1   **Supporting Information for**

2   **Aerosol-Driven Precipitation Modification: Spatiotemporal Heterogeneity in**

3   **Precipitation Microphysics and Vertical Structures over China's Megacity**

4   **Clusters**

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14   **Table S1.** Normalized regional differences in convective precipitation during the

15   summer season. Units: nsRR (mm/h), STH (km), LWP (g/m^2), IWP (g/m^2).

	AOD	BTH	YRD DIFF$_{YRD}$	YRM DIFF$_{YRM}$	PRD DIFF$_{PRD}$
nsRR	[0,0.3)	5.51	8.52+54.63%	8.18+48.46%	6.96+26.32%
	[0.3,0.6)	7.18	8.7+21.17%	9.19+27.99%	7.84+9.19%
	[0.6,~)	9.57	10.62+10.97%	10.01+4.60%	4.83-49.53%
STH	[0,0.3)	8.01	9.32+16.35%	9.12+13.86%	8.86+10.61%
	[0.3,0.6)	8.4	9.13+8.69%	9.12+8.57%	9.4+11.90%
	[0.6,~)	8.78	9.4+7.06%	8.95+1.94%	9.43+7.40%
LWP	[0,0.3)	837.42	1617.55+93.16%	1518.3+81.31%	1433.93+71.23%
	[0.3,0.6)	1131.53	1710.78+51.19%	1734.55+53.29%	1509.09+33.37%
	[0.6,~)	1497.77	1996.99+33.33%	1881.02+25.59%	1108.61-25.98%
IWP	[0,0.3)	537.51	597.32+11.13%	440.41-18.06%	348.23-35.21%
	[0.3,0.6)	560.09	443.33-20.85%	466.95-16.63%	420.32-24.95%
	[0.6,~)	732.25	582.72-20.42%	414.45-43.40%	524.35-28.39%
PEI	[0,0.3)	3.92	3.24-17.35%	3.6-8.16%	3.45-11.99%
	[0.3,0.6)	3.95	3.39-14.18%	3.6-8.86%	3.36-14.94%
	[0.6,~)	3.89	3.44-11.57%	3.65-6.17%	3.09-20.57%

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Table S2. Normalized regional differences in convective precipitation during the

autumn season. Units: nsRR (mm/h), STH (km), LWP (g/m^2), IWP (g/m^2).

	AOD	BTH	YRD DIFF$_{YRD}$	YRM DIFF$_{YRM}$	PRD DIFF$_{PRD}$
nsRR	[0,0.3)	4.44	9.74+119.37%	7.2+62.16%	8.65+94.82%
	[0.3,0.6)	2.94	5.82+97.96%	7.87+167.69%	11.01+274.49%
	[0.6,~)	8.71	7.43-14.70%	9.58+9.99%	11.77+35.13%
STH	[0,0.3)	7.19	8.04+11.82%	8.46+17.66%	8.97+24.76%
	[0.3,0.6)	6.38	7.17+12.38%	8.24+29.15%	9.37+46.87%
	[0.6,~)	6.95	7.55+8.63%	8.31+19.57%	9.31+33.96%
LWP	[0,0.3)	613.46	1945.93+217.21%	1343.45+119.00%	1783.24+190.69%
	[0.3,0.6)	446.46	1207.72+170.51%	1431.84+220.71%	2011.4+350.52%
	[0.6,~)	1300.85	1479.28+13.72%	1799.07+38.30%	2083.57+60.17%
IWP	[0,0.3)	557.81	320.01-42.63%	281.88-49.47%	345.1-38.13%
	[0.3,0.6)	288.79	183.05-36.61%	331.64+14.84%	463.88+60.63%
	[0.6,~)	401.83	205.51-48.86%	371.5-7.55%	371.91-7.45%
PEI	[0,0.3)	3.78	3.82+1.06%	3.77-0.26%	3.57-5.56%
	[0.3,0.6)	3.82	3.56-6.81%	3.86+1.05%	3.54-7.33%
	[0.6,~)	4.48	3.82-14.73%	3.88-13.39%	3.61-19.42%

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Table S3. Normalized regional differences in stratiform precipitation during the

spring season. Units: nsRR (mm/h), STH (km), LWP (g/m^2), IWP (g/m^2).

	AOD	BTH	YRD DIFF$_{YRD}$	YRM DIFF$_{YRM}$	PRD DIFF$_{PRD}$
nsRR	[0,0.3)	0.93	1.36+46.24%	1.46+56.99%	3.05+227.96%
	[0.3,0.6)	1	1.62+62.00%	1.58+58.00%	2.42+142.00%
	[0.6,~)	1.3	1.94+49.23%	1.79+37.69%	2.38+83.08%
STH	[0,0.3)	4.96	6.36+28.23%	6.61+33.27%	8.85+78.43%
	[0.3,0.6)	5.06	6.21+22.73%	6.12+20.95%	8.23+62.65%
	[0.6,~)	5.09	6.13+20.43%	6.19+21.61%	6.59+29.47%
LWP	[0,0.3)	95.98	333.27+247.23%	315.85+229.08%	690.6+619.52%
	[0.3,0.6)	110.85	356.54+221.64%	289.78+161.42%	574.41+418.19%
	[0.6,~)	183.89	390.26+112.22%	339.58+84.66%	482.9+162.60%
IWP	[0,0.3)	144.8	209.34+44.57%	210.08+45.08%	446.22+208.16%
	[0.3,0.6)	153.29	210.26+37.16%	197.12+28.59%	369.52+141.06%
	[0.6,~)	191.16	245.43+28.39%	217.98+14.03%	256.4+34.13%
PEI	[0,0.3)	4.02	2.49-38.06%	2.86-28.86%	2.29-43.03%
	[0.3,0.6)	4.02	2.74-31.84%	3.3-17.91%	2.34-41.79%
	[0.6,~)	3.79	2.92-22.96%	3.24-14.51%	2.85-24.80%

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26 **Table S4.** Normalized regional differences in stratiform precipitation during the

27 summer season. Units: nsRR (mm/h), STH (km), LWP (g/m^2), IWP (g/m^2).

	AOD	BTH	YRD DIFF$_{YRD}$	YRM DIFF$_{YRM}$	PRD DIFF$_{PRD}$
nsRR	[0,0.3)	1.22	2.02+65.57%	1.86+52.46%	1.61+31.97%
	[0.3,0.6)	1.49	2+34.23%	1.94+30.20%	2.01+34.90%
	[0.6,~)	1.7	2.19+28.82%	1.92+12.94%	1.73+1.76%
STH	[0,0.3)	6.54	7.54+15.29%	7.51+14.83%	7.97+21.87%
	[0.3,0.6)	6.8	7.52+10.59%	7.45+9.56%	8.11+19.26%
	[0.6,~)	6.84	7.61+11.26%	7.18+4.97%	8.05+17.69%
LWP	[0,0.3)	257.08	506.57+97.05%	427.8+66.41%	427.38+66.24%
	[0.3,0.6)	315.9	500.38+58.40%	452.6+43.27%	515.3+63.12%
	[0.6,~)	360.3	538.54+49.47%	455.06+26.30%	434.75+20.66%
IWP	[0,0.3)	182.12	279.9+53.69%	242.59+33.20%	250.67+37.64%
	[0.3,0.6)	228.45	276.69+21.12%	243.63+6.64%	293.8+28.61%
	[0.6,~)	264.35	268.24+1.47%	223.43-15.48%	272.26+2.99%
PEI	[0,0.3)	2.91	2.31-20.62%	2.62-9.97%	2.31-20.62%
	[0.3,0.6)	2.66	2.34-12.03%	2.59-2.63%	2.28-14.29%
	[0.6,~)	2.63	2.43-7.60%	2.55-3.04%	2.34-11.03%

28 **Table S5.** Normalized regional differences in stratiform precipitation during the

29 autumn season. Units: nsRR (mm/h), STH (km), LWP (g/m^2), IWP (g/m^2).

	AOD	BTH	YRD DIFF$_{YRD}$	YRM DIFF$_{YRM}$	PRD DIFF$_{PRD}$
nsRR	[0,0.3)	1.08	1.7+57.41%	1.6+48.15%	3.41+215.74%
	[0.3,0.6)	0.98	1.69+72.45%	1.74+77.55%	2.83+188.78%
	[0.6,~)	1.43	1.78+24.48%	1.88+31.47%	3.59+151.05%
STH	[0,0.3)	6.05	7.03+16.20%	6.85+13.22%	8.1+33.88%
	[0.3,0.6)	5.83	6.72+15.27%	6.9+18.35%	8.04+37.91%
	[0.6,~)	5.68	6.96+22.54%	6.9+21.48%	8.03+41.37%
LWP	[0,0.3)	198.21	411.77+107.74%	351.75+77.46%	780.62+293.83%
	[0.3,0.6)	199.89	415.63+107.93%	382.88+91.55%	660.45+230.41%
	[0.6,~)	186.38	439.71+135.92%	418.06+124.31%	812.36+335.86%
IWP	[0,0.3)	236.27	208.2-11.88%	203.79-13.75%	373.67+58.15%
	[0.3,0.6)	155.5	199.16+28.08%	208.03+33.78%	331.96+113.48%
	[0.6,~)	186.38	223.12+19.71%	224.35+20.37%	360.32+93.33%
PEI	[0,0.3)	2.8	2.51-10.36%	2.86+2.14%	2.53-9.64%
	[0.3,0.6)	2.82	2.57-8.87%	2.86+1.42%	2.36-16.31%
	[0.6,~)	3.1	2.52-18.71%	2.86-7.74%	2.73-11.94%

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Table S6. Normalized seasonal differences in convective precipitation during the summer season. Units: nsRR (mm/h), STH (km), LWP (g/m^2), IWP (g/m^2).

	AOD	BTH DIFF$_{summer}$	YRD DIFF$_{summer}$	YRM DIFF$_{summer}$	PRD DIFF$_{summer}$	BTH DIFF$_{autumn}$	YRD DIFF$_{autumn}$	YRM DIFF$_{autumn}$	PRD DIFF$_{autumn}$
nsRR	[0,0.3)	5.51+83.67%	8.52+101.42%	8.18-21.50%	6.96-67.48%	4.44+48.00%	9.74+130.26%	7.2-30.90%	8.65-59.58%
	[0.3,0.6)	7.18+122.29%	8.7-4.40%	9.19+18.58%	7.84-33.33%	2.94-8.98%	5.82-36.04%	7.87+1.55%	11.01-6.38%
	[0.6,~)	9.57+54.60%	10.62+6.09%	10.01+8.10%	4.83-69.47%	8.71+40.71%	7.43-25.77%	9.58+3.46%	11.77-25.60%
STH	[0,0.3)	8.01+14.59%	9.32+33.72%	9.12+2.82%	8.86-14.40%	7.19+2.86%	8.04+15.35%	8.46-4.62%	8.97-13.33%
	[0.3,0.6)	8.4+23.71%	9.13+22.39%	9.12+14.00%	9.4-3.89%	6.38-6.04%	7.17-3.89%	8.24+3.00%	9.37-4.19%
	[0.6,~)	8.78+22.45%	9.4+26.34%	8.95+12.86%	9.43+5.60%	6.95-3.07%	7.55+1.48%	8.31+4.79%	9.31+4.26%
LWP	[0,0.3)	837.42+135.82%	1617.55+81.25%	1518.3-4.72%	1433.93-59.05%	613.46+72.75%	1945.93+118.05%	1343.45-15.70%	1783.24-49.08%
	[0.3,0.6)	1131.53+172.94%	1710.78+5.41%	1734.55+39.56%	1509.09-25.29%	446.46+7.69%	1207.72-25.59%	1431.84+15.20%	2011.4-0.42%
	[0.6,~)	1497.77+95.79%	1996.99+21.83%	1881.02+32.90%	1108.61-53.96%	1300.85+70.05%	1479.28-9.76%	1799.07+27.11%	2083.57-13.47%
IWP	[0,0.3)	537.51-8.06%	597.32+199.98%	440.41-26.15%	348.23-56.50%	557.81-4.58%	320.01+60.71%	281.88-52.73%	345.1-56.89%
	[0.3,0.6)	560.09+20.05%	443.33+38.92%	466.95+22.48%	420.32-23.88%	288.79-38.10%	183.05-42.64%	331.64-13.01%	463.88-15.99%
	[0.6,~)	732.25+41.16%	582.72+60.88%	414.45-1.20%	524.35-23.48%	401.83-22.53%	205.51-43.26%	371.5-11.44%	371.91-45.73%
PEI	[0,0.3)	3.92+5.95%	3.24-7.16%	3.6-10.22%	3.45-17.27%	3.78+2.16%	3.82+9.46%	3.77-5.99%	3.57-14.39%
	[0.3,0.6)	3.95-1.50%	3.39-13.08%	3.6-14.49%	3.36-10.40%	3.82-4.74%	3.56-8.72%	3.86-8.31%	3.54-5.60%
	[0.6,~)	3.89-15.62%	3.44-19.44%	3.65-16.48%	3.09-28.64%	4.48-2.82%	3.82-10.54%	3.88-11.21%	3.61-16.63%

Table S7. Normalized seasonal differences in stratiform precipitation during the summer season. Units: nsRR (mm/h), STH (km), LWP (g/m^2), IWP (g/m^2).

	AOD	BTH DIFF$_{summer}$	YRD DIFF$_{summer}$	YRM DIFF$_{summer}$	PRD DIFF$_{summer}$	BTH DIFF$_{autumn}$	YRD DIFF$_{autumn}$	YRM DIFF$_{autumn}$	PRD DIFF$_{autumn}$
nsRR	[0,0.3)	1.22+31.18%	2.02+48.53%	1.86+27.40%	1.61-47.21%	1.08+16.13%	1.7+25.00%	1.6+9.59%	3.41+11.80%
	[0.3,0.6)	1.49+49.00%	2+23.46%	1.94+22.78%	2.01-16.94%	0.98-2.00%	1.69+4.32%	1.74+10.13%	2.83+16.94%
	[0.6,~)	1.7+30.77%	2.19+12.89%	1.92+7.26%	1.73-27.31%	1.43+10.00%	1.78-8.25%	1.88+5.03%	3.59+50.84%
STH	[0,0.3)	6.54+31.85%	7.54+18.55%	7.51+13.62%	7.97-9.94%	6.05+21.98%	7.03+10.53%	6.85+3.63%	8.1-8.47%
	[0.3,0.6)	6.8+34.39%	7.52+21.10%	7.45+21.73%	8.11-1.46%	5.83+15.22%	6.72+8.21%	6.9+12.75%	8.04-2.31%
	[0.6,~)	6.84+34.38%	7.61+24.14%	7.18+15.99%	8.05+22.15%	5.68+11.59%	6.96+13.54%	6.9+11.47%	8.03+21.85%
LWP	[0,0.3)	257.08+167.85%	506.57+52.00%	427.8+35.44%	427.38-38.11%	198.21+106.51%	411.77+23.55%	351.75+11.37%	780.62+13.04%
	[0.3,0.6)	315.9+184.98%	500.38+40.34%	452.6+56.19%	515.3-10.29%	199.89+80.32%	415.63+16.57%	382.88+32.13%	660.45+14.98%
	[0.6,~)	360.3+95.93%	538.54+38.00%	455.06+34.01%	434.75-9.97%	186.38+1.35%	439.71+12.67%	418.06+23.11%	812.36+68.23%
IWP	[0,0.3)	182.12+25.77%	279.9+33.71%	242.59+15.48%	250.67-43.82%	236.27+63.17%	208.2-0.54%	203.79-2.99%	373.67-16.26%
	[0.3,0.6)	228.45+49.03%	276.69+31.59%	243.63+23.59%	293.8-20.49%	155.5+1.44%	199.16-5.28%	208.03+5.53%	331.96-10.16%
	[0.6,~)	264.35+38.29%	268.24+9.29%	223.43+2.50%	272.26+6.19%	186.38-2.50%	223.12-9.09%	224.35+2.92%	360.32+40.53%
PEI	[0,0.3)	2.91-27.61%	2.31-7.23%	2.62-8.39%	2.31+0.87%	2.8-30.35%	2.51+0.80%	2.86+0.00%	2.53+10.48%
	[0.3,0.6)	2.66-33.83%	2.34-14.60%	2.59-21.52%	2.28-2.56%	2.82-29.85%	2.57-6.20%	2.86-13.33%	2.36+0.85%
	[0.6,~)	2.63-30.61%	2.43-16.78%	2.55-21.30%	2.34-17.89%	3.1-18.21%	2.52-13.70%	2.86-11.73%	2.73-4.21%
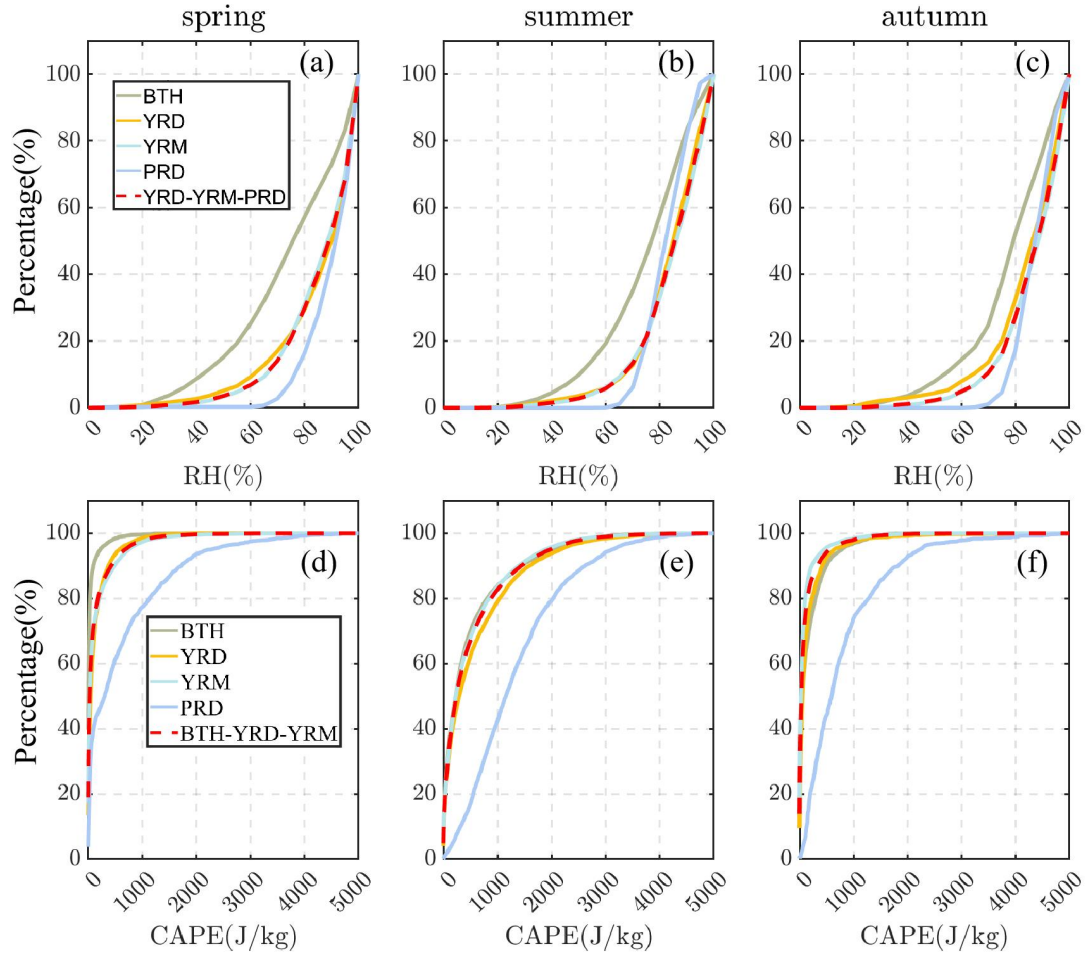
Fig. S1. Cumulative Distribution Functions (CDFs) of RH and CAPE for different regions in the three seasons. The gray-green curve represents the BTH, yellow-YRD, green-YRM, and blue-PRD. For RH (a-c), the red dashed line shows the CDF after merging data from YRD, YRM, and PRD; for CAPE (d-f), the red dashed line shows the CDF after merging data from BTH, YRD, and YRM.
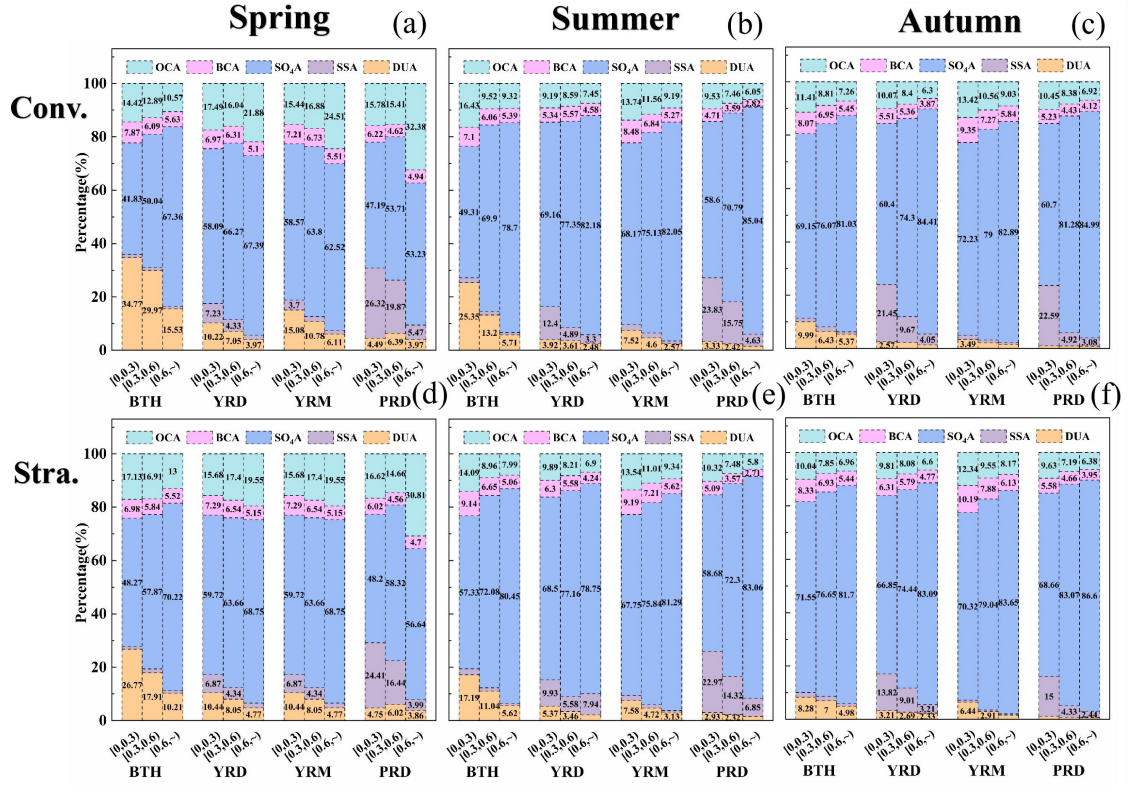
Fig. S2. Proportion of AOD in convective precipitation and stratiform precipitation under different AOD loads in spring, summer, and autumn in the four regions.
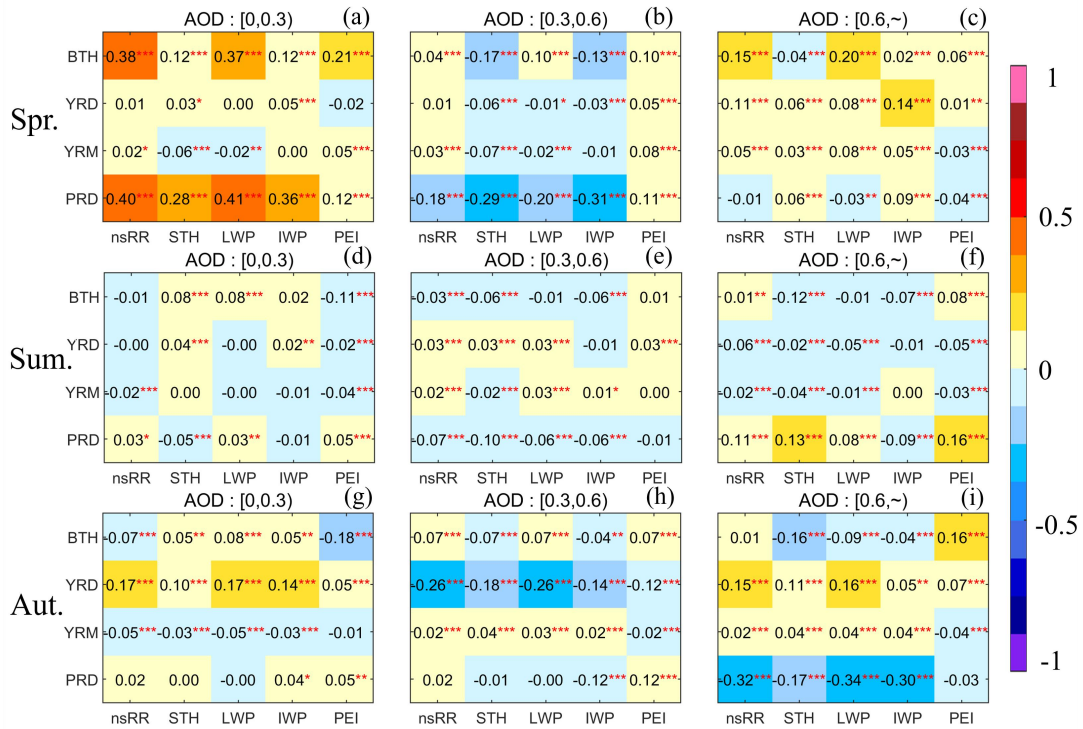
Fig. S3. Spearman correlation coefficients between AOD and precipitation parameters (nsRR, STH, LWP, IWP, and PEI) for stratiform precipitation across regions and seasons under three AOD regimes. The form of this expression is similar to that shown in Figure 2.
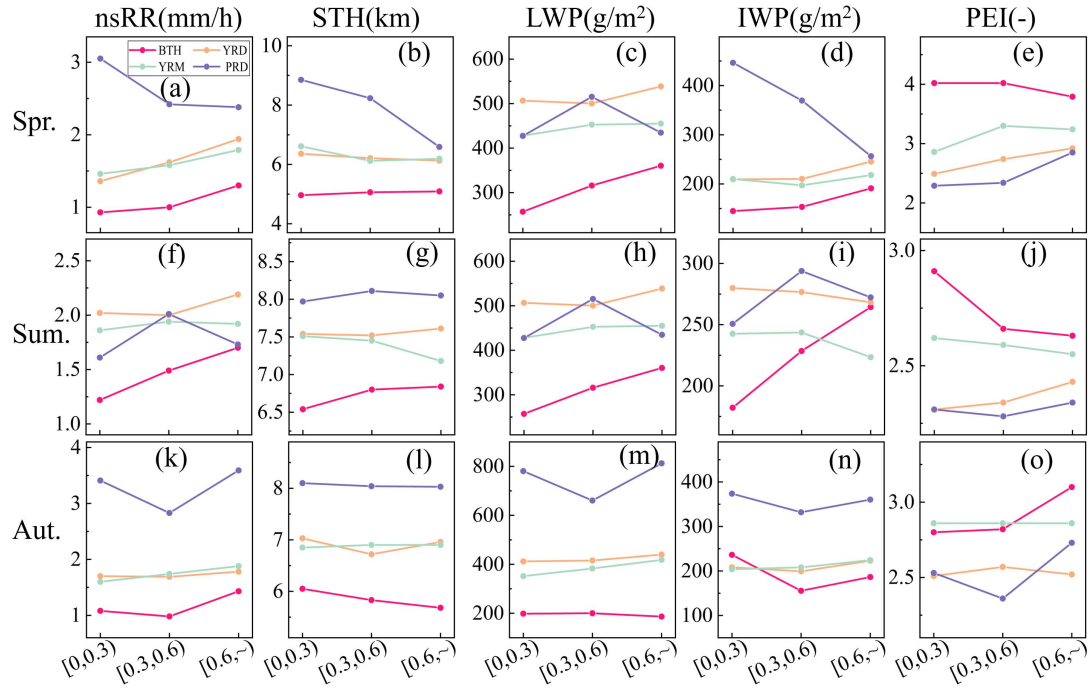
Fig. S4. Average point line plots of nsRR, STH, LWP, IWP, and PEI under the three AOD conditions for stratiform precipitation across various regions and seasons. The form of the expression is similar to that shown in Fig. 3.
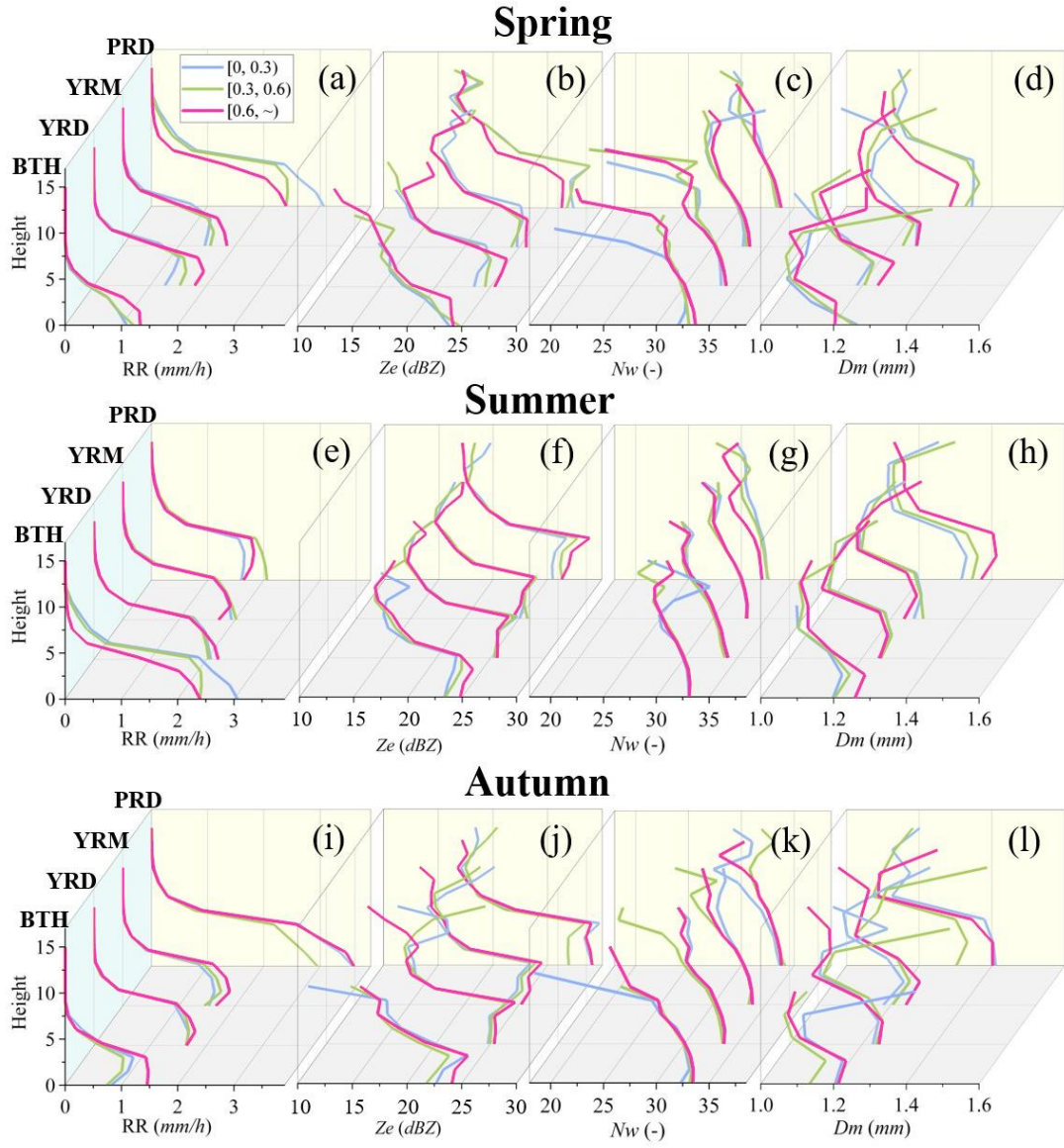
Fig .S5. Vertical profiles of the average stratiform precipitation parameters Z_e, D_m, N_w, and RR for different regions in different seasons under three AOD conditions. The form of this expression is similar to that shown in Fig. 4.
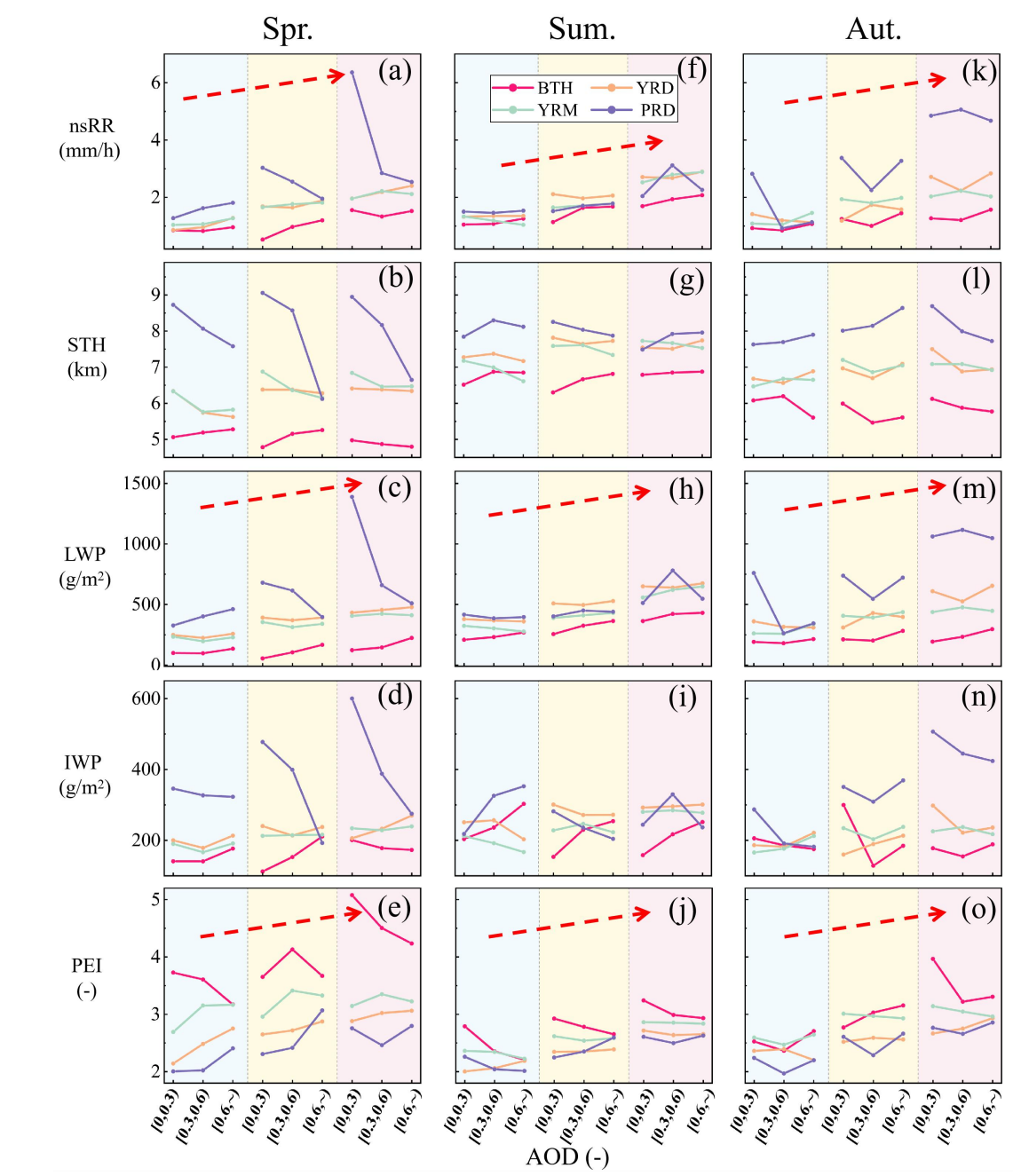
Fig. S6. Point-line graphs of mean values for stratiform precipitation parameters across seasons and regions. The analysis is based on three AOD intervals and various RH scenarios. The form of this expression is similar to that shown in Fig. 6.
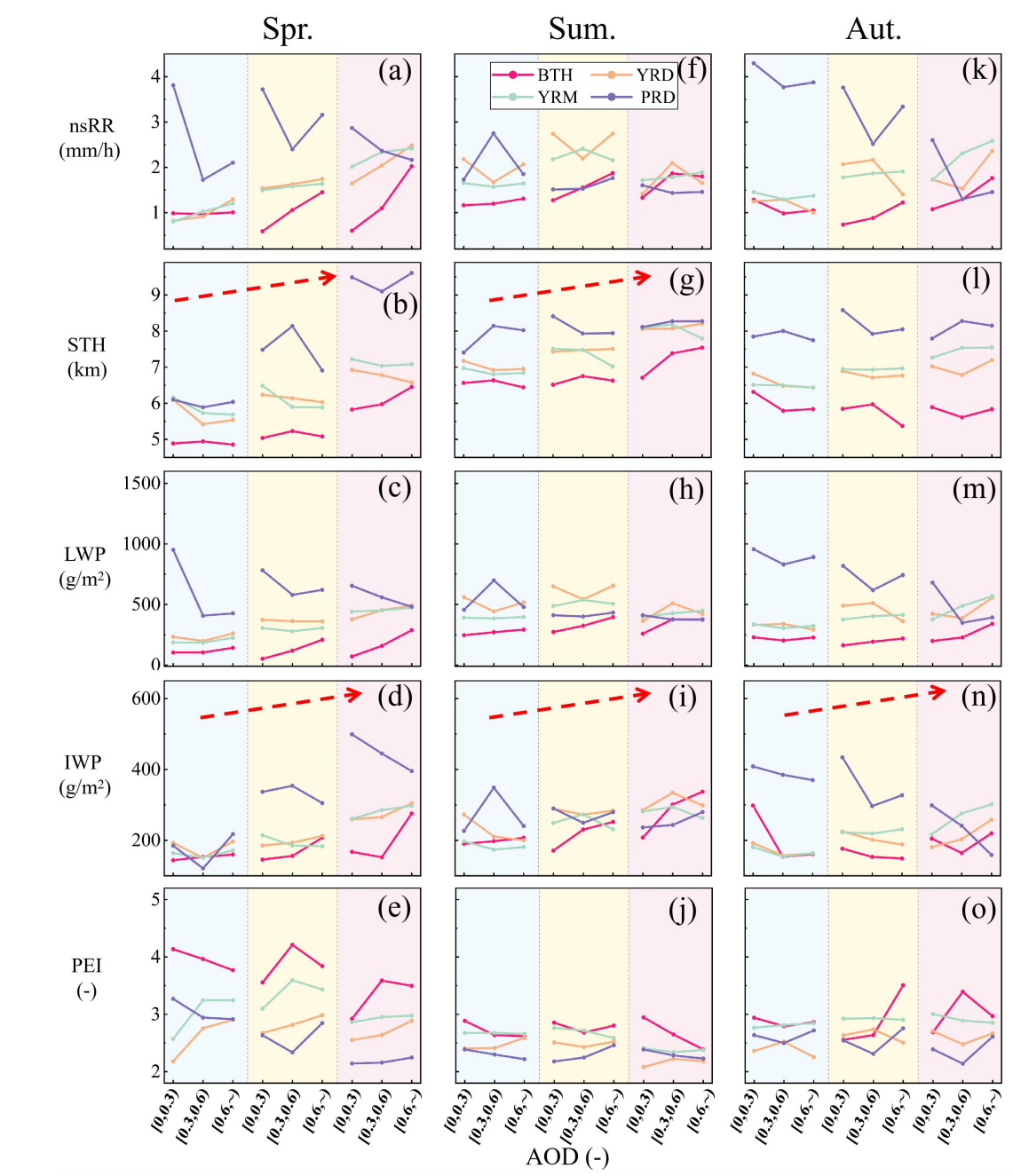
Fig. S7. Point-line graphs of mean values for stratiform precipitation parameters across seasons and regions. The analysis is based on three AOD intervals and the CAPE scenarios. The form of expression is similar to Fig. 6.
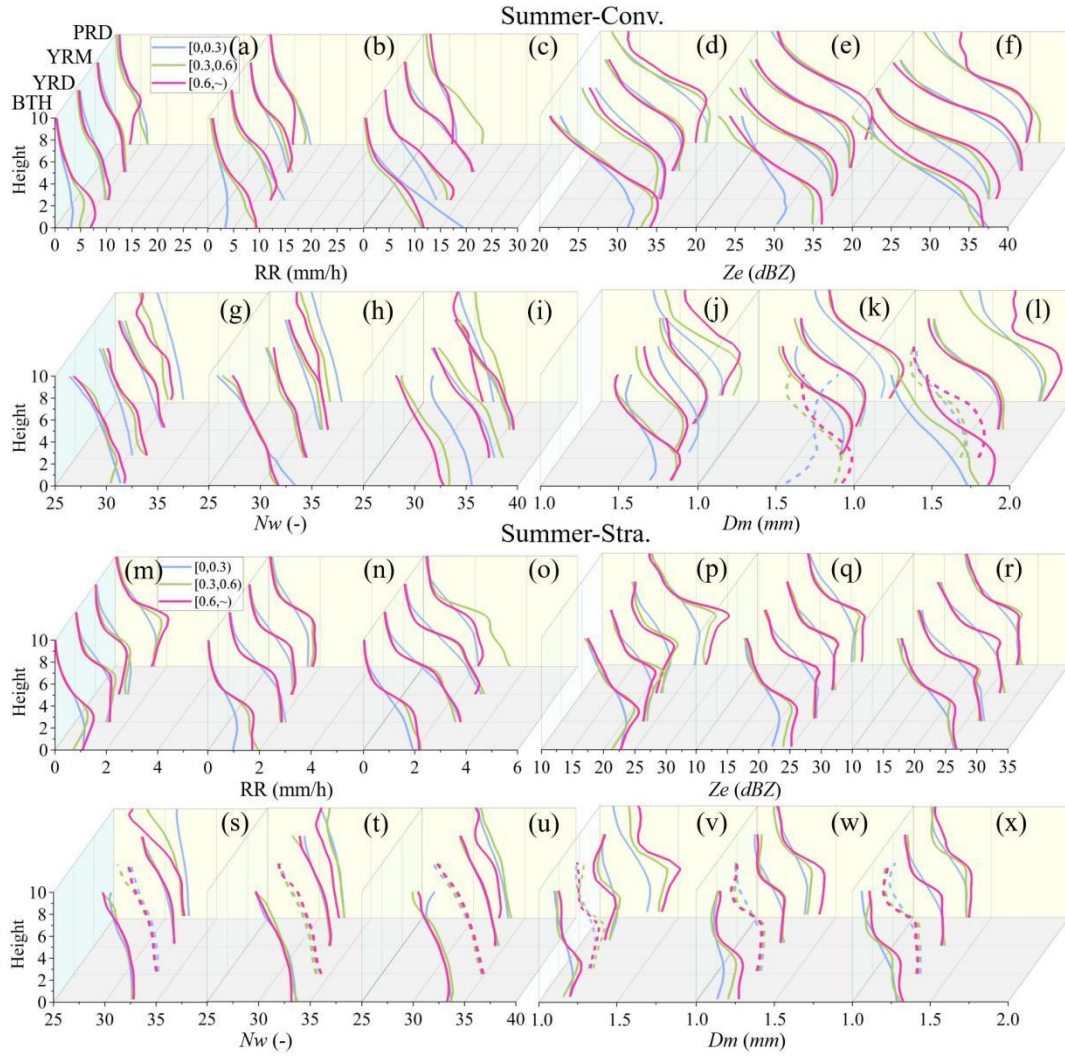
Fig. S8. Vertical profiles of mean precipitation parameters for convective and stratiform precipitation in summer across the four regions. The profiles are shown for the three AOD scenarios and RH conditions. The form of this expression is similar to that shown in Fig. 8.
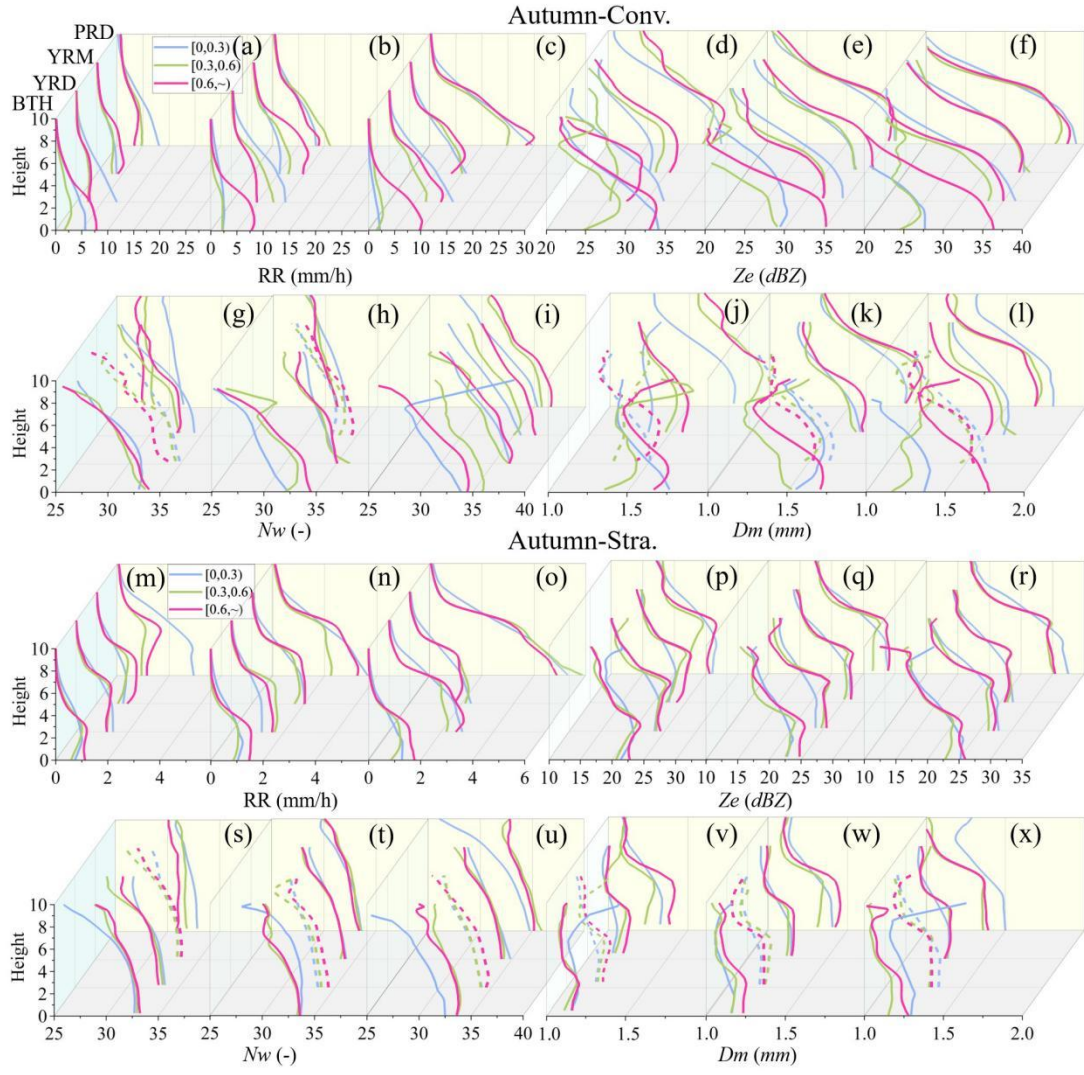
Fig. S9. It is similar to that shown in Fig. 8 but in in autumn across the four regions.
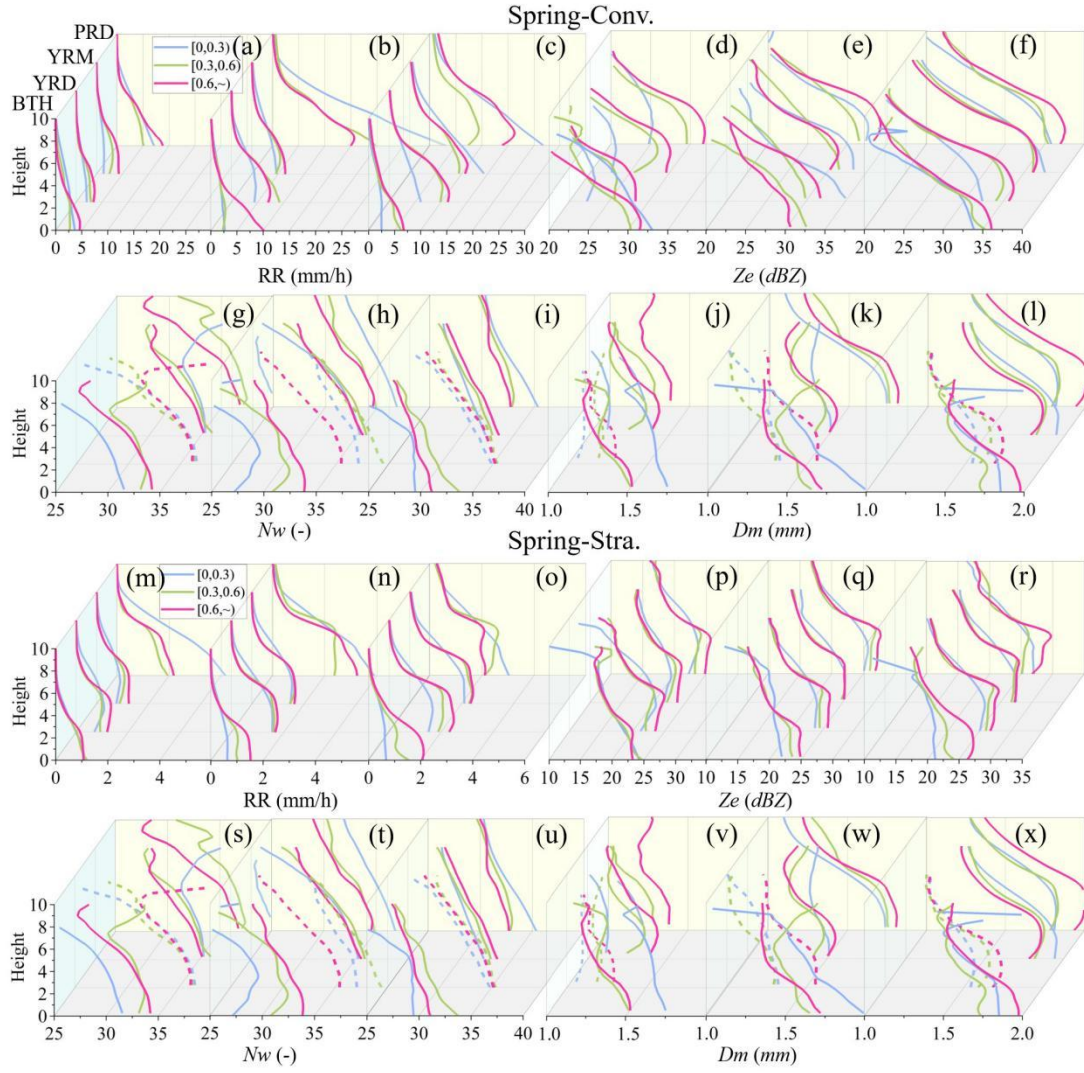
Fig. S10. Vertical profiles of mean precipitation parameters for convective and stratiform precipitation in spring across the four regions. The profiles are shown for the three AOD and CAPE scenarios. The form of this expression is similar to that shown in Fig. 8.
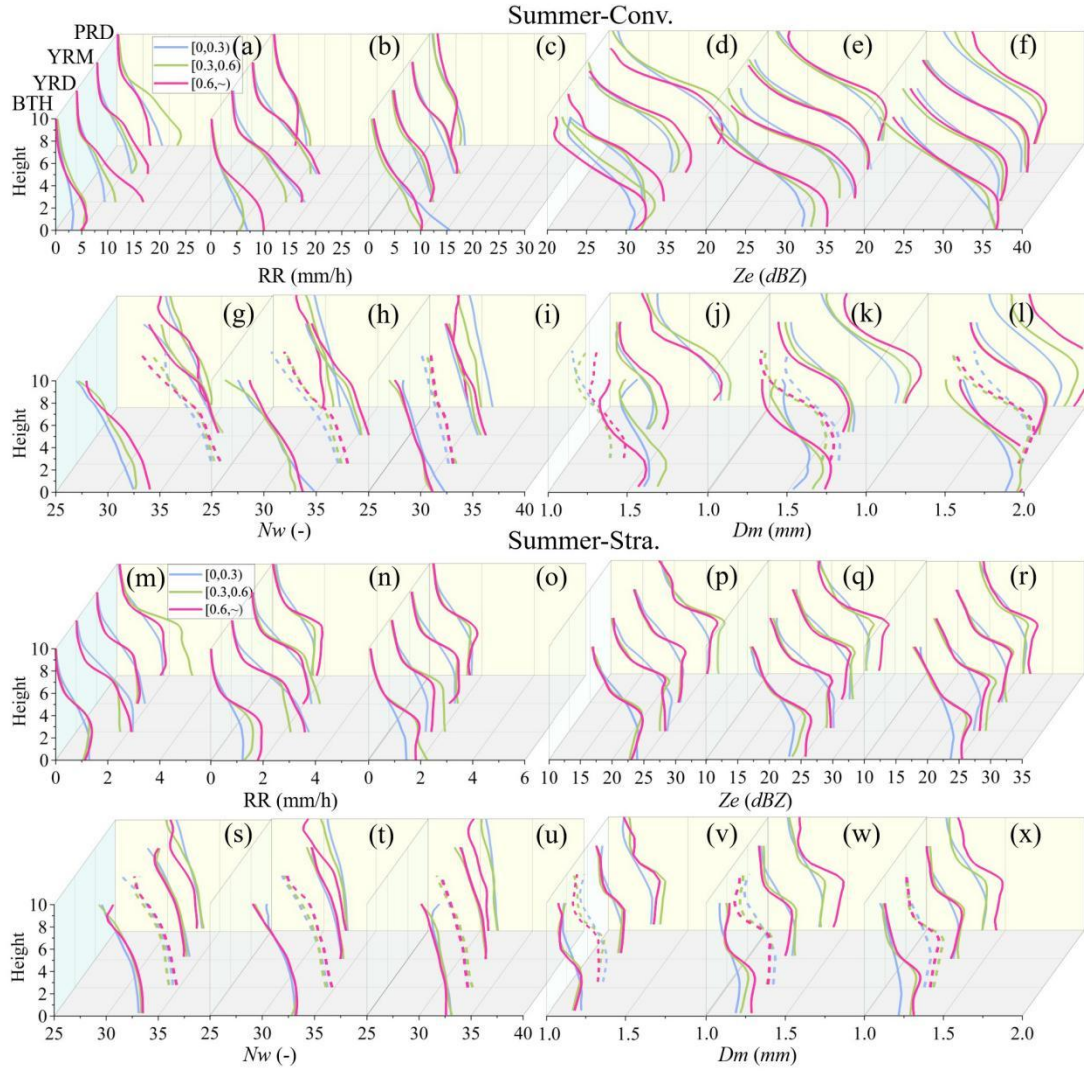
Fig. S11. Vertical profiles of mean precipitation parameters for convective and stratiform precipitation in summer across four regions. The profiles are shown under three AOD scenarios and CAPE conditions. as solid lines. The form of this expression is similar to that shown in Fig. 8.
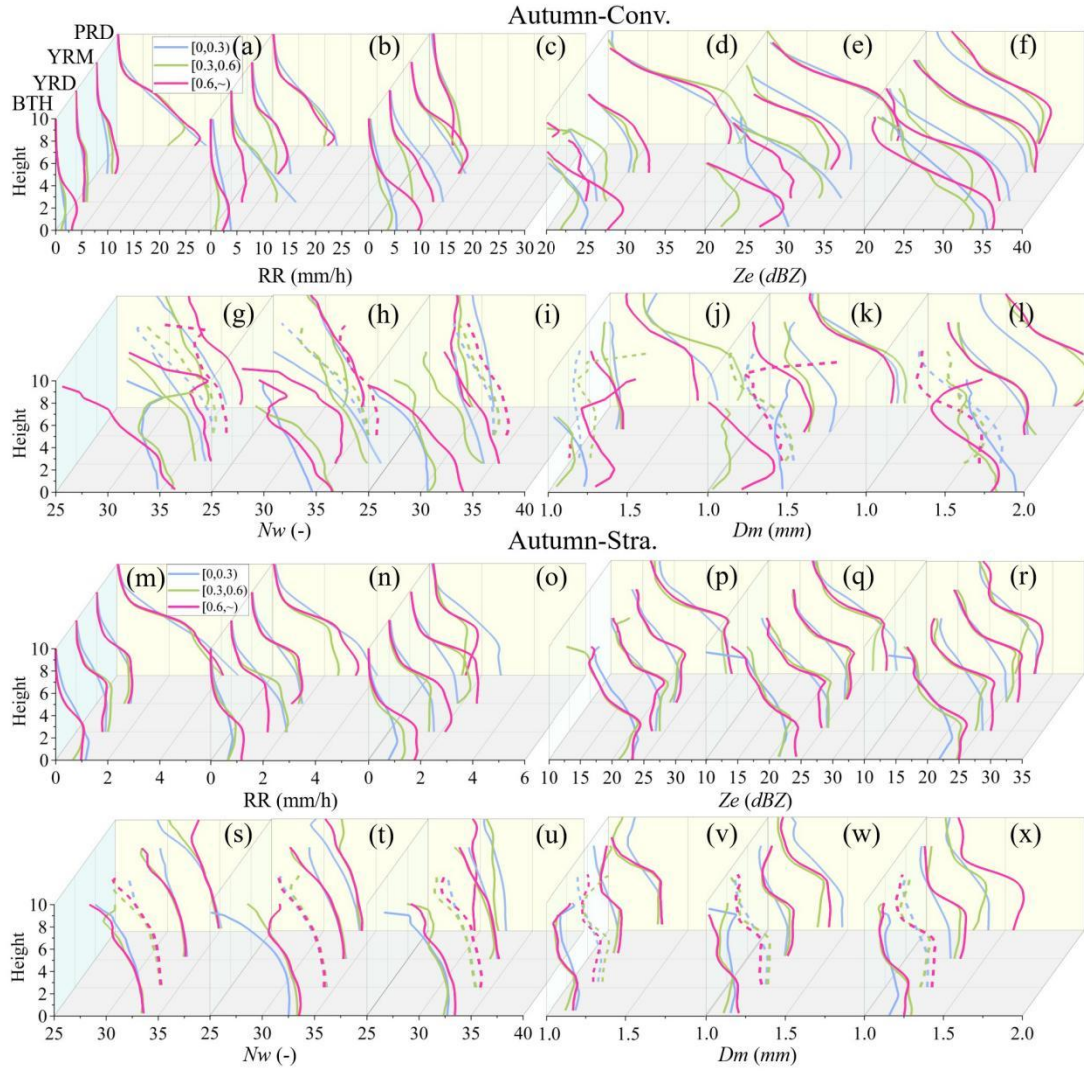
Fig. S12. Vertical profiles of mean precipitation parameters for convective and stratiform precipitation in autumn across four regions. The profiles are shown under three AOD scenarios and CAPE conditions. as solid lines. The form of this expression is similar to that shown in Fig. 8.
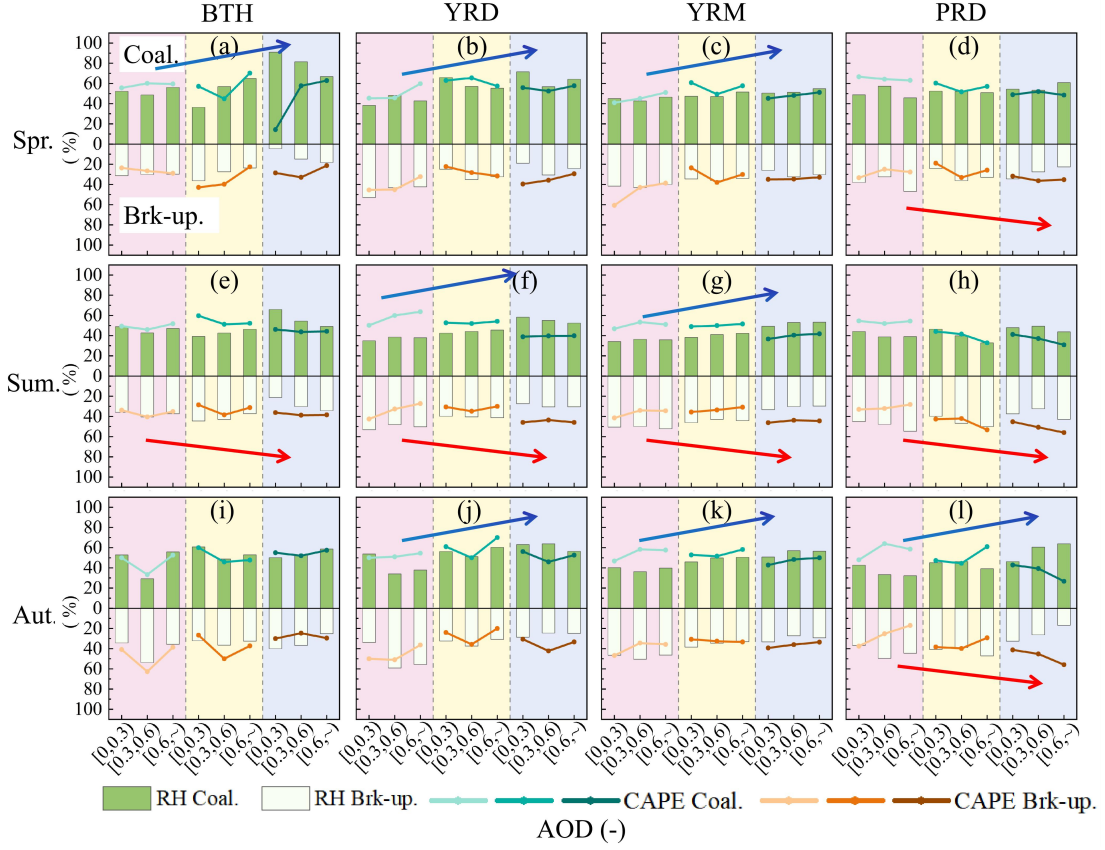
Fig. S13. Convective precipitation coalescence and break-up processes under varying RH and CAPE conditions in spring (a–d), summer (e–h), and autumn (i–l) across regions sorted by AOD loading. Each subpanel is split as follows: upper for the coalescence proportion and lower for the break-up proportion. The bar charts show RH variations under different AODs, and the line charts show CAPE variations. Meteorological conditions (left to right): low (pink background), medium (yellow background), and high (blue background) RH, and CAPE. The blue arrows indicate increasing coalescence proportions as RH rises, whereas the red arrows denote growing break-up proportions with enhanced CAPE.
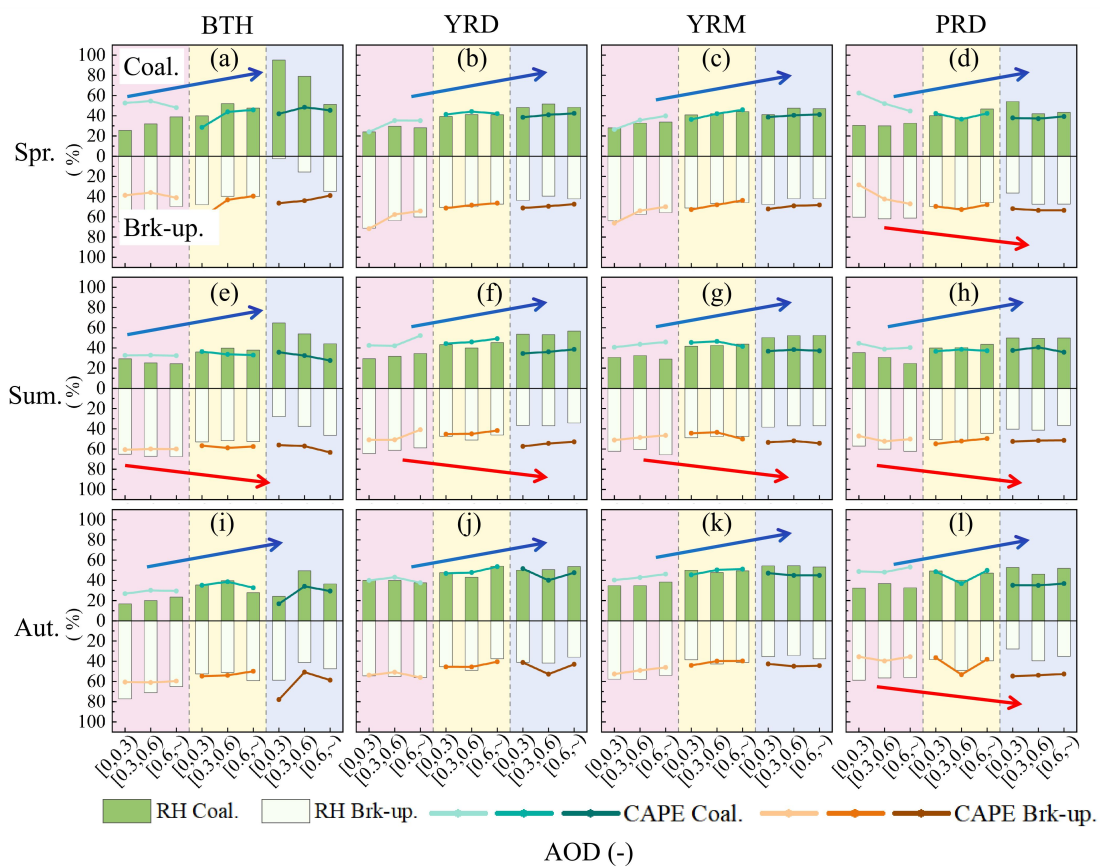
Fig. S14. Stratiform precipitation coalescence and break-up processes under varying RH and CAPE conditions in spring (a–d), summer (e–h), and autumn (i–l) across regions sorted by AOD loading. The form of this expression is similar to that shown in Fig. S13.