Supporting Information

Table S1. Definitions and physical meanings of cloud macrophysical characteristics taken from CloudSat data in this study.

Abbreviation	Full name	Unit	Definition	Physical Meaning
CTH	Cloud Top Height	km	It is referred to as the height of the cloud top above sea level.	It can provide information about the vertical structure of clouds.
CBH	Cloud Base Height	km	It is referred to as the height of the cloud base above sea level.	It can provide information about the vertical structure of clouds and determine atmospheric stability.
CT	Cloud Thickness	km	It is the difference between CTH and CBH.	It can indicate the amount of water vapor in the cloud and the intensity of convection.
CF	Cloud Fraction	%	It is the percentage of each gridbox that is covered with clouds.	It can be used to describe how much of the sky is covered by clouds in a certain location or area.

Table S2. Definitions and physical meanings of cloud microphysical characteristics taken from CloudSat data in this study.

Abbreviation	Full name	Unit	Definition	Physical Meaning
IER	Ice particle Effective Radius	μm	It is defined as the ratio of the third moment of the ice particle size distribution to the second moment, averaged over a layer of clouds.	It is a representation of the ice particle size distribution of clouds.
LER	Liquid droplet Effective Radius	μm	Similar to IER's definition, but for liquid droplets.	It is a representation of the liquid droplet size distribution of clouds.
INC	Ice particle Number Concentration	L^{-1}	It refers to the number of ice particles contained within a unit volume of air.	It can help describe the concentration and distribution of ice particles in clouds.
LNC	Liquid droplet Number	cm^{-3}	Similar to INC's definition, but for liquid	It can help describe the concentration and

	Concentration		droplets.	distribution of liquid droplets in clouds.
IWP	Ice Water Path	g m^{-2}	It refers to the total mass of ice water contained within a vertical column of the atmosphere extending from the Earth's surface to the top of a cloud, per unit area.	It reflects the concentration level of ice-phase water within a vertical columnar region.
LWP	Liquid Water Path	g m^{-2}	Similar to IWP's definition, but for liquid water.	It reflects the concentration level of liquid-phase water within a vertical columnar region.

Table S3. Definitions and physical meanings of meteorological factors taken from ERA5 data in this study.

Abbreviation	Full name	Unit	Definition	Physical Meaning
U	U-component of wind	m s^{-1}	It is the eastward component of the wind.	It is the horizontal speed of air moving towards the east, a negative sign indicates air moving towards the west.
V	V-component of wind	m s^{-1}	It is the northward component of the wind.	It is the horizontal speed of air moving towards the north, a negative sign indicates air moving towards the south.
PVV	Pressure Vertical Velocity	Pa s^{-1}	It is the speed of air motion in the upward or downward direction. The ECMWF Integrated Forecasting System (IFS) uses a pressure based vertical coordinate system and pressure decreases with height, therefore negative values of vertical velocity indicate upward motion.	It can be useful to understand the large-scale dynamics of the atmosphere, including areas of upward motion/ascent (negative values) and downward motion/subsidence (positive values).
T	Temperature	K	It is the temperature in the atmosphere.	It is a measure of temperature at different levels of the Earth's

				atmosphere.
RH	Relative Humidity	%	It is the water vapour pressure as a percentage of the value at which the air becomes saturated.	It is a measure of how much water vapor is in a water-air mixture compared to the maximum amount possible.
PWV	Precipitable Water Vapor	kg m^{-2}	It is defined as the total water vapor in the vertical atmospheric column above the ground.	It serves as a measure of atmospheric moisture, higher values indicate more moisture.
CAPE	Convective Available Potential Energy	J kg^{-1}	In the ECMWF IFS, CAPE is calculated by considering parcels of air departing at different model levels below the 350 hPa level. If a parcel of air is more buoyant (warmer and/or with more moisture) than its surrounding environment, it will continue to rise (cooling as it rises) until it reaches a point where it no longer has positive buoyancy. CAPE is the potential energy represented by the total excess buoyancy.	It measures the atmospheric stratification's instability, higher CAPE values signify greater instability.
SP	Surface Pressure	Pa	It is the pressure (force per unit area) of the atmosphere at the surface of land, sea and inland water.	It is a measure of the weight of all the air in a column vertically above a point on the Earth's surface.

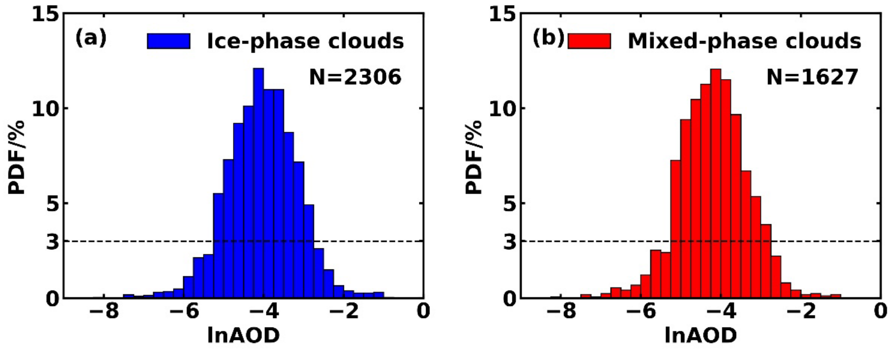

Figure S1. During the nighttime of MAM and JJA over the Tibetan Plateau, the histogram of the Probability Density Function (PDF) for the logarithm of Aerosol Optical Depth (lnAOD) for single-layer non-precipitating (a) ice phase clouds, (b) mixed phase clouds based on CALIPSO data, N represents the total sample number in the figure.

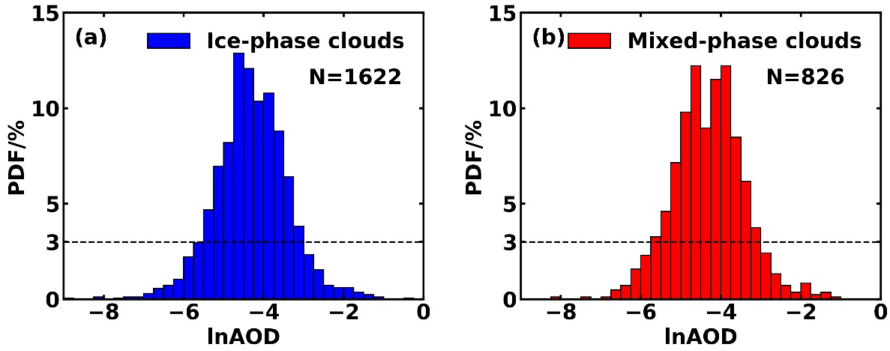

Figure S2. During the nighttime of SON and DJF over the Tibetan Plateau, the histogram of the Probability Density Function (PDF) for the logarithm of Aerosol Optical Depth (lnAOD) for single-layer non-precipitating (a) ice phase clouds, (b) mixed phase clouds based on CALIPSO data, N represents the total sample number in the figure.

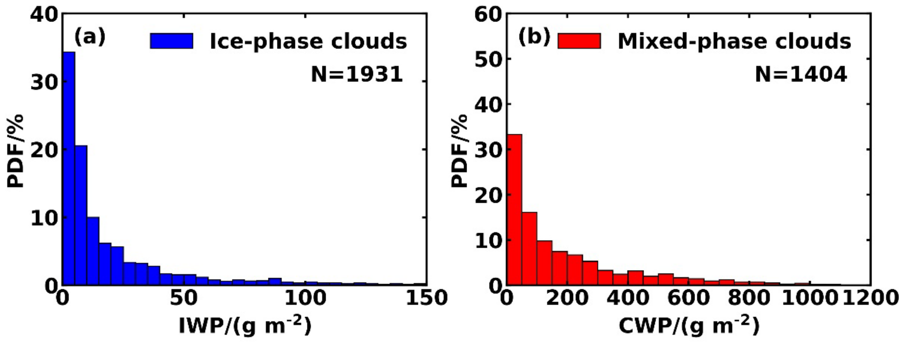

Figure S3. During the nighttime of MAM and JJA over the Tibetan Plateau, the histogram of the Probability Density Function (PDF) for the for the (a) Ice Water Path (IWP) of single-layer non-precipitating ice phase clouds, and (b) Cloud Water Path (CWP) of single-layer non-precipitating mixed phase clouds based on CloudSat data, N represents the total sample number in the figure.

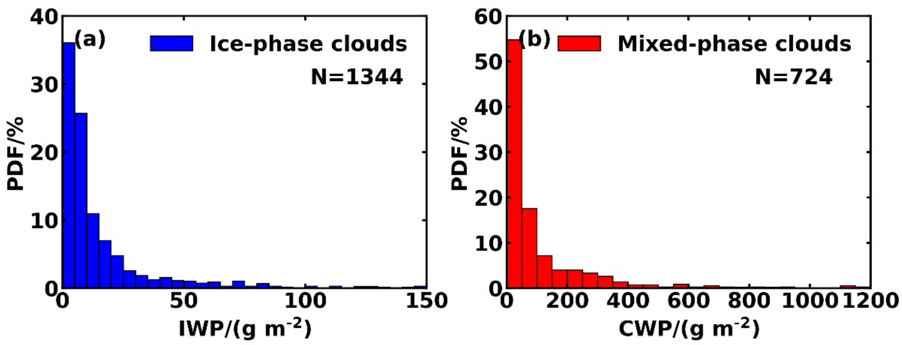

Figure S4. During the nighttime of SON and DJF over the Tibetan Plateau, the histogram of the Probability Density Function (PDF) for the for the (a) Ice Water Path (IWP) of single-layer non-precipitating ice phase clouds, and (b) Cloud Water Path (CWP) of single-layer non-precipitating mixed phase clouds based on CloudSat data, N represents the total sample number in the figure.

Table S4. Equations from piecewise linear fitting of macrophysical cloud characteristics in Figure 4, between the Cloud Top Height (CTH), Cloud Base Height (CBH), Cloud Thickness (CT), Cloud Fraction (CF), and logarithm of Aerosol Optical Depth (lnAOD), under conditions of lnAOD ≤ -4.0 and lnAOD > -4.0, respectively. * indicating passing the 95% significance test.

	Ice-phase clouds		Mixed-phase clouds	
	lnAOD ≤ -4.0	lnAOD > -4.0	lnAOD ≤ -4.0	lnAOD > -4.0
lnAOD-CTH	y = -0.13x + 8.24	y = 0.61x + 11.20*	y = -0.41x + 5.45	y = 0.24x + 8.15
lnAOD-CBH	y = 0.28x + 8.62*	y = 0.31x + 8.70*	y = 0.06x + 6.25	y = 0.01x + 6.18
lnAOD-CT	y = - 0.41x - 0.37*	y = 0.30x + 2.49	y = -0.47x - 0.80*	y = 0.23x + 1.97
lnAOD-CF	y = 0.67x + 26.00	y = 7.90x + 55.10*	y = -7.05x - 17.56*	y = -1.12x + 6.73

Table S5. Similar to Table S4, but for fitting the trends in Figure 5.

	Ice-phase clouds		Mixed-phase clouds	
	lnAOD ≤ -4.0	lnAOD > -4.0	lnAOD ≤ -4.0	lnAOD > -4.0
lnAOD-CTH	y = -0.10x + 7.57	y = 0.45x + 9.69	y = -0.34x + 5.04*	y = 0.28x + 7.57
lnAOD-CBH	y = 0.09x + 7.21	y = 0.11x + 7.23	y = -0.11x + 5.07	y = 0.19x + 6.40
lnAOD-CT	y = -0.19x + 0.37*	y = 0.34x + 2.46	y = -0.22x - 0.03	y = 0.08x + 1.17
lnAOD-CF	y = -0.83x + 22.14	y = 3.61x + 41.26	y = -1.93x + 0.75	y = 7.88x + 38.51*

Table S6. Equations from piecewise linear fitting of microphysical cloud characteristics in Figure 6, between the Ice particle Effective Radius (IER), Ice particle Number Concentration (INC), Ice Water Path (IWP), Liquid droplet Effective Radius (LER), Liquid droplet Number Concentration (LNC), Liquid Water Path (LWP) and logarithm of Aerosol Optical Depth (lnAOD), under conditions of lnAOD ≤ -4.0 and lnAOD > -4.0, respectively. * indicating passing the 95% significance test.

	Ice-phase clouds		Mixed-phase clouds	
	lnAOD ≤ -4.0	lnAOD > -4.0	lnAOD ≤ -4.0	lnAOD > -4.0
lnAOD-IER	y = -2.06x + 44.91*	y = -0.00x + 53.52	y = -1.95x + 46.63*	y = 0.59x + 56.38
lnAOD-INC	y = -2.96x + 10.79*	y = 2.22x + 32.39*	y = -1.90x + 11.36	y = 5.00x + 38.44
lnAOD-IWP	y = -18.54x - 56.89*	y = 17.96x + 90.83	y = -12.33x - 34.98	y = 30.39x + 128.37*
lnAOD-LER			y = -0.49x + 9.92	y = 0.36x + 12.90
lnAOD-LNC			y = -4.35x + 16.47	y = -2.30x + 23.51
lnAOD-LWP			y = -111.11x - 297.99*	y = 33.09x + 267.99

Table S7. Similar to Table S6, but for fitting the trends in Figure 7.

	Ice-phase clouds		Mixed-phase clouds	
	lnAOD ≤ -4.0	lnAOD > -4.0	lnAOD ≤ -4.0	lnAOD > -4.0
lnAOD-IER	y = -1.14x + 47.29	y = 1.05x + 56.14	y = -1.04x + 48.17	y = -0.07x + 51.50
lnAOD-INC	y = -2.30x + 13.15	y = 2.47x + 32.05	y = 0.57x + 22.12	y = 0.84x + 19.95
lnAOD-IWP	y = -3.62x + 3.77	15.40x + 72.48*	y = -0.85x + 9.42	y = -1.02x + 4.49

lnAOD-LER			y = -0.44x + 9.12	y = 0.33x + 11.89
lnAOD-LNC			y = -4.87x + 6.05*	y = 0.29x + 29.11
lnAOD-LWP			y = -59.30x - 166.00*	y = 13.03x + 133.04

Table S8. Equations from piecewise linear fitting of microphysical cloud characteristics in Figure 8, between the Precipitable Water Vapor (PWV), (b) Convective Available Potential Energy (CAPE), (c) Pressure Vertical Velocity (PVV) at 400 (500) hPa for Ice-Phase (Mixed-Phase) clouds and logarithm of Aerosol Optical Depth (lnAOD), under conditions of lnAOD ≤ -4.0 and lnAOD > -4.0, respectively. * indicating passing the 95% significance test.

	Ice-phase clouds		Mixed-phase clouds	
	lnAOD ≤ -4.0	lnAOD > -4.0	lnAOD ≤ -4.0	lnAOD > -4.0
lnAOD-PWV	y = -1.15x + 1.59*	y = 0.28x + 7.07	y = -1.85x - 0.53*	y = 0.18x + 7.63
lnAOD-CAPE	y = -13.54x - 33.25*	y = -1.46x + 19.48	y = -13.51x - 29.03*	y = -0.66x + 26.47
lnAOD-$PVV_{400(500)}$	y = 0.05x + 0.20*	y = 0.02x + 0.06	y = 0.03x + 0.09	y = -0.00x - 0.01

Table S9. Similar to Table S8, but for fitting the trends in Figure 9.

	Ice-phase clouds		Mixed-phase clouds	
	lnAOD ≤ -4.0	lnAOD > -4.0	lnAOD ≤ -4.0	lnAOD > -4.0
lnAOD-PWV	y = -0.40x + 1.43	y = 0.83x + 6.65*	y = -1.48x -1.66*	y = 1.28x + 10.12
lnAOD-CAPE	y = -6.58x - 16.13*	y = 11.57x + 57.71	y = -14.89x -47.08*	y = 24.22x + 113.59
lnAOD-$PVV_{400(500)}$	y = -0.004x - 0.01	y = 0.01x + 0.04	y = 0.001x + 0.004	y = 0.003x + 0.02

Table S10. During the nighttime of MAM and JJA over the Tibetan Plateau, when the total correlation coefficient between the macrophysical characteristics of single-layer non-precipitating ice-phase clouds and mixed-phase clouds and lnAOD is significant, controlling for a certain meteorological factor or all meteorological factor parameters, and calculating the absolute difference between the partial correlation coefficient and the total correlation coefficient, the meteorological factors are sorted from top to bottom according to the absolute magnitude of the difference.

lnAOD ≤ -4.0					lnAOD > -4.0			
Ice-phase clouds		Mixed-phase clouds			Ice-phase clouds			
CBH	CT	CTH	CT	CF	CTH	CBH	CT	CF
All para	All para	**T_{400}**	PWV	**All para**	RH_{250}	RH_{250}	**All para**	**All para**
CAPE	PWV	**T_{350}**	All para	PWV	All para	All para	**RH_{350}**	**RH_{250}**
PVV_{400}	CAPE	**T_{500}**	T_{350}	T_{350}	T_{350}	RH_{350}	**RH_{250}**	**RH_{350}**
T_{400}	RH_{400}	**All para**	T_{400}	T_{400}	T_{400}	V_{350}	T_{350}	**T_{250}**
RH_{400}	PVV_{350}	V_{400}	CAPE	RH_{500}	SP	T_{250}	T_{400}	**T_{350}**
V_{350}	T_{400}	PWV	T_{500}	T_{500}	RH_{350}	V_{400}	T_{250}	U_{250}
RH_{250}	PVV_{400}	CAPE	V_{400}	V_{400}	PVV_{250}	T_{350}	RH_{400}	**T_{400}**
PVV_{350}	T_{350}	RH_{500}	RH_{500}	CAPE	V_{350}	T_{400}	PWV	RH_{400}
T_{350}	T_{250}	RH_{400}	RH_{400}	V_{350}	T_{250}	U_{250}	SP	U_{350}
V_{400}	V_{350}	V_{350}	PVV_{350}	RH_{400}	U_{250}	U_{350}	V_{400}	PWV
T_{250}	RH_{250}	PVV_{350}	PVV_{500}	PVV_{350}	PWV	RH_{400}	V_{350}	PVV_{250}
PWV	PVV_{250}	V_{500}	V_{350}	PVV_{500}	U_{350}	U_{400}	PVV_{250}	PVV_{350}
U_{250}	V_{400}	PVV_{500}	SP	V_{500}	U_{400}	PVV_{350}	CAPE	U_{400}
U_{400}	V_{250}	SP	V_{500}	SP	RH_{400}	PVV_{400}	PVV_{400}	PVV_{400}
V_{250}	SP	U_{350}	RH_{350}	U_{500}	PVV_{400}	PWV	PVV_{350}	SP
U_{350}	U_{400}	PVV_{400}	PVV_{400}	RH_{350}	V_{400}	V_{250}	U_{350}	CAPE
PVV_{250}	RH_{350}	RH_{350}	U_{500}	PVV_{400}	CAPE	PVV_{250}	U_{250}	V_{350}
SP	U_{250}	U_{500}	U_{350}	U_{400}	V_{250}	SP	U_{400}	V_{250}

[1] Bold indicates that when controlling for a certain meteorological factor, the partial correlation coefficient between cloud characteristics and lnAOD did not pass the significance test, indicating a greater impact of the meteorological factor on the correlation between cloud characteristics and lnAOD. The higher the sorting, the greater the impact.

Table S11. Same as Table S10, but for SON and DJF.

lnAOD ≤ -4.0		
Mixed-phase clouds		
CTH	CT	CF
All para	**PWV**	**All para**
T450	**T450**	**T400**
T400	**T400**	**T450**
T500	**All para**	**PWV**

PWV	**T500**	**T500**
CAPE	**CAPE**	**CAPE**
U450	RH400	U450
U400	U450	U500
U500	RH500	U400
RH400	RH450	V450
RH450	U400	PVV400
SP	U500	V500
RH500	V450	PVV450
V450	PVV400	RH500
PVV400	V400	SP
V500	V500	V400
PVV450	PVV450	RH450
V400	SP	RH400
PVV500	PVV500	PVV500

Table S12. Same as Table S10, but for microphysical characteristics of clouds.

lnAOD ≤ -4.0							
Ice-phase clouds			Mixed-phase clouds				
IER	INC	IWP	IER	IWP	LER	LNC	LWP
All para	**RH_{400}**	All para	**All para**	**PWV**	**All para**	**PWV**	PWV
CAPE	**CAPE**	CAPE	**PWV**	V_{400}	**PWV**	**All para**	All para
PWV	**All para**	RH_{400}	CAPE	All para	**CAPE**	**T_{350}**	T_{350}
T_{250}	**PVV_{350}**	PVV_{350}	RH_{500}	CAPE	**RH_{500}**	**T_{400}**	T_{400}
T_{350}	**PVV_{400}**	PWV	T_{400}	RH_{500}	**T_{400}**	**T_{500}**	T_{500}
T_{400}	T_{350}	PVV_{400}	T_{350}	T_{500}	**T_{350}**	**CAPE**	V_{400}
PVV_{350}	T_{400}	V_{350}	T_{500}	T_{400}	**T_{500}**	V_{400}	CAPE
RH_{400}	T_{250}	PVV_{250}	V_{400}	T_{350}	**V_{400}**	RH_{500}	RH_{500}
PVV_{400}	**V_{350}**	T_{400}	RH_{400}	RH_{400}	**RH_{400}**	V_{350}	V_{500}
V_{350}	**PVV_{250}**	V_{400}	PVV_{350}	V_{350}	PVV_{350}	V_{500}	SP
V_{400}	V_{400}	RH_{250}	PVV_{500}	PVV_{350}	PVV_{500}	SP	RH_{400}
PVV_{250}	RH_{350}	T_{350}	SP	PVV_{500}	V_{350}	RH_{400}	V_{350}
RH_{250}	U_{250}	T_{250}	V_{350}	V_{500}	V_{500}	PVV_{350}	PVV_{500}
V_{250}	V_{250}	V_{250}	V_{500}	PVV_{400}	SP	RH_{350}	PVV_{350}
RH_{350}	U_{400}	RH_{350}	U_{500}	U_{500}	U_{500}	PVV_{500}	U_{350}
U_{250}	RH_{250}	U_{250}	RH_{350}	U_{400}	RH_{350}	U_{350}	U_{500}
U_{400}	PWV	U_{400}	U_{400}	SP	PVV_{400}	U_{500}	U_{400}
SP	U_{350}	SP	PVV_{400}	U_{350}	U_{350}	PVV_{400}	RH_{350}
U_{350}	SP	U_{350}	U_{350}	RH_{350}	U_{400}	U_{400}	PVV_{400}

Table S13. Same as Table S10, but for microphysical characteristics of clouds in SON and DJF.

lnAOD ≤ -4.0				
Ice-phase clouds	Mixed-phase clouds			
IER	IER	LER	LNC	LWP
RH_{400}	**PWV**	**PWV**	**T_{400}**	**All para**
RH_{350}	**T_{450}**	**T_{450}**	**T_{450}**	**T_{400}**
T_{350}	**T_{400}**	**T_{400}**	**All para**	**T_{450}**
T_{400}	**T_{500}**	**T_{500}**	**T_{500}**	T_{500}
T_{450}	**All para**	**All para**	**PWV**	PWV
PWV	**CAPE**	CAPE	SP	CAPE
All para	SP	U_{450}	**CAPE**	SP
V_{450}	U_{450}	U_{400}	U_{450}	U_{450}
PVV_{400}	U_{500}	U_{500}	V_{450}	U_{400}
V_{400}	U_{400}	SP	U_{400}	U_{500}
RH_{450}	PVV_{400}	V_{450}	RH_{500}	PVV_{400}
PVV_{450}	V_{450}	PVV_{400}	PVV_{450}	PVV_{450}
PVV_{350}	V_{500}	V_{500}	V_{500}	V_{450}
CAPE	PVV_{450}	RH_{400}	PVV_{400}	V_{500}
U_{350}	RH_{400}	PVV_{450}	RH_{450}	PVV_{500}
U_{450}	PVV_{500}	V_{400}	RH_{400}	RH_{400}
U_{400}	RH_{500}	PVV_{500}	PVV_{500}	RH_{500}
SP	RH_{450}	RH_{500}	U_{500}	RH_{450}
V_{350}	V_{400}	RH_{450}	V_{400}	V_{400}