Supplement of Atmos. Chem. Phys., 22, 8321–8342, 2022
https://doi.org/10.5194/acp-22-8321-2022-supplement

Atmospheric Chemistry and Physics
Open Access

Supplement of

Temporal and vertical distributions of the occurrence of cirrus clouds over a coastal station in the Indian monsoon region

Saleem Ali et al.

Correspondence to: Sanjay Kumar Mehta (ksanjaym@gmail.com, sanjaykr@srmist.edu.in)

Supplementary Material (Contains One Table and Seven Figures):

Table S1: Statistics of total hours of operation, total cirrus observation, and percentage of occurrence, along with a seasonal average of CPT altitude (CPH), COH, and TTL thickness (TTlt) from 2016 to 2018.

Figure S1: (a) Time height section of the normalized backscattered (NRB) signals over the altitude 0.3 -20 km observed on 15:00 IST on the first day (26-07-2016) to 11:00 IST on the second day (27-07-2016) displaying the multi-layered cirrus clouds. The vertical dashed lines indicate the timings that are taken for SNR analysis. (b)-(e) display the NRB signals from surface to 30 km at 16:30 IST, 20:30 IST, 03:40 IST, and 06:00 IST with the background mean plus one and two standard deviations are obtained from the NRB signal between 25 km and 30 km.

Figure S2. Comparison of the diurnal variation of the total percentage occurrence of the cirrus clouds using the ground-based (MPL) and space-borne (AIRS and IASI) observations over Kattankulathur.

Figure S3. The vertical profile of cloud fraction as a function of local time of observation over the land in the Northern Hemisphere tropics during (a) DJF and (b) JJA from 2015 to 2017 (Reproduced from Noel et al., 2018). The occurrence of cirrus clouds as a function of time and altitude was observed over Kattankulathur (India) during (c) DJF and (d) JJA from 2016 to 2018.

Figure S4: Time height section of the monthly variation of the zonal wind shear from 2016 to 2018 over Chennai. The monthly mean CPT altitude (black) and COH (blue) are shown as dashed lines.

Figure S5: (a) The total MPL operations simultaneous to radiosonde observations during 2016-2018. (b) The total cirrus observations and (c) percentage occurrence of the cirrus clouds occurring above the CPT.(d) the difference between the altitudes of cirrus clouds top and CPT.

Figure S6: The vertical profile of the POC obtained using MPL from 2016 to 2018 averaged between 19:00 IST to 05:00 IST (a) over the whole year, (b) during winter (DJF), (c) pre-monsoon (MAM), (d) monsoon (JJA), (e) post-monsoon seasons. The red and black dotted lines correspond to the CPH and COH, respectively, in a given season.

Figure S7: (a) Monthly averaged OLR value observed across central India (Black), Tamil Nadu (Red), and Chennai (blue) during 2016-2018. Time series of (b) El Nino Southern Oscillation (ENSO) and (c) Quai-Biennial Oscillation (QBO) indices during 2016-2018.

Table S1: Statistics of total hours of operation, total cirrus observation, and percentage of occurrence, along with a seasonal average of CPT altitude (CPH), CO,H and TTL thickness (TTlt) from 2016 to 2018.

	Total Obs. (h)	Cirrus Obs. (h)	PO (%)	CPH (km)	COH (km)	TTLt (km)
2016						
DJF	463	225	48.6	17.6	11.8	5.8
MAM	935	513	54.9	17.8	11.8	6
JJA	745	537	72.1	17	12.6	4.4
SON	930	442	47.5	17	12.2	4.8
Annual	3073	1717	55.9	-	-	-
2017						
DJF	991	169	17.1	17.5	11.6	5.9
MAM	1308	496	37.9	17.4	11.5	5.9
JJA	1079	576	53.4	17	12.4	4.6
SON	938	430	45.8	17.1	12.2	4.9
Annual	4316	1671	38.7	-	-	-
	2018					
DJF	1271	324	25.5	17.5	11.4	6.1
MAM	1247	530	42.5	17.4	11.9	5.5
JJA	1006	461	45.8	16.9	12.3	4.6
SON	865	299	34.6	16.9	11.8	5.1
Annual	4389	1614	36.8	-	-	-
Overall (**2016-2018)**						
DJF	2725	718	26.3	17.5	11.6	5.9
MAM	3490	1539	44.1	17.5	11.7	5.8
JJA	2830	1574	55.6	17	12.4	4.5
SON	2733	1171	42.8	17	12	4.9
Annual	11778	5002	42.5	-	-	-

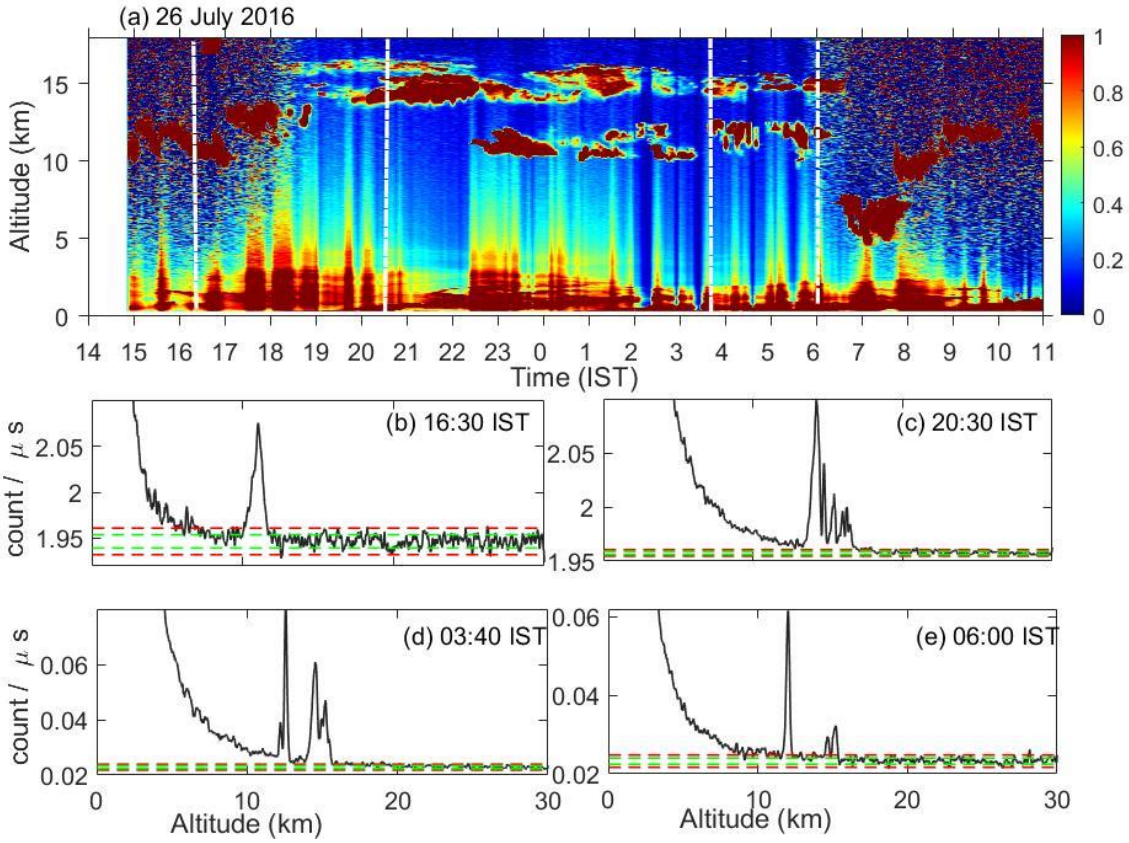

Figure S1: (a) Time height section of the normalized backscattered (NRB) signals over the altitude 0.3 -20 km observed on 15:00 IST on the first day (26-07-2016) to 11:00 IST on the second day (27-07-2016) displaying the multi-layered cirrus clouds. The vertical dashed lines indicate the timings that are taken for SNR analysis. (b)-(e) display the NRB signals from surface to 30 km at 16:30 IST, 20:30 IST, 03:40 IST, and 06:00 IST with the background mean plus one and two standard deviations are obtained from the NRB signal between 25 km and 30 km.

Explanation: To illustrate the threshold value for identifying the cirrus cloud, we have considered the typical case of the multiple cirrus clouds observations as shown in Figure S1. We have taken the vertical profiles of the NRB signals from surface to 30 km at 16:30 IST, 20:30 IST, 03:40 IST, and 06:00 IST, as shown in Figures S1b-e, respectively. The background mean plus one and two standard deviations are obtained from the NRB signal between 25 km and 30 km. During daytime (16:30 IST), the NRB signal up to the attitude of ~ 6 km is much higher than the background signals shown as dashed lines (cyan and red for one and two standard deviations, respectively). Above it, the NRB signals again go below the threshold value. However, the NRB signal again started to increase and become higher than the threshold value at ~ 9 km due to the cirrus clouds. During night times (20:30 IST and 3:40 IST), the NRB signals are higher than the threshold value up to altitude ~16-17 km. However, during the morning hours, the NRB signals are higher than the threshold value up to the altitude of ~ 10 km. The cirrus clouds were ~ 12 km and ~ 16 km. Thus, we see that, though the NRB signal

is poor during the daytime, it provides the detection of the cirrus clouds. However, detection is limited to the optically thicker clouds.

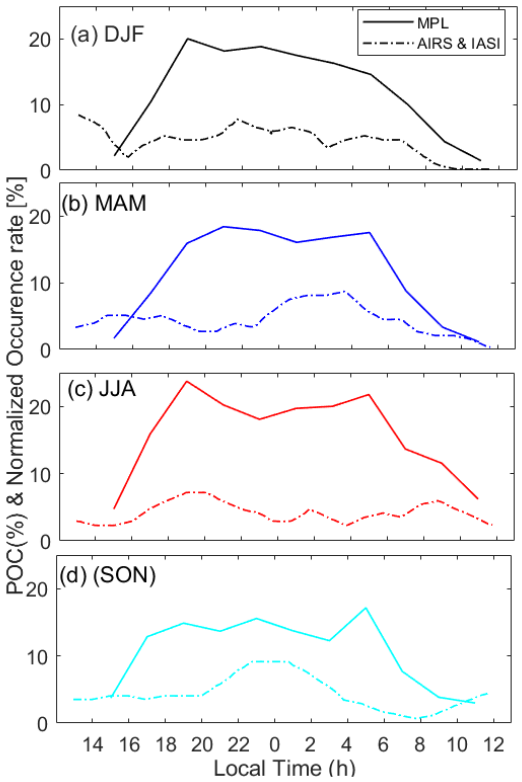

Figure S2. Comparison of the diurnal variation of the total percentage occurrence of the cirrus clouds using the ground-based (MPL) and space-borne (AIRS and IASI) observations over Kattankulathur.

Explanations: The comparison of diurnal pattern the cirrus occurrence using space-borne observations (IASI and AIRS) with the total occurrence of cirrus occurrence using observation (MPL). Both space-borne and ground-based observations show that evening peak (18:00-20:00 h) during JJA, and morning peak (02:00-4:00 h) during MAM. However, the diurnal cycle of the total cirrus occurrence is not pronounced as the single and multi-layer cirrus clouds. Thus, result was kept aside from the original manuscript, and different single and multi-layer clouds that show the pronounced diurnal cycle were analyzed. Note that the space-borne observation usually detects the cloud top layer, so the distinction between single and multi-layer cirrus is difficult from the AIRS and IASI observations.

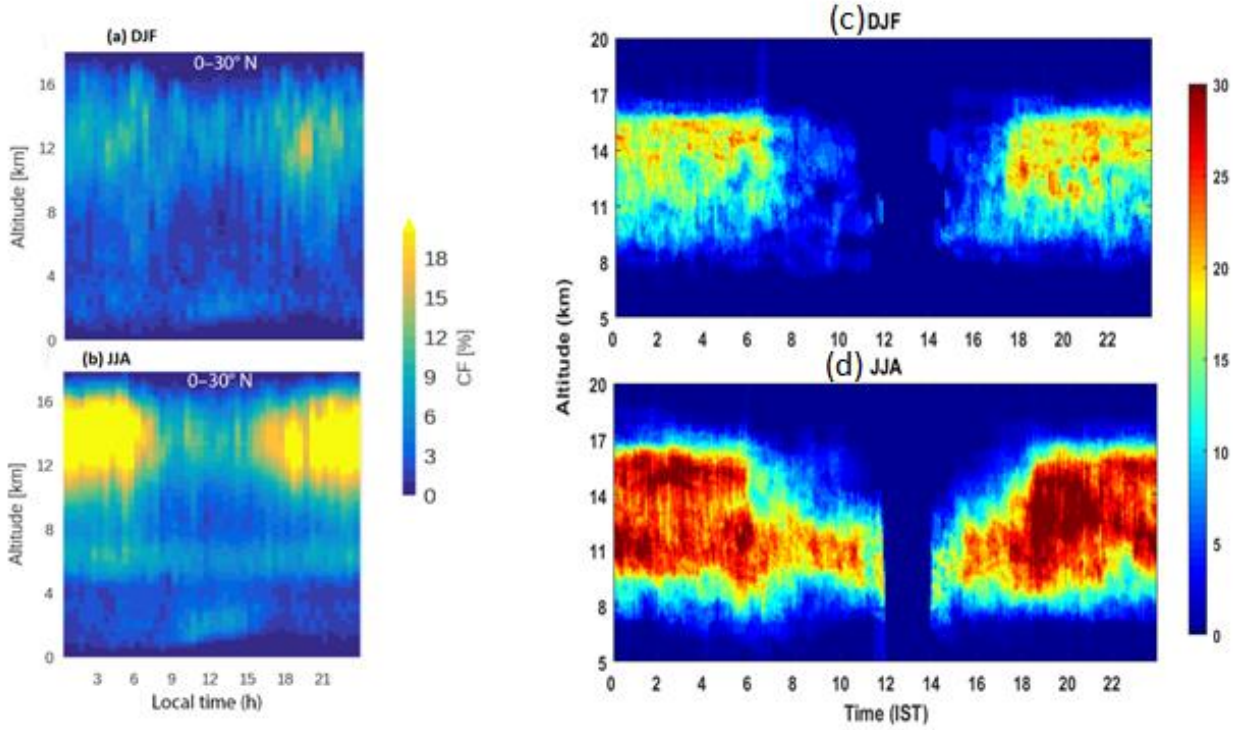

Figure S3. The vertical profile of cloud fraction as a function of local time of observation over the land in the Northern Hemisphere tropics during (a) DJF and (b) JJA from 2015 to 2017 (Reproduced from Noel et al., 2018). The occurrence of cirrus clouds as a function of time and altitude observed over Kattankulathur (India) during (c) DJF and (d) JJA from 2016 to 2018.

Explanations: The comparison of the total cirrus occurrence using MPL with high-level clouds using CATS (*Noel et al., 2018*) is carried out as shown in Figure S1. It can be seen that the diurnal features of the cirrus clouds occurrence during DJF and JJA calculated over the NH tropics (0-30 N) from CATS observations compared well with the MPL observations over Kattankulathur. The occurrence of the cirrus clouds over the altitude ~ 8-17 km is consistent in both ground-based and space-borne observations. Also, the occurrence is higher during the NH summer than NH winter. However, the total POC does not show pronounced diurnal variation.

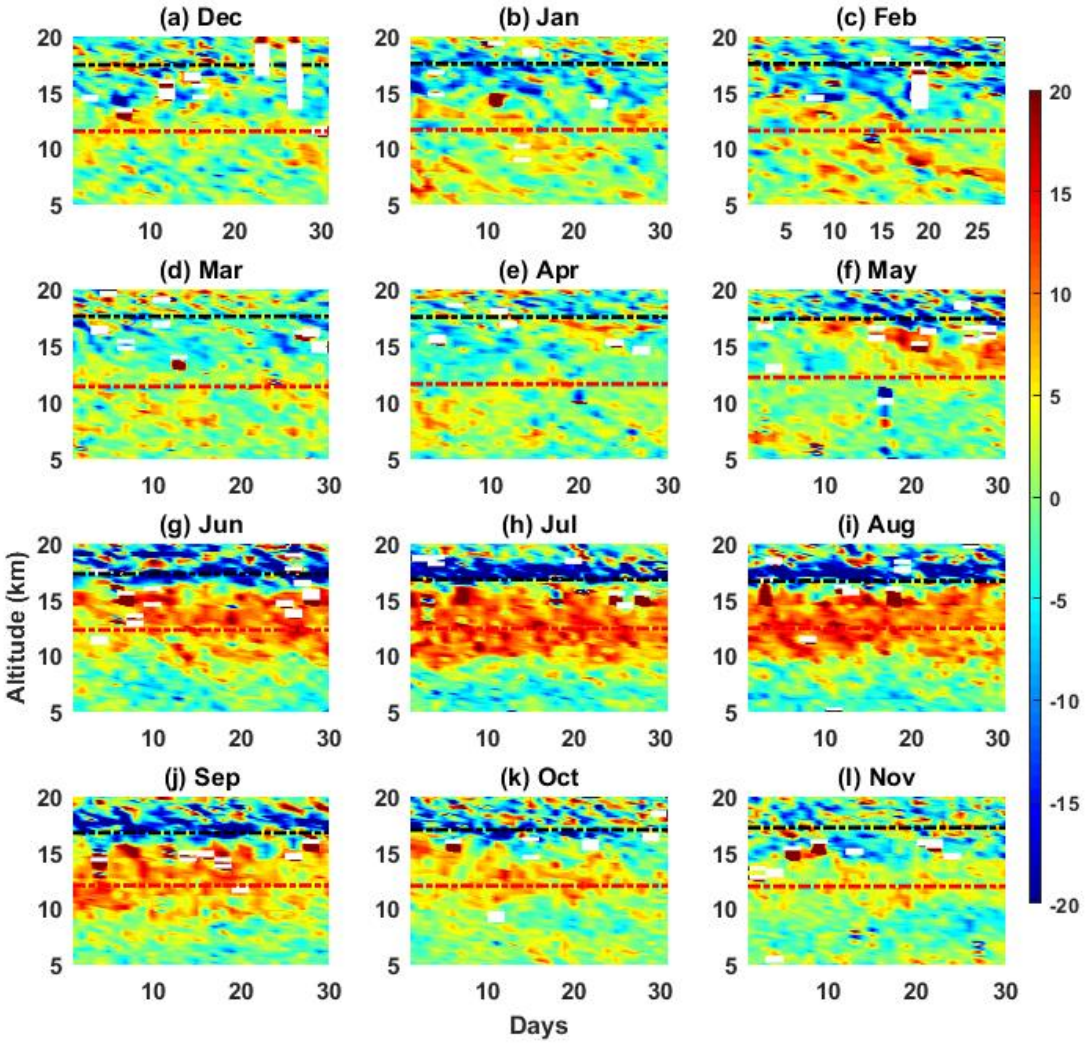

Figure S4: Time height section of the monthly variation of the zonal wind shear during 2016 to 2018 over Chennai. Monthly mean CPT altitude (black) and COH (blue) are shown as dashed lines.

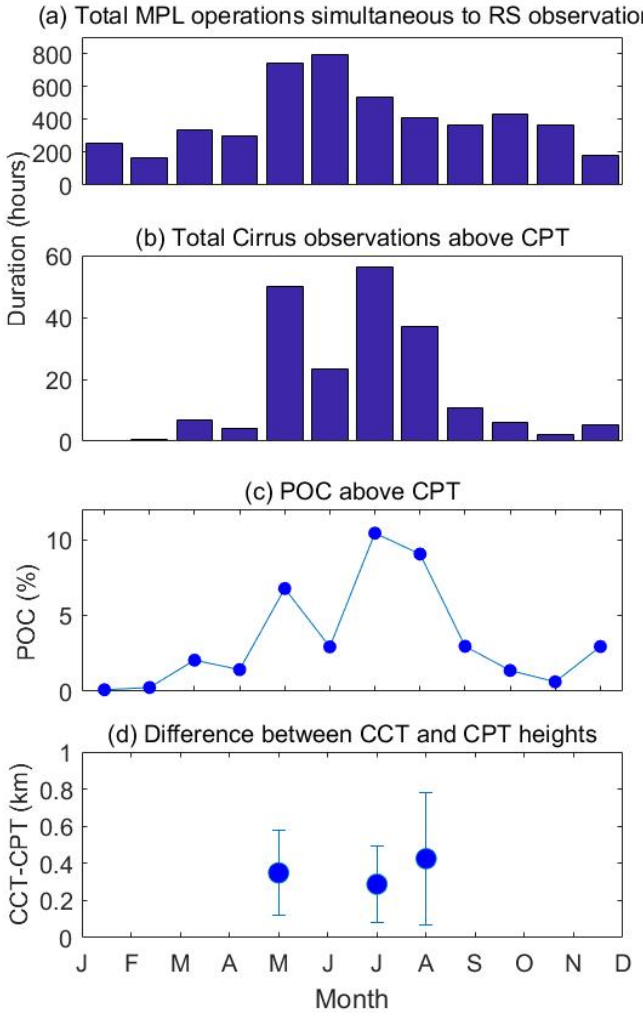

Figure S5: (a) The total MPL operations simultaneous to radiosonde observations during 2016-2018. (b) The total cirrus observations and (c) percentage occurrence of the cirrus clouds occurring above the CPT.(d) the difference between the altitudes of cirrus clouds top and CPT.

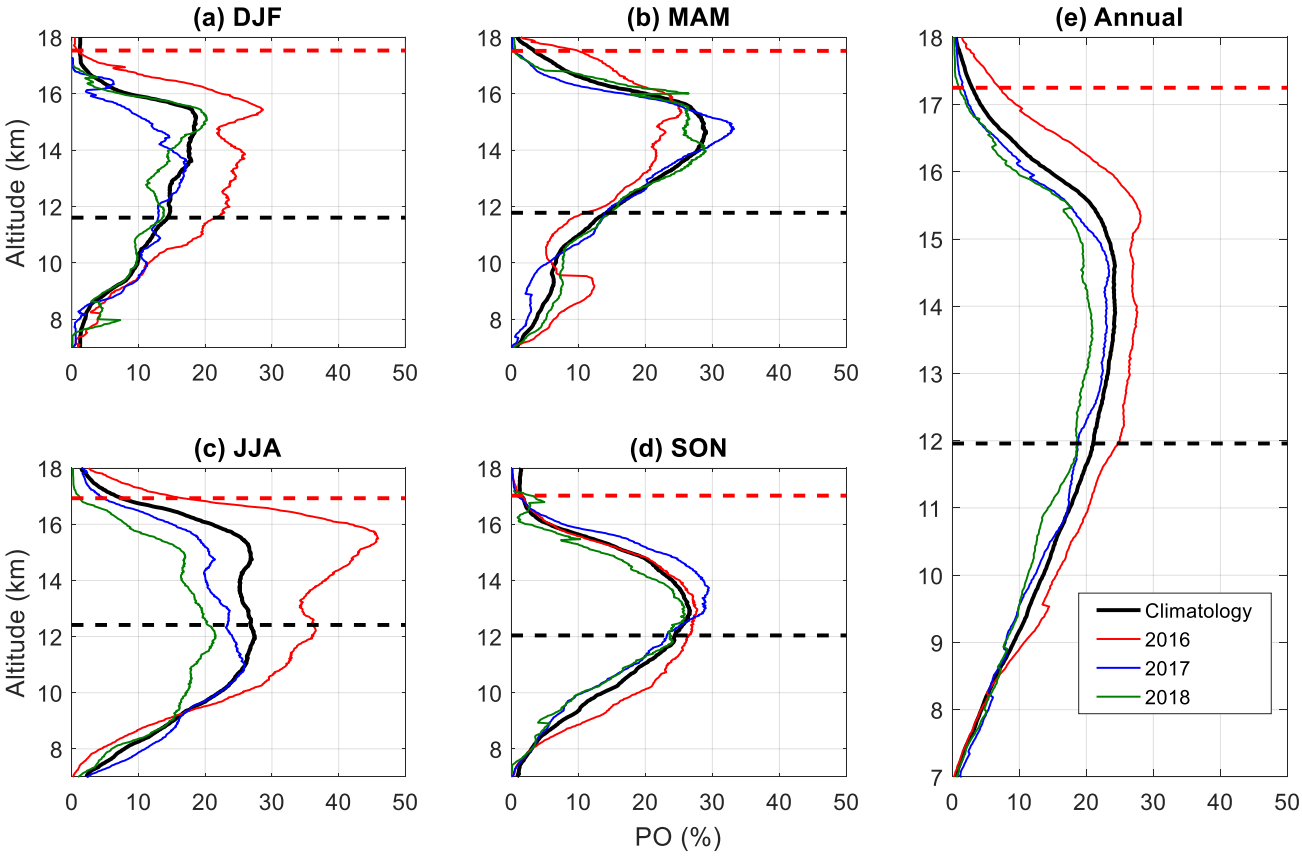

Figure S6: The vertical profile of the POC obtained using MPL during 2016 to 2018 averaged in between 19:00 IST to 05:00 IST (a) over the whole year, (b) during winter (DJF), (c) pre-monsoon (MAM), (d) monsoon (JJA), (e) post-monsoon seasons. The red and black dotted lines correspond to the CPH and COH, respectively, in a given season.

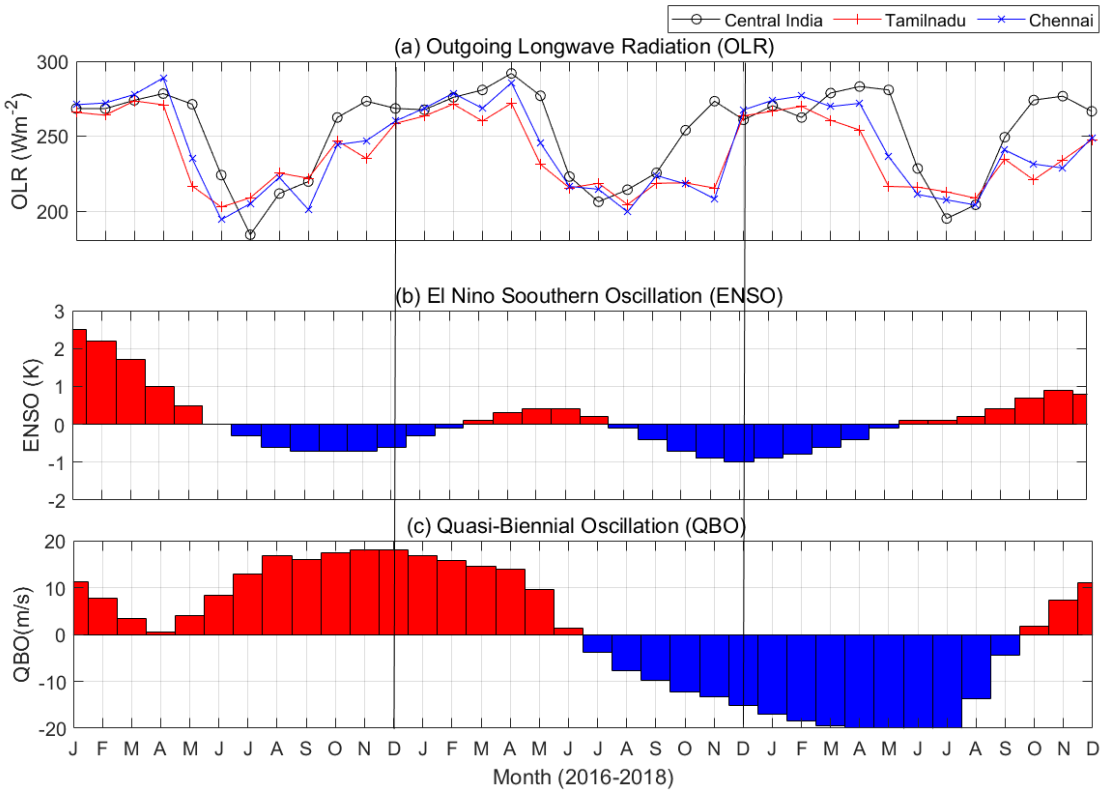

Figure S7: (a) Monthly averaged OLR value observed across central India (Black), Tamil Nadu (Red), and Chennai (blue) during 2016-2018. Time series of (b) El Nino Southern Oscillation (ENSO) and (c) Quai-Biennial Oscillation (QBO) indices during 2016-2018.

----End----