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Strong aerosol indirect radiative effect from dynamic-driven diurnal variations of cloud water adjustments

Jiayi Li et al.

Correspondence to: Jiming Li (lijiming@lzu.edu.cn)

Contents of this file

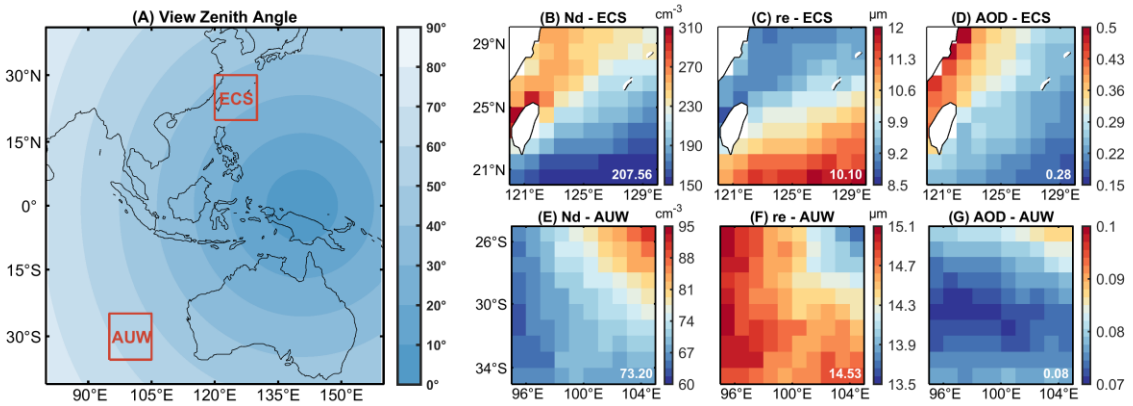

Figure S1: Distributions of cloud properties in two typical regions: the East China Sea (ECS: 20º-30ºN, 120º-130ºE) and the west of Australia (AUW: 25º-35ºS, 95º-105ºE). (A) Geographical distribution of the view zenith angle of Satellite Cloud and Radiation Property retrieval System (SatCORPS) Himawari-8 data. The selected regions are marked by red boxes. Spatial distributions of cloud droplet number concentration (N_d) (B, E), effective radius (r_e) (C, F) and total column aerosol optical depth (AOD) (D, G) from MERRA-2 data are presented. The numbers in the lower right corner represent regional averages being weighted by the cosine of latitude.

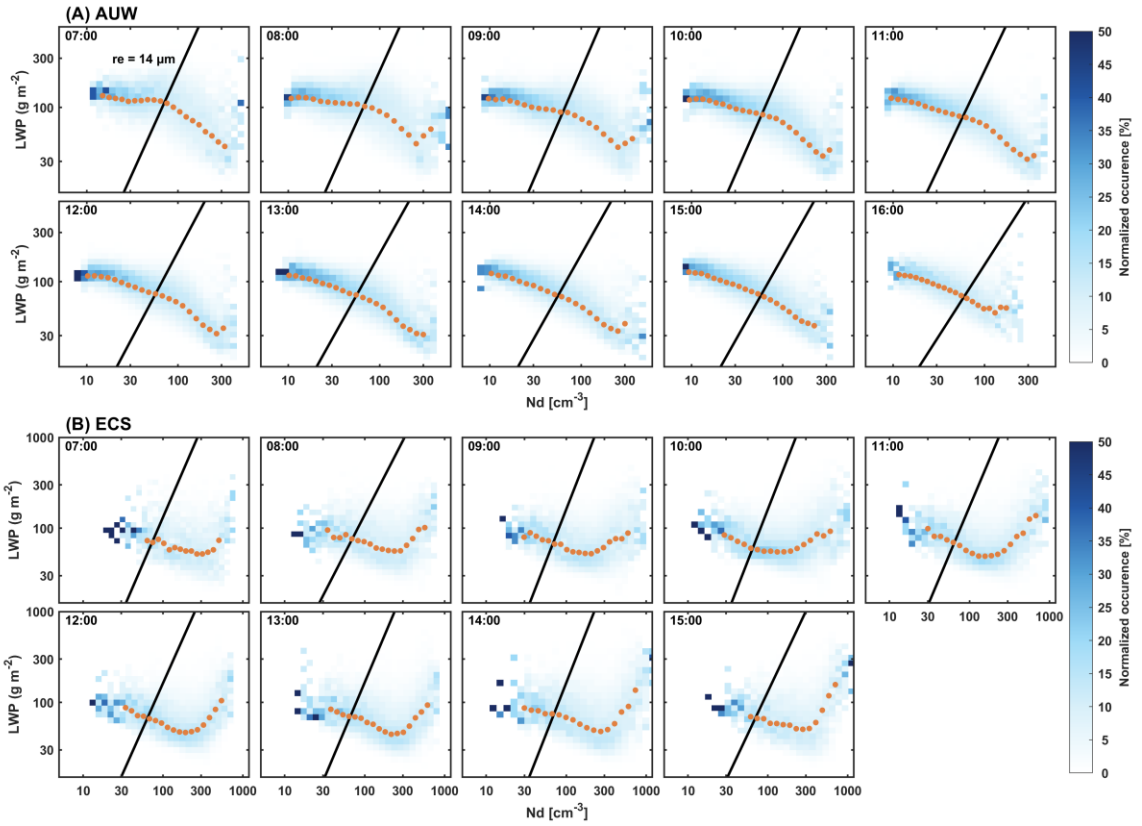

Figure S2: The complete diurnal pictures of normalized joint histograms of N_d and LWP in the AUW (A) and ECS (B) region. Orange dots represent the median LWP in each N_d bins with a sample size greater than 50.

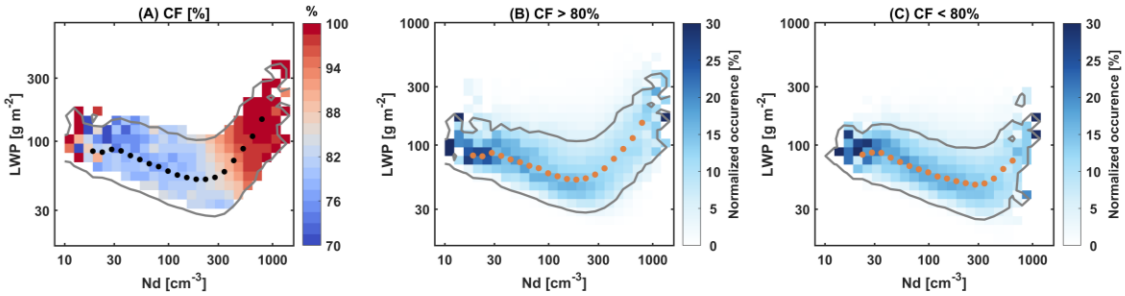

Figure S3: (A) The median cloud fraction (CF) in N_d-LWP log-log space in the ECS region. Only the bins with at least 5% occurrence are shown, bounded by the gray line. Panels (B) and (C) show the normalized joint histograms of N_d and LWP in log-log space in the ECS region, with CF greater than 80% and less than 80%, respectively. Black and orange dots represent the median LWP in each N_d bins with a sample size greater than 50.

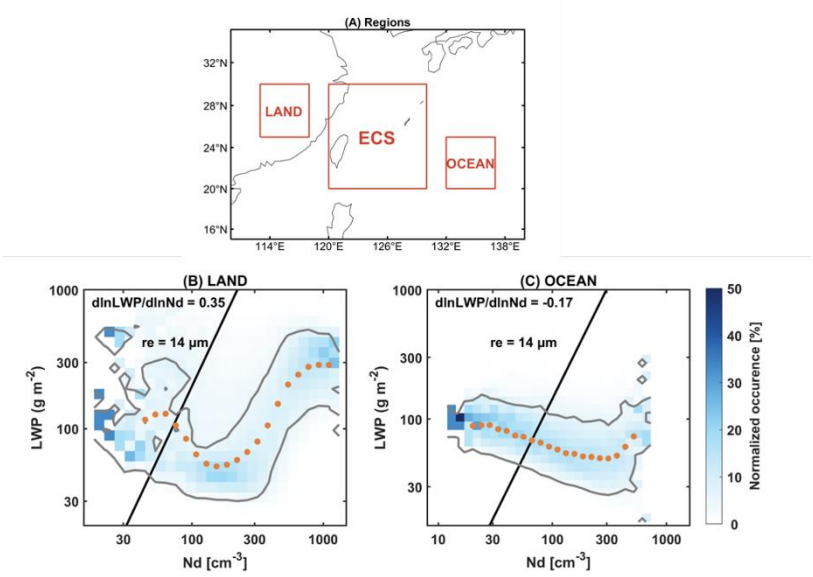

Figure S4: Normalized joint histograms of N_d and LWP in log-log space (B) in the west land and (C) in the east ocean of the East China Sea. Panel (A) shows the geographical location of the selected regions (ECS: 20º-30ºN, 120º-130ºE, LAND: 25º-30ºN, 113º-118ºE, OCEAN: 20º-25ºN, 132º-137ºE). Orange dots in panels (B) and (C) represent the median LWP in each N_d bins with a sample size greater than 50. The black lines are fitted based on the bins in the joint histogram with the effective radius (r_e) closest to 14 μm. Gray contours indicate 5% occurrence levels.

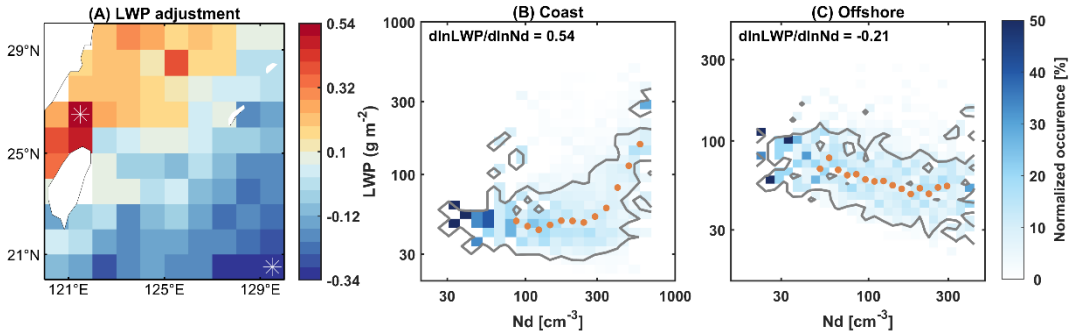

Figure S5: (A) Spatial distribution of LWP adjustments over the ECS region. White asterisks mark the coast and offshore areas for which normalized joint histograms of N_d and LWP in log-log space are presented in panels (B) and (C), respectively. Orange dots in (B) and (C) represent the median LWP in each N_d bins with a sample size greater than 20. Gray contours indicate 5% occurrence levels.

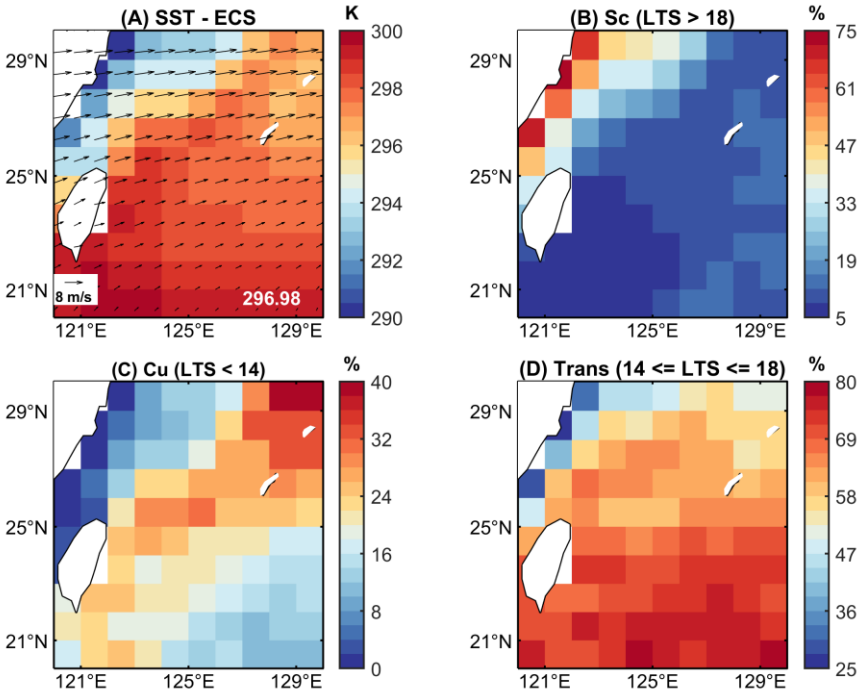

Figure S6: Distributions of meteorological factors and different cloud regimes in the ECS region. (A) Sea Surface Temperature (SST), the composite wind field (arrows) on 700 hPa. The numbers in the lower right corner represent regional averages being weighted by the cosine of latitude. Distributions of the proportion of cloud regimes for (B) Stratocumulus (Sc, LTS > 18 K), (C) Cumulus (Cu, LTS < 14 K), (D) Sc to Cu transition regime (Trans, 14 K <= LTS <= 18 K) are shown.

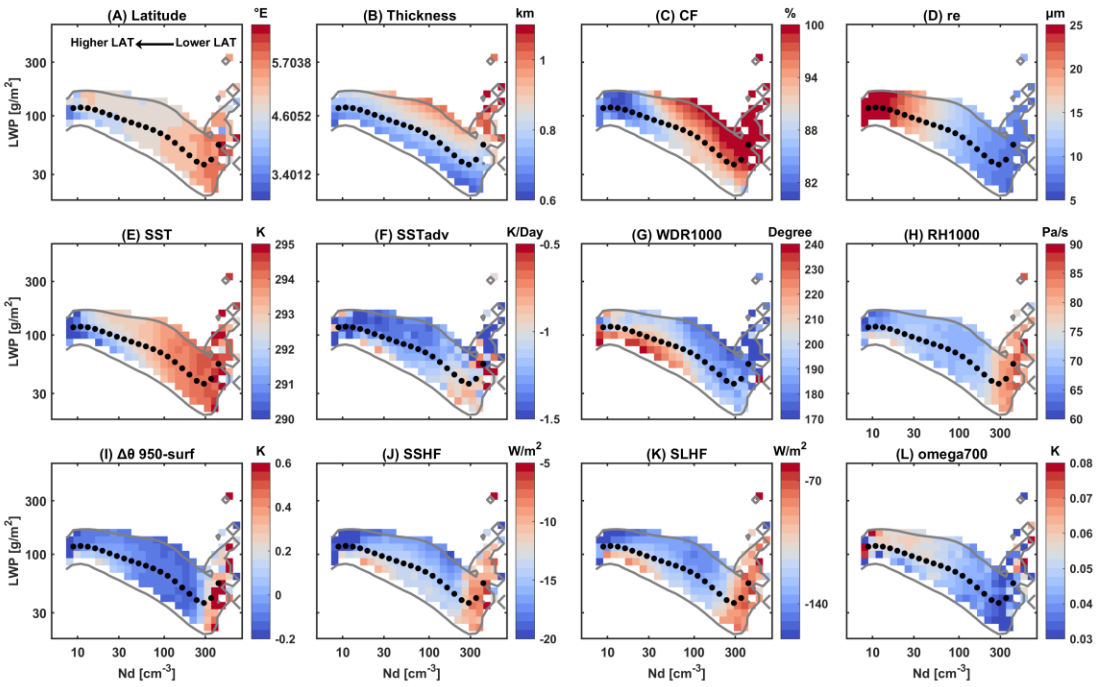

Figure S7: Distributions of meteorological conditions in N_d-LWP log-log space in the AUW region. The color scale represents the median values in each bin. Only the bins with at least 5% occurrence are shown, bounded by the gray lines. (A) Longitude. (B) Cloud thickness. (C) Cloud fraction (CF). (D) Cloud effective radius (r_e). (E) Sea surface temperature (SST). (F) Horizontal temperature advection at the surface (SST_{adv}). (G) Wind direction on 1000 hPa. 0 degree indicates north wind. (H) Relative humidity on 1000 hPa (RH1000). (I) The potential temperature difference between 950 hPa and 2 m above the sea surface ($\Delta\theta_{950\text{-}surf}$), a proxy of the sub-cloud layer stability. (J) Surface sensible heat flux (SSHF). (K) Surface latent heat flux (SLHF). For the vertical fluxes, the negative is upwards. (L) Large-scale subsidence is represented by vertical velocity on 700 hPa (omega700), positive (negative) values indicate downdraft (updraft). Black dots represent the median LWP in each N_d bins with a sample size greater than 50.

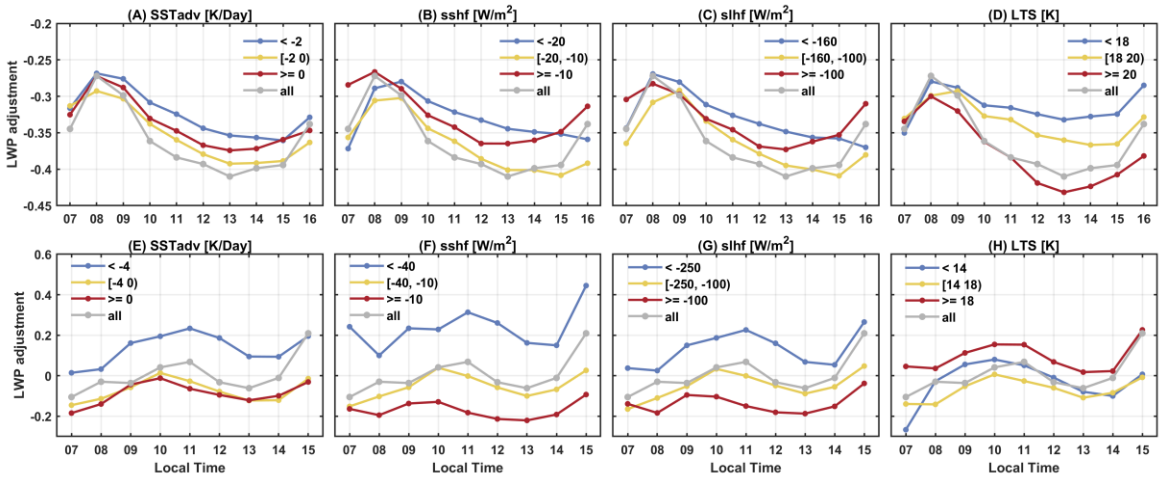

Figure S8: **Diurnal patterns of LWP adjustments within different bins of meteorological factors (SST_{adv}, SSHF, SLHF, LTS).** The top row shows results for the AUW region, and the bottom row shows results for the ECS region. Due to sample size limitations, LWP adjustment at each point is the regression slope of N_d and LWP in log-log space for all samples at that condition.

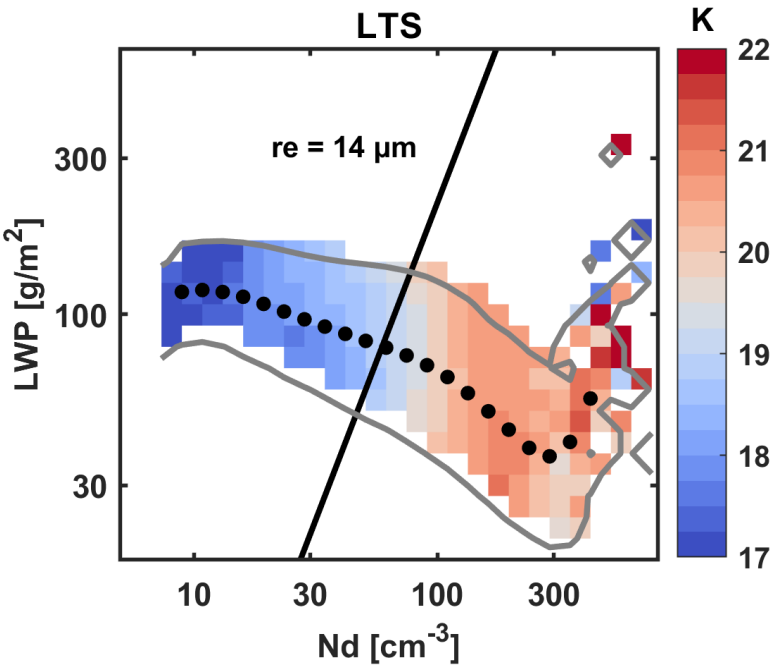

Figure S9: The median LTS in N_d-LWP log-log space in the AUW region. Only the bins with at least 5% occurrence are shown, bounded by the gray line. Black dots represent the median LWP in each N_d bins with a sample size greater than 50.

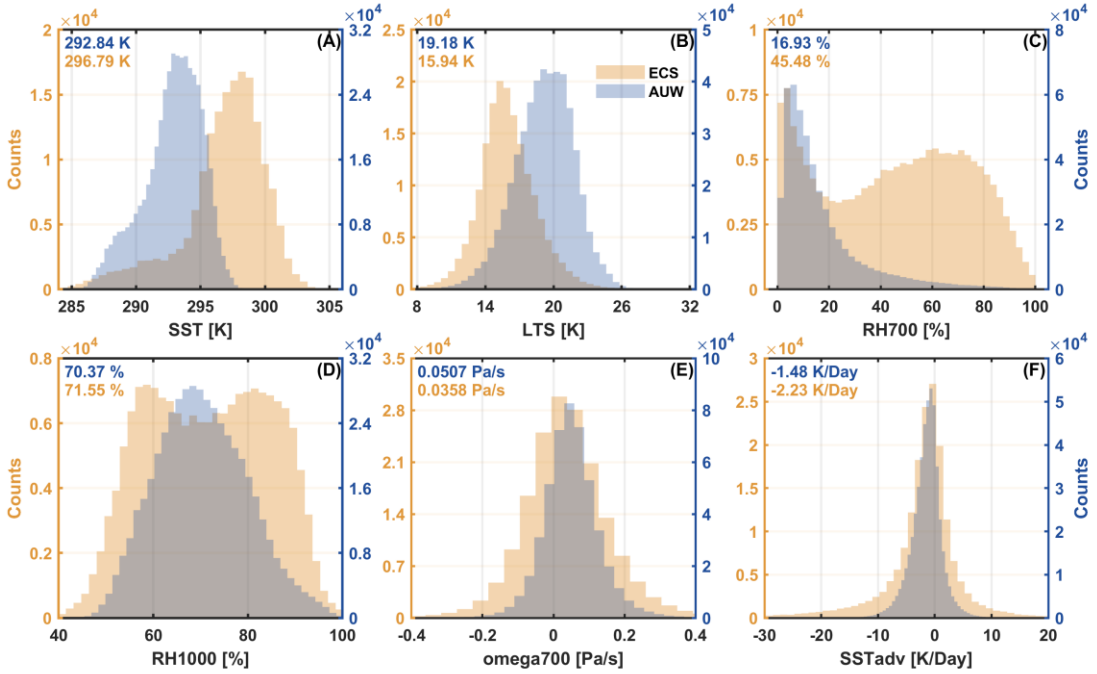

Figure S10: Histograms of 4-year meteorological conditions in the AUW and ECS regions from 2016 to 2019. The mean values are labeled in the top-left corner. Data are directly or indirectly derived from ERA5. For vertical velocities on 700 hPa (omega700), positive (negative) values indicate downdraft (updraft).

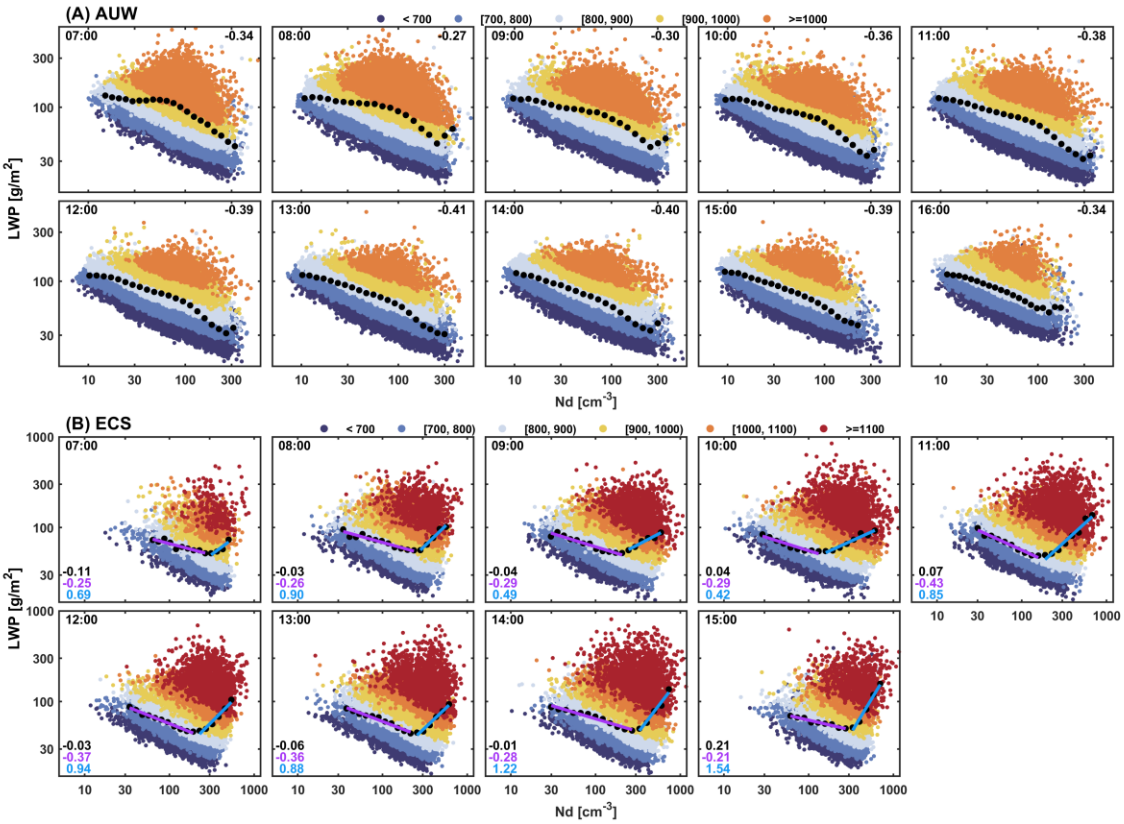

Figure S11: The complete diurnal pictures of LWP adjustments in the AUW (A) and ECS (B) region. Colored dots are samples in different cloud thickness (H) bins (unit: m). Black dots represent the median LWP in each N_d bin. The colored lines are the fits of black dots at different stages, with values shown in the corresponding color. The black number means the fitted value of all the black dots. The fitted value for each N_d stage is labeled with the corresponding color.

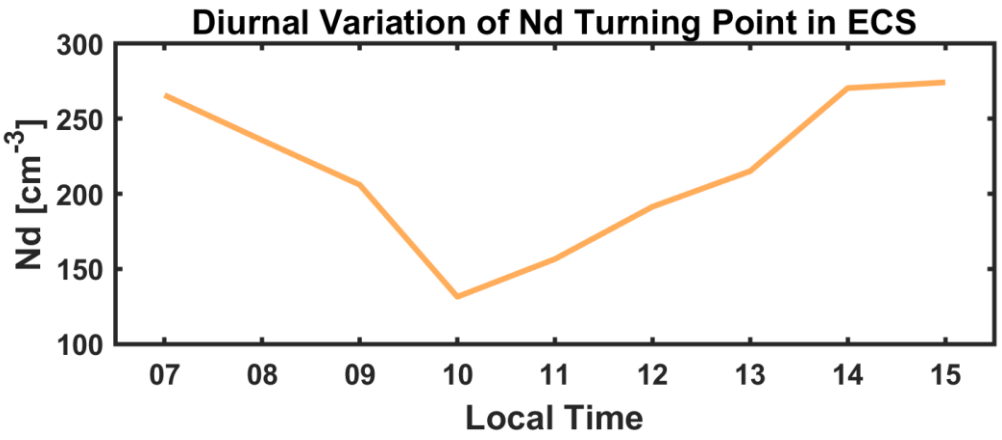

Figure S12: Diurnal variation of N_d turning point across V shape in the ECS region.

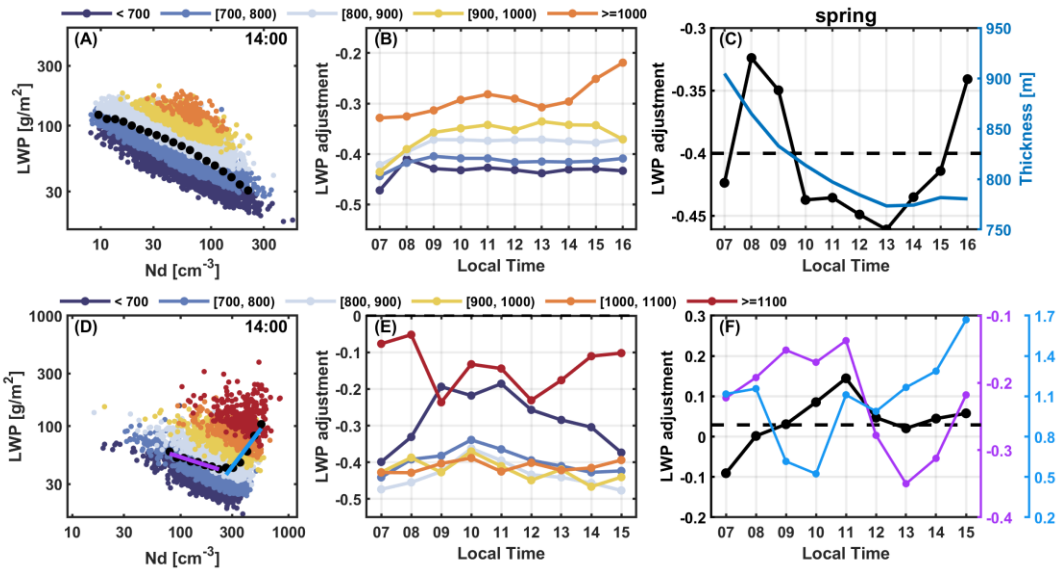

Figure S13: LWP adjustments in log-log spaces and their diurnal patterns in two typical regions (the west of Australia, AUW and the East China Sea, ECS) for spring. The total sample size is 135568 for the AUW region and 54109 for the ECS region. Cloud samples scattered in N_d-LWP log space at 1400 LT in the (A) AUW and (D) ECS region. Colored dots are samples in different cloud thickness (H) bins (unit: m). Black dots represent the median LWP in each N_d bin. The colored lines are the fits of black dots at different stages in the ECS region. Diurnal variations of LWP adjustments binned by H in the (B) AUW and (E) ECS regions are shown. Colored lines in (F) are diurnal variations of different stages in (D), while black lines in (C) and (F) are the overall diurnal variations of LWP adjustments in the two regions, respectively. The blue line in (C) represents the diurnal variation of H. Dashed lines represent the average LWP adjustments considering diurnal variations.

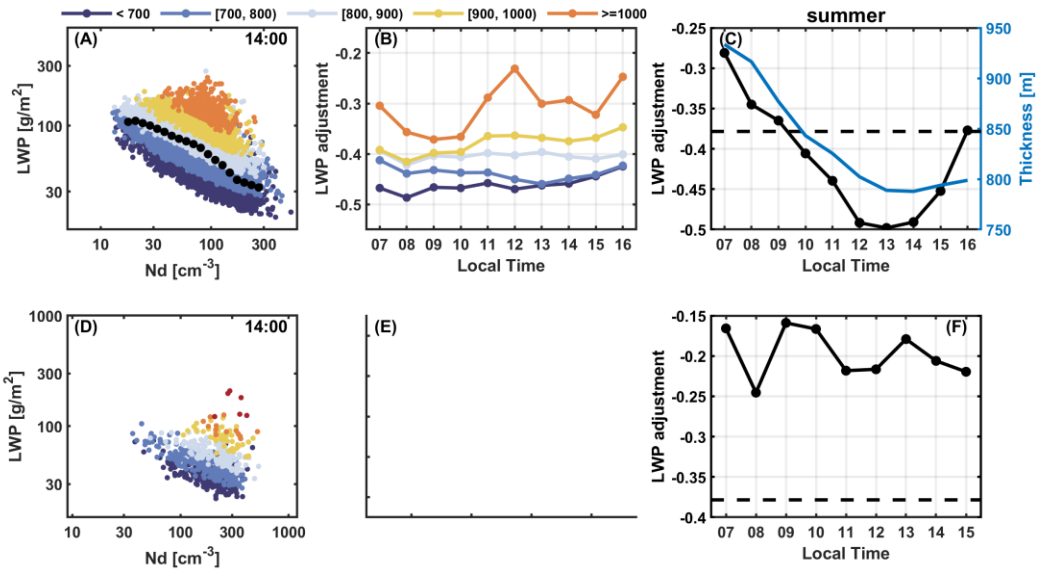

Figure S14: Same as Fig. S13 but for summer. The total sample size is 187646 for the AUW region and 5062 for the ECS region. Note that insufficient sample size in the ECS region made LWP adjustment in different H bins impractical, resulting in an empty Fig. E.

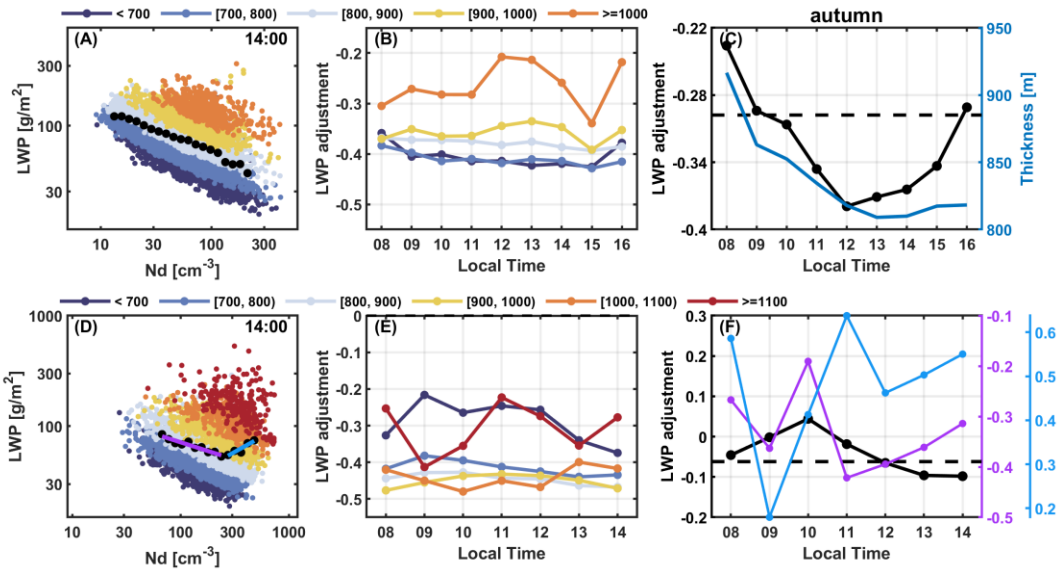

Figure S15: Same as Fig. S13 but for autumn. The total sample size was 94311 for the AUW region and 37387 for the ECS region.

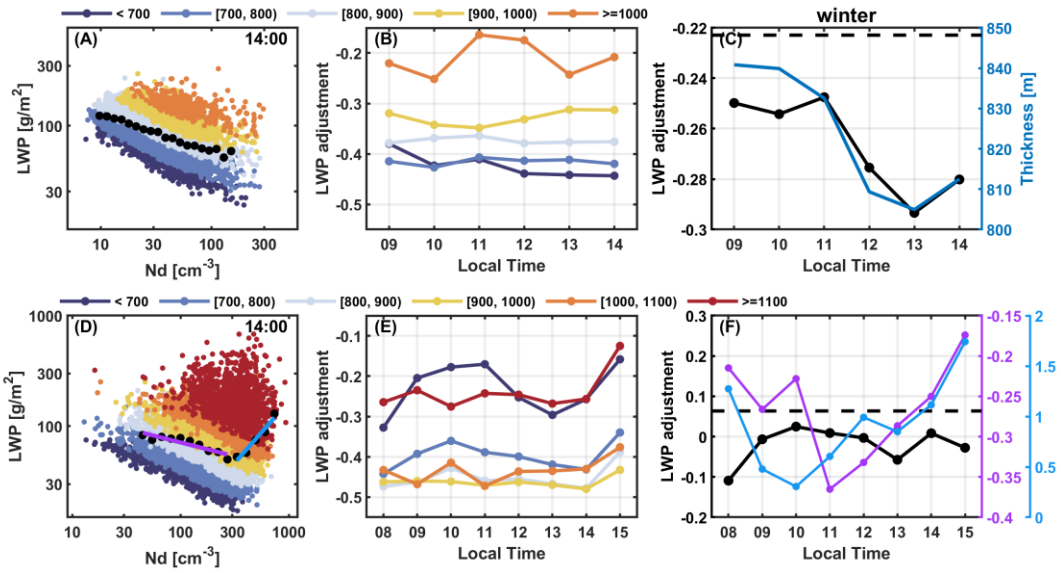

Figure S16: Same as Fig. S13 but for winter. The total sample size was 62664 for the AUW region and 76623 for the ECS region.

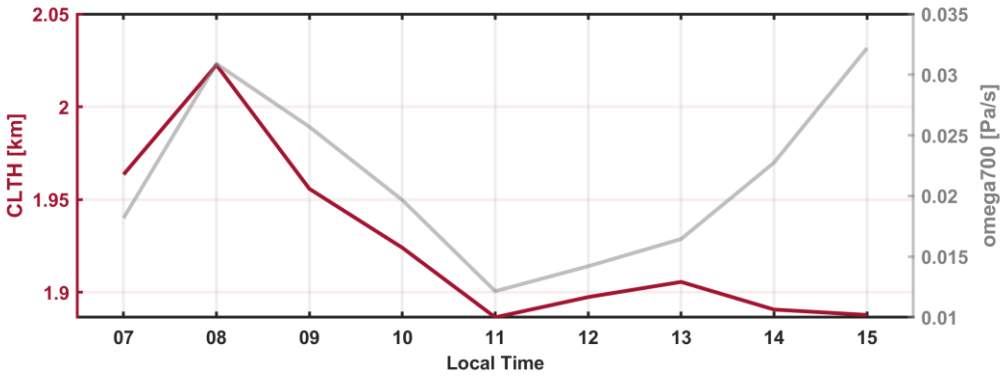

Figure S17: Diurnal variations of cloud-top height (CLTH) and vertical velocity on 700 hPa (omega700, positive values indicate downdraft) for spring in the ECS region.

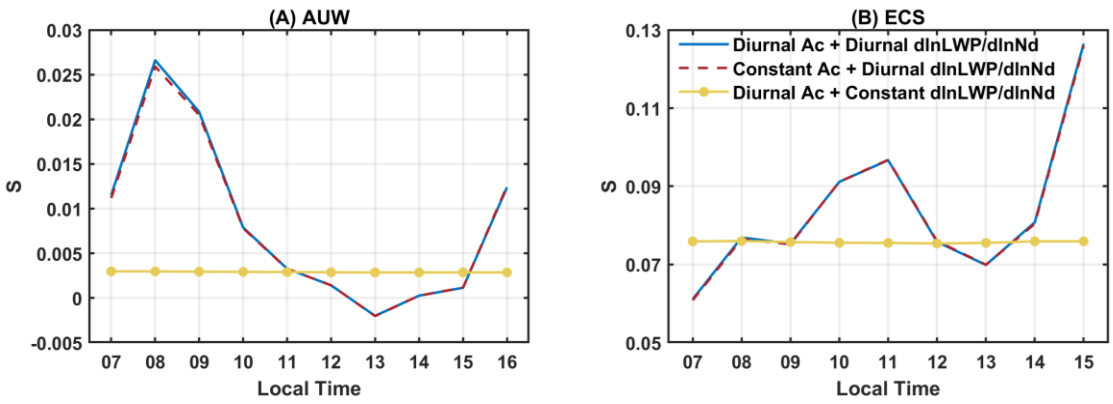

Figure S18: The susceptibility (S) of A_c to N_d calculated by Eq. (6) under three input combinations in the (A) AUW and (B) ECS regions: (1) diurnally varying A_c and dlnLWP/dlnN_d, (2) MODIS-averaged A_c (Terra at 1030 LT and Aqua at 1330 LT) and diurnally varying dlnLWP/dlnN_d, and (3) MODIS-averaged dlnLWP/dlnN_d and diurnally varying A_c.

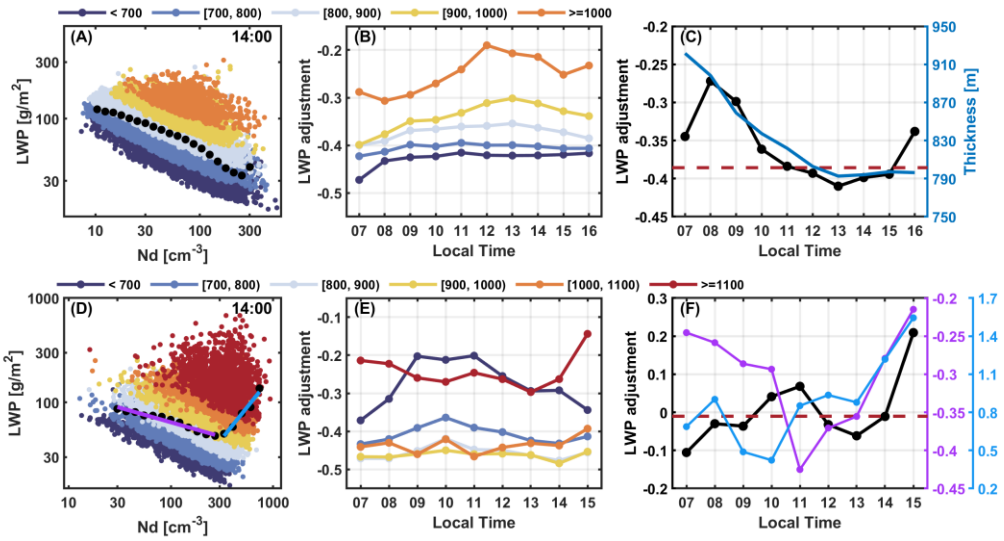

Figure S19: LWP adjustments in log-log spaces and their diurnal patterns in two typical regions. Cloud samples are scattered in N_d-LWP log space at 1400 LT in the (A) AUW and (D) ECS region. The complete pictures of all available daytime are presented in Fig. S11. Colored dots are samples in different cloud thickness (H) bins (unit: m). Black dots represent the median LWP in each N_d bin. The colored lines are the fits of black dots at different stages in the ECS region. Diurnal variations of LWP adjustments binned by H in the (B) AUW and (E) ECS regions are shown. Colored lines in (F) are diurnal variations of different stages in (D), while black lines in (C) and (F) are the overall diurnal variations of LWP adjustments in two regions, respectively. The blue line in (C) represents the diurnal variation of H. Red dashed lines represent the average LWP adjustments during MODIS Terra (1030 LT) and Aqua (1330 LT) overpasses, –0.39 for the AUW region (C) and –0.01 for the ECS region (F).

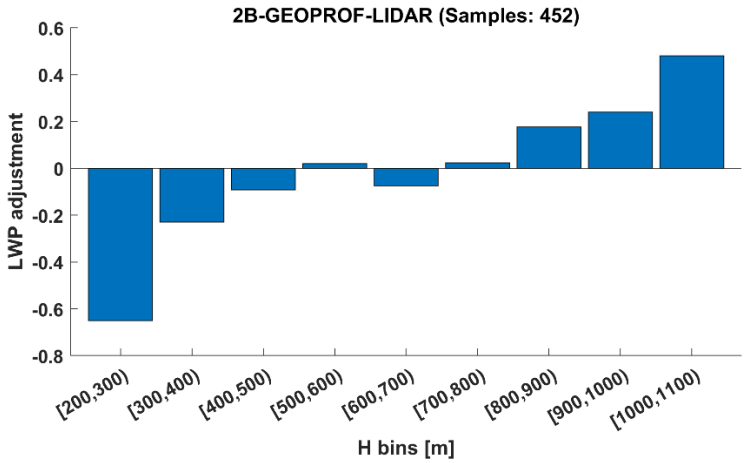

Figure S20: LWP adjustments binned by H for the AUW region (25º-35ºS, 95º-105ºE) during 2016-2017. H is derived from the CloudSat-CALIPSO 2B-GEOPROF-LIDAR product. LWP adjustment is calculated by the N_d and LWP obtained from the CER_GEO_ED4_HIM08_SH_V01.2 product.

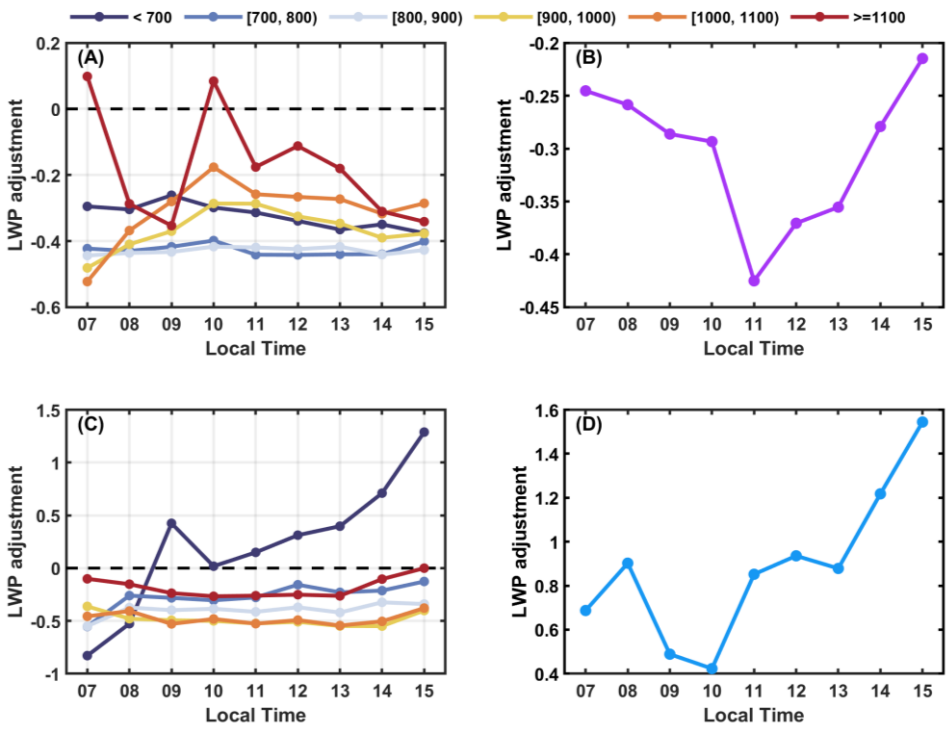

Figure S21: Panels (A) and (C) present the diurnal variations of LWP adjustments binned by H for two different N_d stages of the ECS region in Fig. S19D. Panels (B) and (D) display the overall diurnal patterns for the two stages.

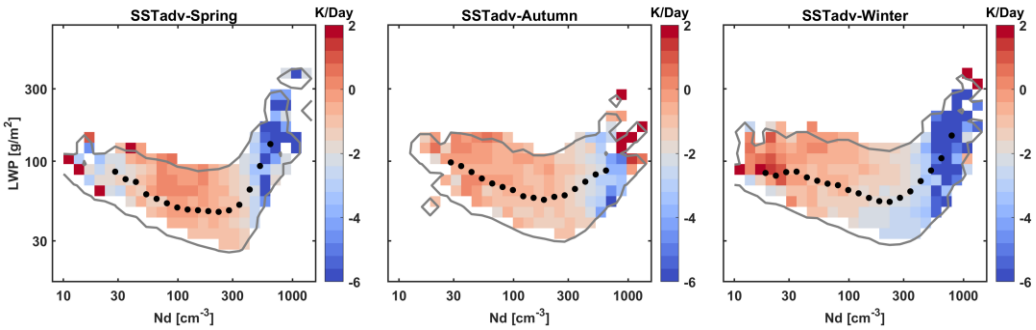

Figure S22: The median horizontal temperature advection at the surface (SST_{adv}) in N_d-LWP log-log space for spring, autumn, and winter in the ECS region.