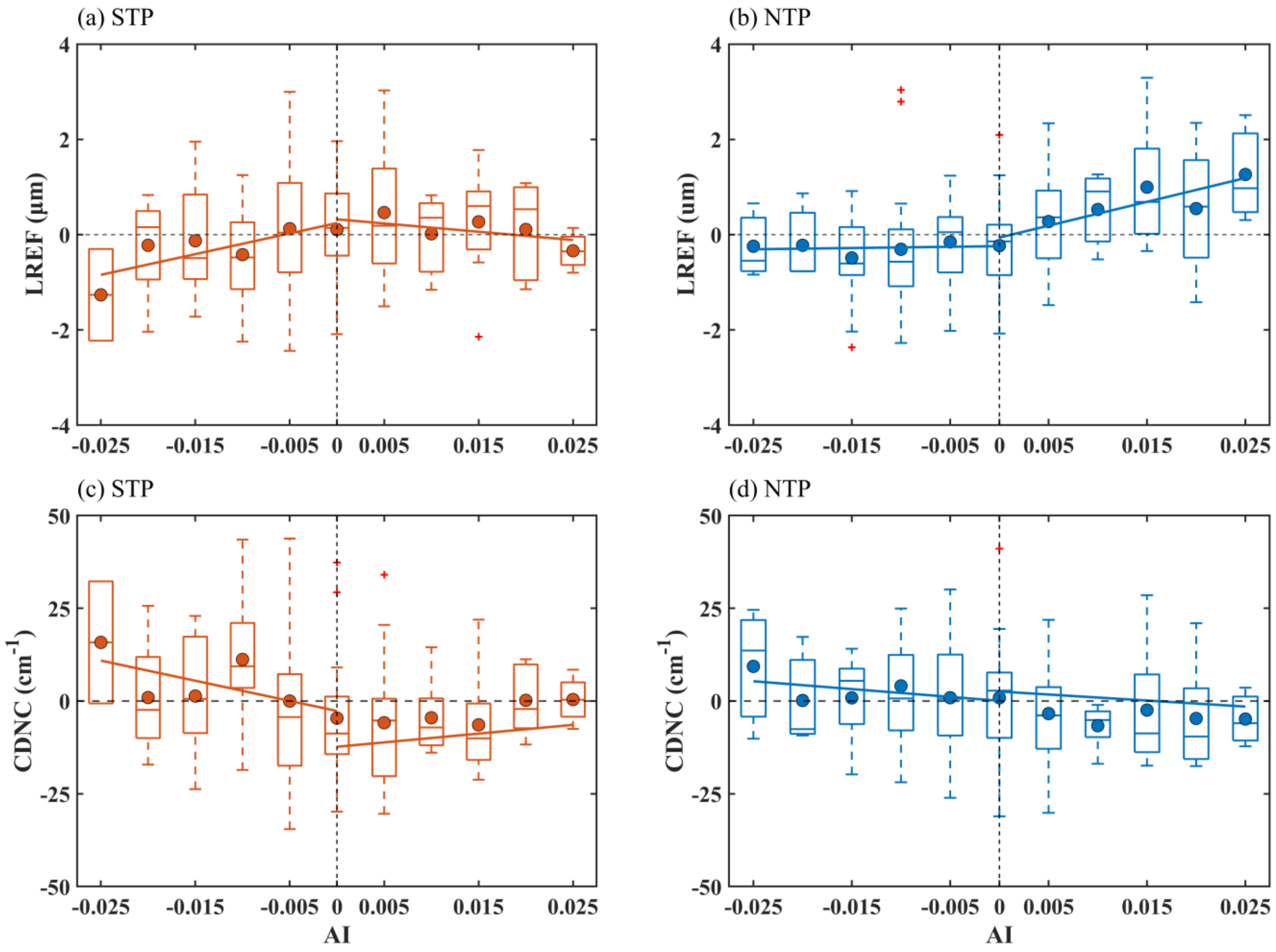
Aerosol Index and Cloud Properties



The frequency distribution of CAPE and CTP over the NTP and STP in the warm season. CAPE and CTP in the warm season were divided into 21 bins, and the percentage of samples in each bin to the total number of samples in the warm season was defined as the frequency distribution.

- CAPE in the STP is significantly higher than that in the NTP.
- CTH in the STP is significantly higher than in the NTP.

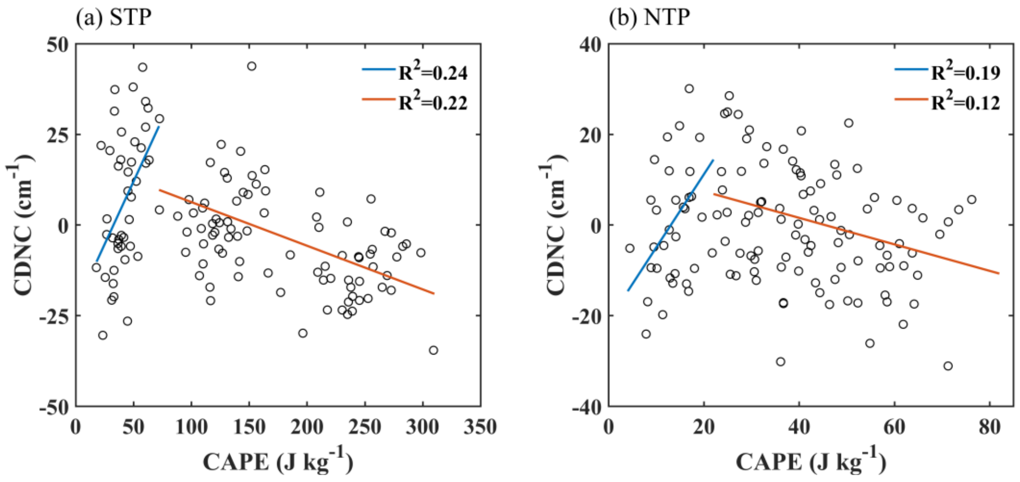
Aerosol Index and Cloud Properties



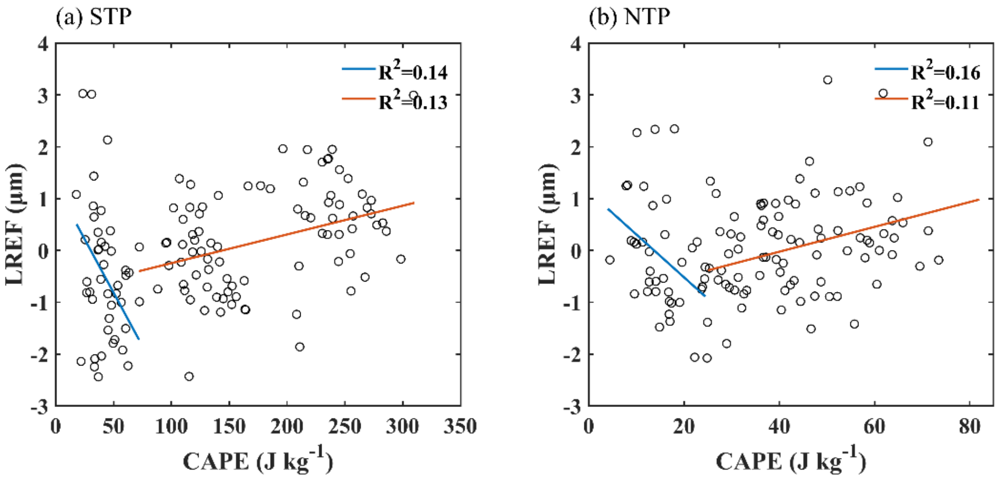
The variation of LREF (μm) and CDNC (cm-3) anomalies with AI anomaly over the NTP and STP in the warm season. Red represents the STP, and blue represents the NTP. AI anomalies are divided into 11 bins, each bin with nearly equal sample size. The solid point is the average value of LREF (panel a and b) and CDNC (panel c and d) in each bin, and the solid line is the linear fitting line of the average values. The average values with AI anomalies larger than 0 and less than 0 are fitted respectively.

- When AI is lower, the LREF in the STP and NTP is lower.
- When AI is higher, the LREF is higher.
- Aerosol radiative force!
- STP, with the increase of AI, the LREF increases first, then decreases;
- NTP, with the increase of AI, the LREF increase;
- Show the aerosol microphysical effect, depending on the local environment, cloud properties and characteristics of aerosol!

Impacts of Thermodynamic and Dynamic Parameters on the Correlations



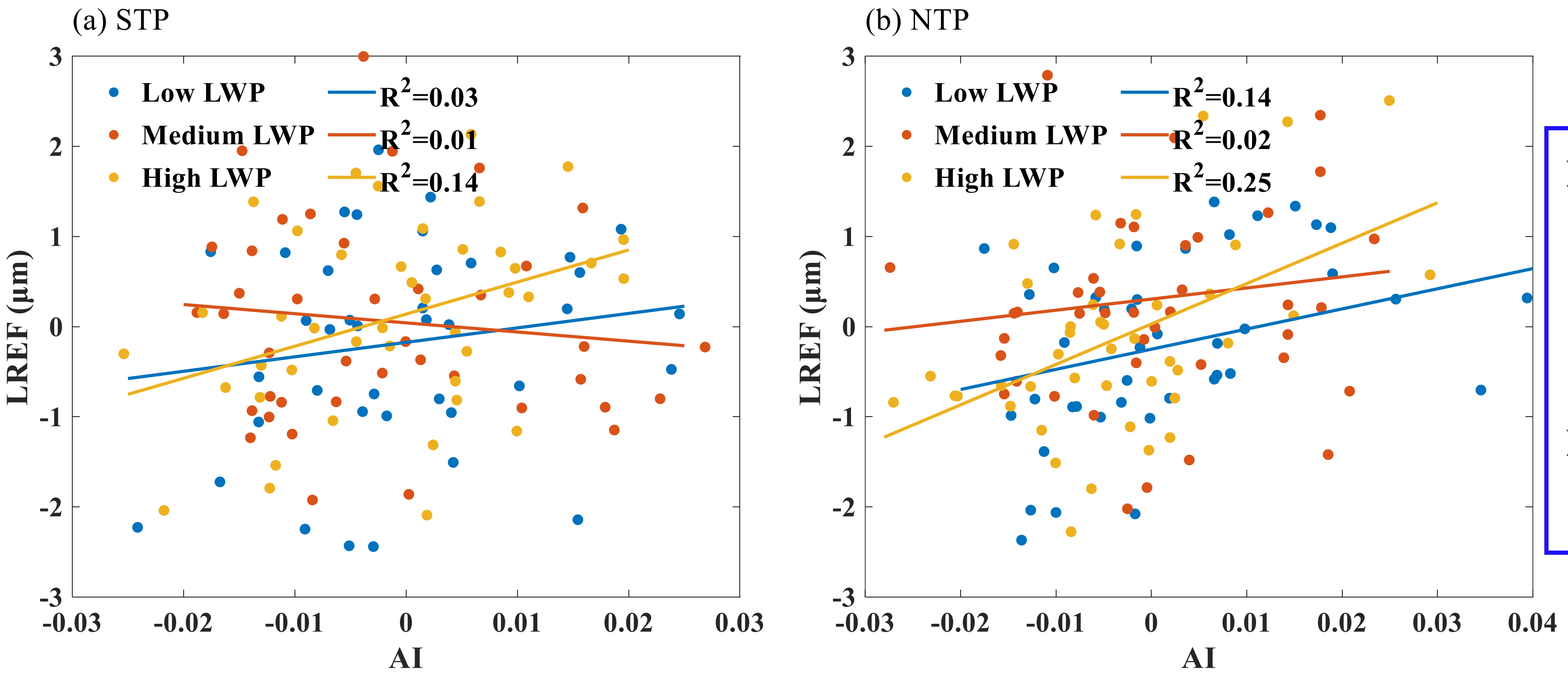
Variation of CDNC anomaly with CAPE in the warm season over the STP (a) and NTP (b).



Variation of LREF anomaly with CAPE in the warm season over the STP (a) and NTP (b).

- Over the TP, the CDNC increases first and then decreases with the increase of CAPE.
- The aerosol radiative effect reduce the solar radiation on the ground, suppresses convection;
- Over the TP, the CAPE is lower, the cloud droplet is less, and the radius is larger.

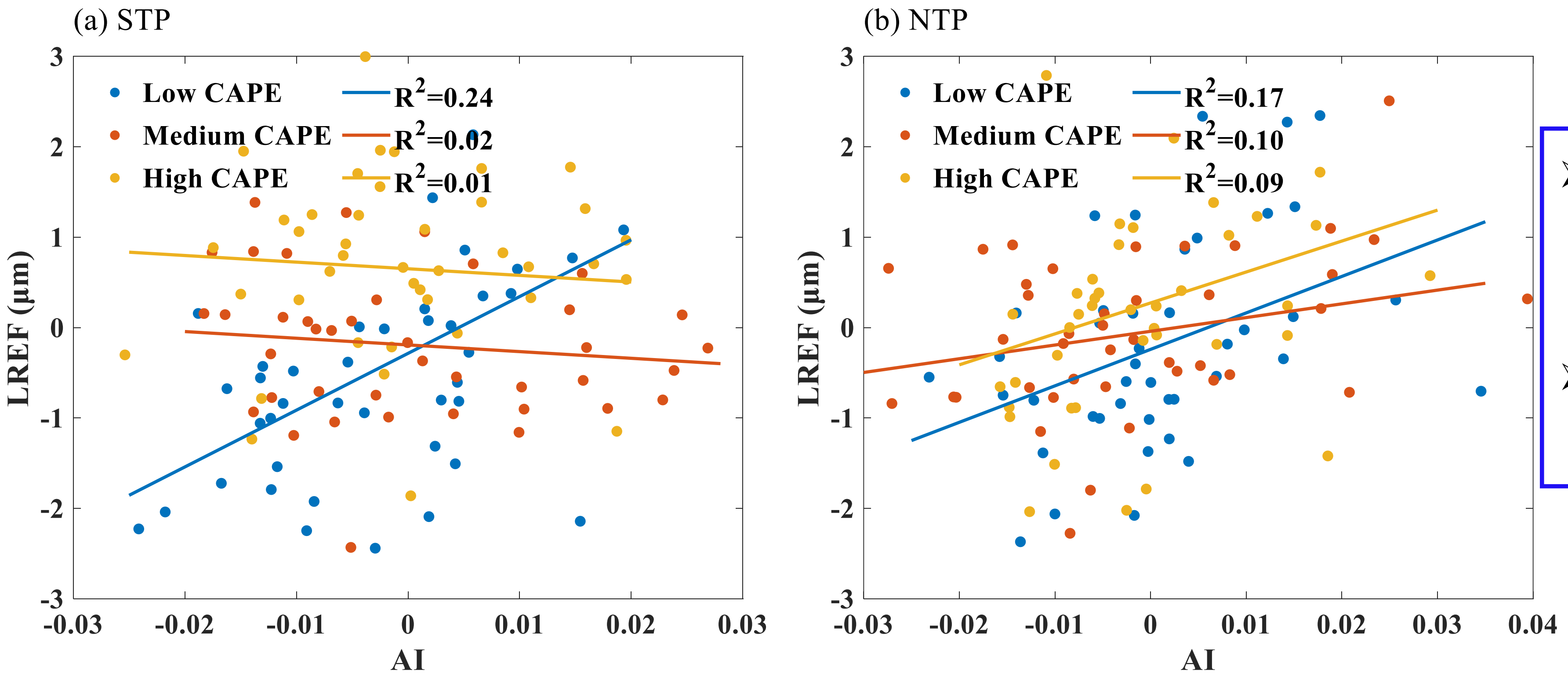
Impacts of Thermodynamic and Dynamic Parameters on the Correlations



- In the STP, the aerosol has a relatively significant positive correlation to the LREF at high LWP.
- In the NTP, high and low LWP, positive correlation.

Variation of LREF anomaly with AI anomaly under different LWP conditions over the STP (a) and NTP (b) in the warm season.

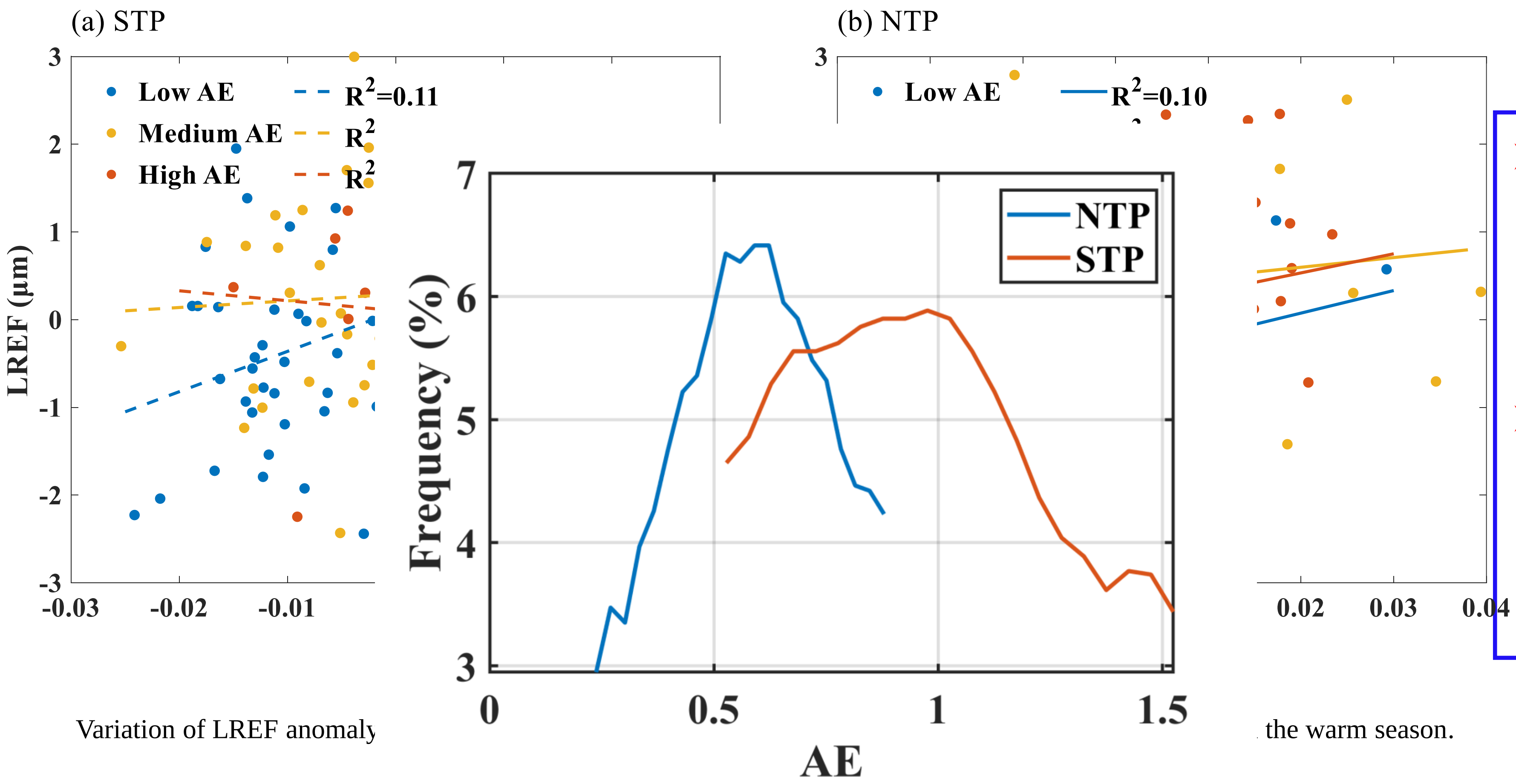
Impacts of Thermodynamic and Dynamic Parameters on the Correlations



- In the STP, at high CAPE, the aerosol has a relatively significant positive correlation to the LREF.
- In the NTP, under different CAPE, positive correlation.

Variation of LREF anomaly with AI anomaly under different CAPE conditions over the STP (a) and NTP (b) in the warm season.

Impacts of Thermodynamic and Dynamic Parameters on the Correlations



Variation of LREF anomaly ... the warm season.

- ➢ In the STP, there is a relatively significant positive correlation between aerosol and LREF at low AE.
- ➢ In the NTP, high and low AE, aerosols have relatively significant positive correlation with the LERF.

Summary

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- **The influence of aerosol on the microphysical properties of liquid cloud is different in space over the Tibetan Plateau.**
- **In the STP and NTP, the effects of aerosol on liquid cloud are similar, which reflects the aerosol radiative effect.**
- **The difference of aerosol microphysical effects in the STP and NTP may be due to the difference of thermal dynamic conditions and aerosol types.**

1. **Zhao Pengguo**, Zhao Wen, Yuan Liang, et al. Spatial Heterogeneity of Aerosol Effect on Liquid Cloud Microphysical Properties in the Warm Season Over Tibetan Plateau[J]. *Journal of Geophysical Research: Atmospheres*, 2023, 128(2): e2022JD037738.
2. **Zhao Pengguo**, Li Zhanqing, Xiao Hui, et al. Distinct aerosol effects on cloud-to-ground lightning in the plateau and basin regions of Sichuan, Southwest China[J]. *Atmospheric Chemistry and Physics*, 2020, 20(21): 13379-13397. DOI: https://doi.org/10.5194/acp-20-13379-2020
3. **Zhao Pengguo**, Xiao Hui, Liu Jia, Zhou Yunjun. Precipitation efficiency of cloud and its influencing factors over the Tibetan plateau[J]. *International Journal of Climatology*, 2022, 1-19. DOI: https://doi.org/10.1002/joc.7251

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