



Supplement of

Influence of irradiance and mixing layer height on the vertical trace matter distribution in the lower planetary boundary layer – drone-based investigation

Lasse Moormann et al.

Correspondence to: Frank Drewnick (frank.drewnick@mpic.de)

The copyright of individual parts of the supplement might differ from the article licence.

Table S1: Instruments used for characterization of the lower troposphere.

Instrument	Measured variables	Time resolution
MoLa (Drewnick et al., 2012)		
CPC ^a	Particle number concentration (> 2.5 nm)	1 s
EDM ^b	Particulate matter PM ₁	6 s
FMPS ^c	Particle size distribution (5.6 to 560 nm) based on electrical mobility diameter	1 s
Meteorological station ^d	Wind direction, wind speed, relative humidity, temperature, rain intensity, pressure	1 s
OPC ^e	Particle size distribution (0.25 to 32 µm) based on optical diameter	6 s
O ₃ -monitor ^f	Mixing ratio of O ₃	2 s
Pyranometer ^g	Solar irradiance	1s
^a Condensation Particle Counter Model 3786, TSI, Inc., USA. ^b Environmental Dust Monitor EDM180, Grimm Aerosoltechnik, Germany. ^c Fast Mobility Particle Sizer Model 3091, TSI, Inc., USA. ^d WXT520, Vaisala Oyj, Finland. ^e Optical Particle Counter Model 1.109, Grimm Aerosoltechnik GmbH, Germany. ^f Monitor 205 Dual Beam Ozone Monitor, 2B Technologies, Inc., USA. ^g CMP3 Pyranometer Sensor, Campbell Scientific Inc., UK.		
FLab (Moormann et al., 2025)		
Anemometer ^h	Horizontal wind speed and direction; temperature; relative humidity; pressure	1 s
CPC ⁱ	Particle number concentration (> 10 nm)	1 s
CBO ^j	Mixing ratio of CO ₂	2 s
OPC ^k	Particle size distribution (0.350 to 40 µm) based on optical diameter; temperature; relative humidity	1 s
O ₃ -monitor ^l	Mixing ratio of O ₃	2 s
UAS: Matrice 600 ^m	3D orientation; 3D flight velocity; GPS position; wind speed and direction; altitude based on pressure level and GPS; propeller rotation rate; various internal data	≤1 s
^h TriSonica™ Mini, Anemoment LLC, USA. ⁱ Condensation Particle Counter Model 3007, TSI, Inc., USA. ^j CARBOCAP® Carbon Dioxide Probe GMP343, Vaisala Oyj, Finland. ^k OPC-N3, Alphasense AMETEK®, United Kingdom. ^l Model 205 Dual Beam Ozone Monitor, 2B Technologies, Inc., USA. ^m Matrice 600, SZ DJI Technology Co., Ltd., China.		
Flux tower		
Ultra-sonic anemometer ⁿ	3D wind direction, humidity, temperature	0.05 s
ⁿ CSAT3B 3-D Sonic Anemometer, Campbell Scientific, Inc., Logan, Utah, USA.		

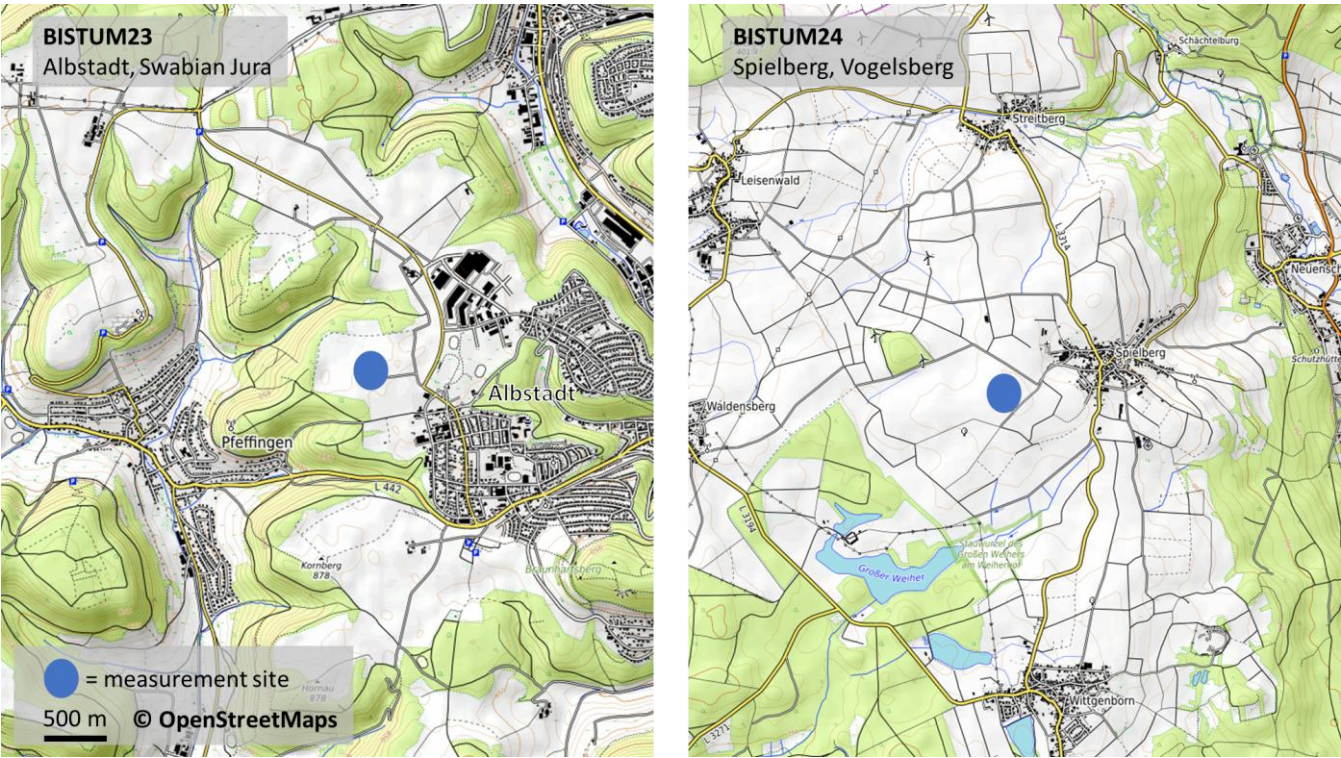


Figure S1: Topographic maps of the rural measurement sites during BISTUM23 and BISTUM24.

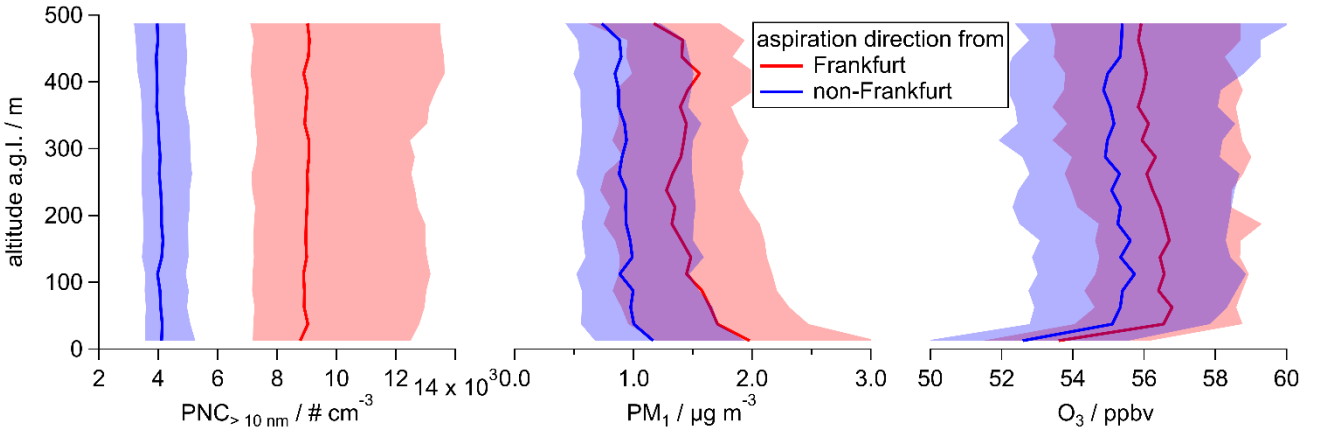


Figure S2: Median vertical profiles of anthropogenic tracers for air masses passing the Frankfurt-Rhine-Main metropolitan area (red) and only rural areas (blue): during BISTUM24 the particle number concentration (a), the PM_1 mass concentration (b) and O_3 mixing ratio (c). Shaded areas represent the respective interquartile ranges.

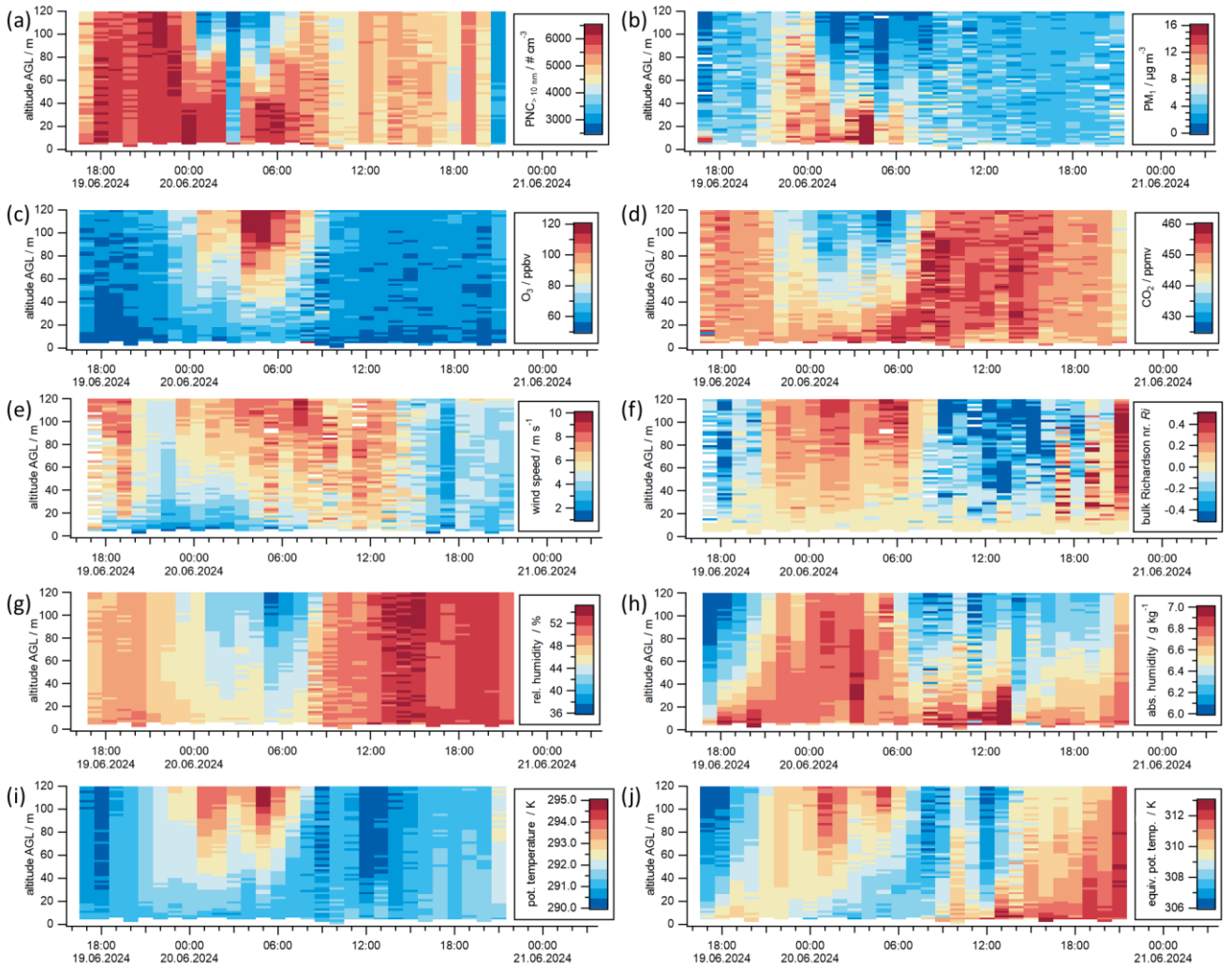


Figure S3: Hourly high-resolution (2 m bins) vertical profiles throughout a full day and night during BISTUM24, including: the particle number concentration measured with the CPC ($\text{PNC}_{>10 \text{ nm}}$) (a), PM_{10} (b), O_3 (c), CO_2 (d), wind speed (e), bulk Richardson number (f), relative and absolute humidity (g and h), and potential and equivalent potential temperature (i and j).

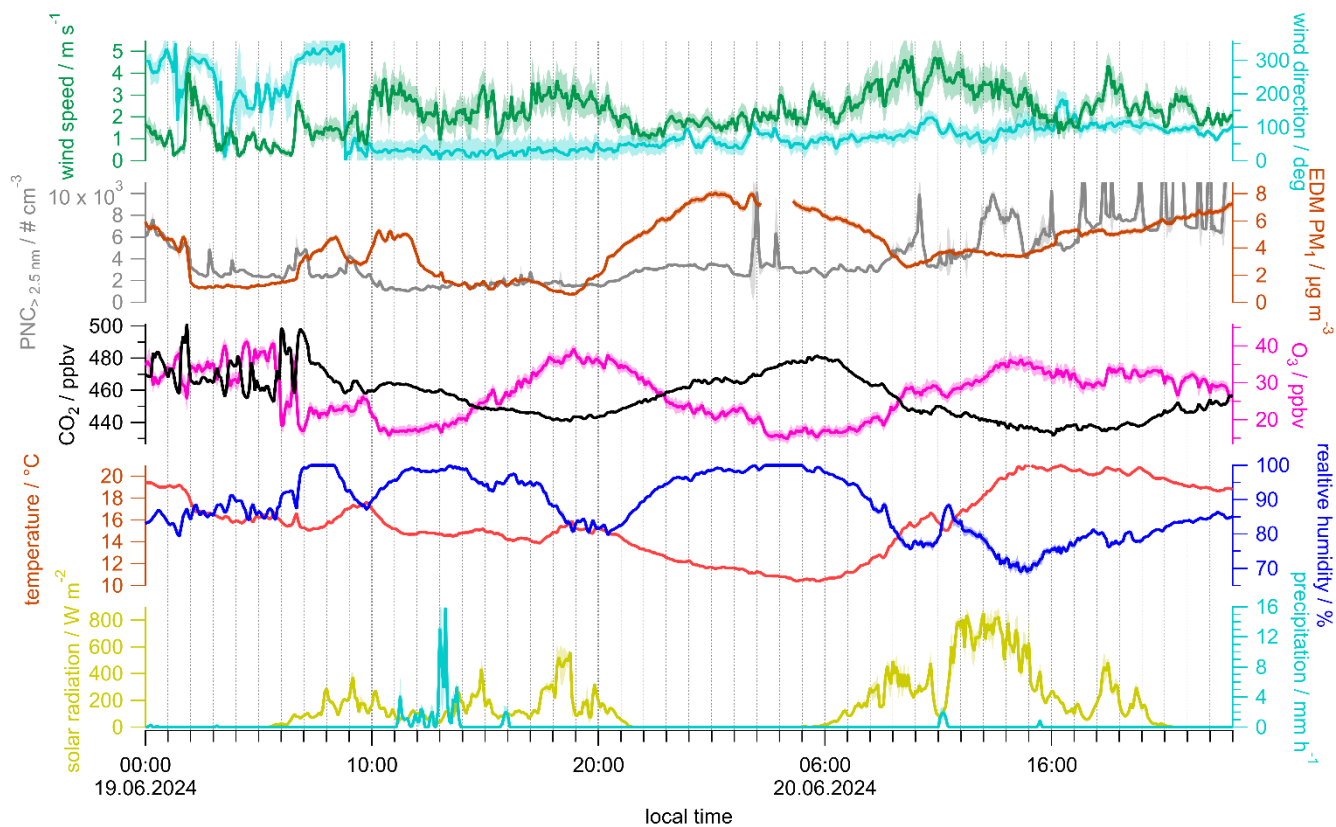


Figure S4: Ground-based measurements on June 19 to June 21, 2024 show low solar irradiation on June 19 and fog between 03:00 and 05:00 on June 20 that led to an increase of the measured PM₁ (dried, orange) and particle number concentration (grey), but a strong reduction of O₃ (pink), while air temperature (red), wind (green and turquoise) and CO₂ (black) appear unchanged.

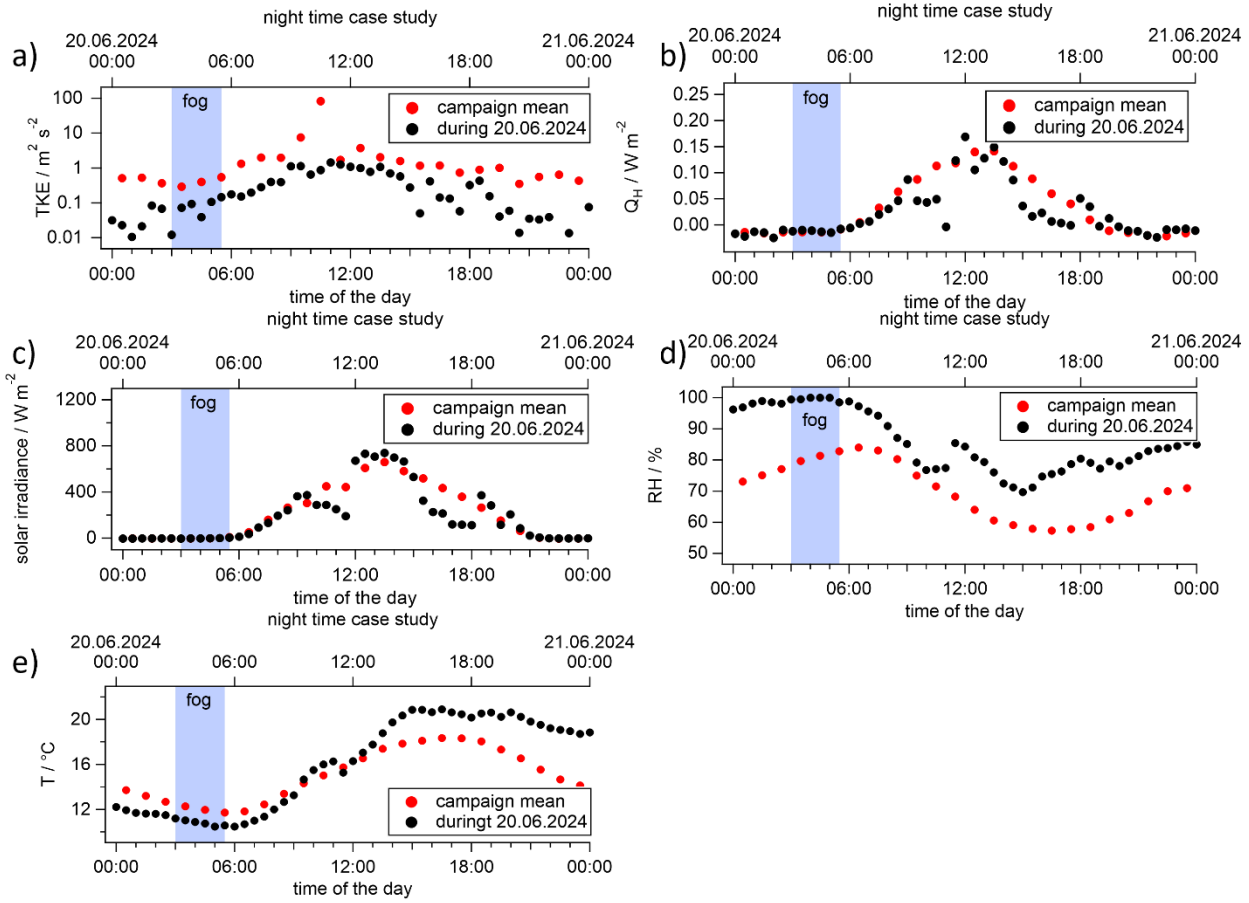


Figure S5: The comparison of the thermodynamical variables turbulent kinetic energy (a), latent heat flux (b), solar irradiance (c), relative humidity (d) and the temperature (e) between the night of the case study and the diurnal mean of the campaign shows similar irradiance and latent heat flux levels, while the turbulent kinetic energy is decreased in the case study night. Available energy is consumed to dry the air rather than to enhance convective mixing, which postpones the expansion of the lowermost atmospheric layer.

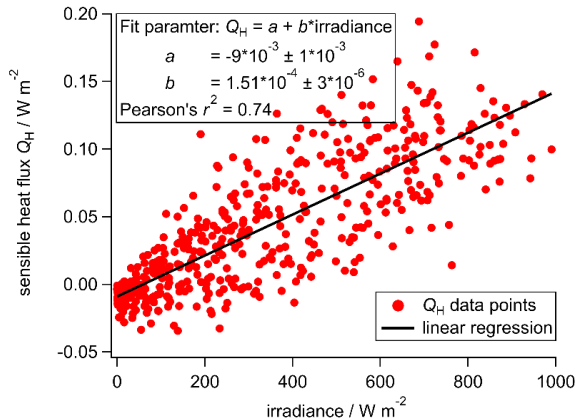
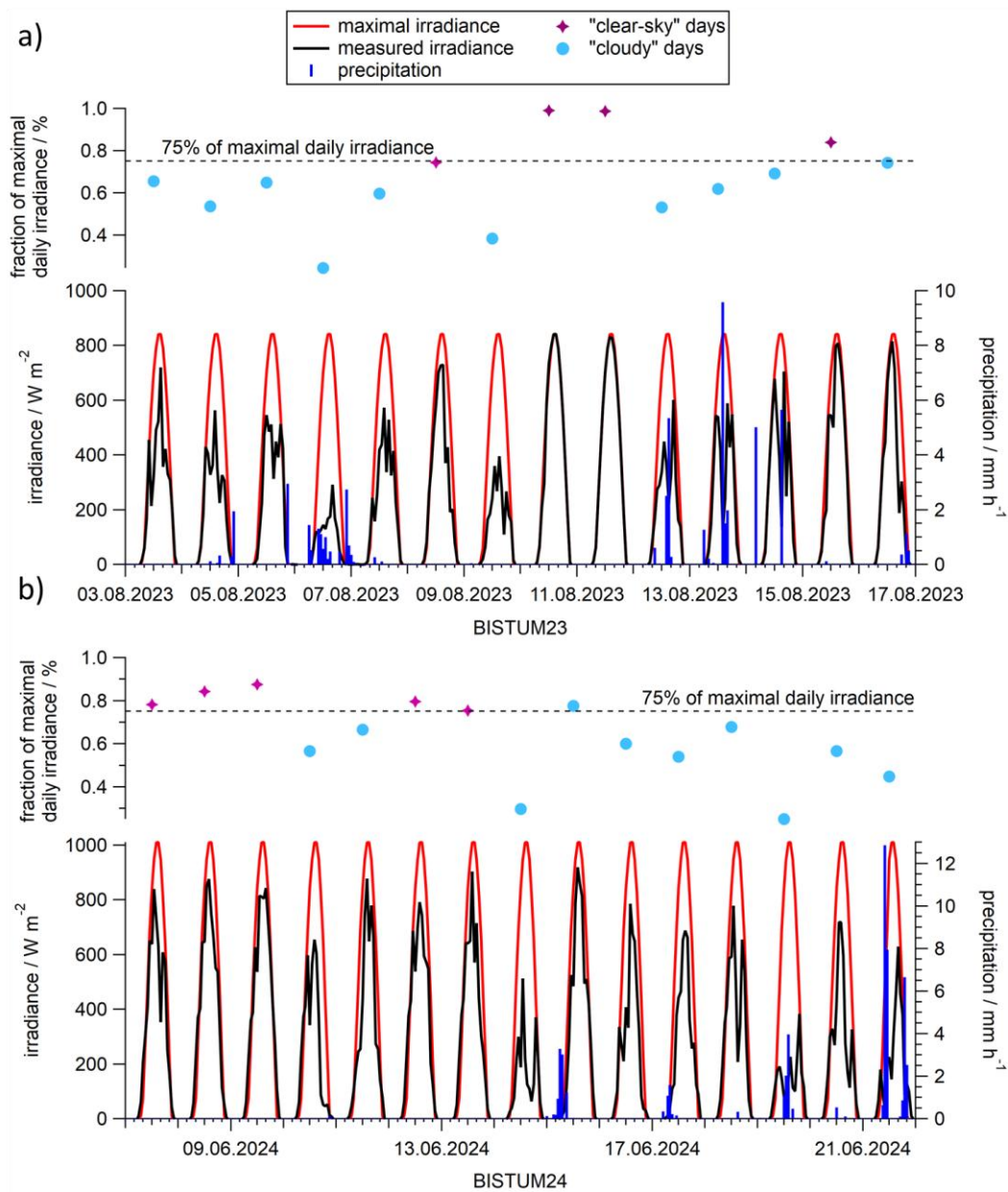


Figure S6: The sensible heat flux plotted versus solar irradiance during BISTUM24 show a good correlation (Pearson's $r^2 = 0.74$).



40 **Figure S7:** “Clear-sky” days (violet markers) and “cloudy” days (bluish markers) were classified by the criteria whether more or less than 75% of maximal daily possible irradiance (red traces) were measured (black traces) integrated throughout a day, respectively, and that precipitation (blue) was less/more than 5 mm day⁻¹. The classification of individual days is displayed for BISTUM23 (a) and BISTUM24 (b).

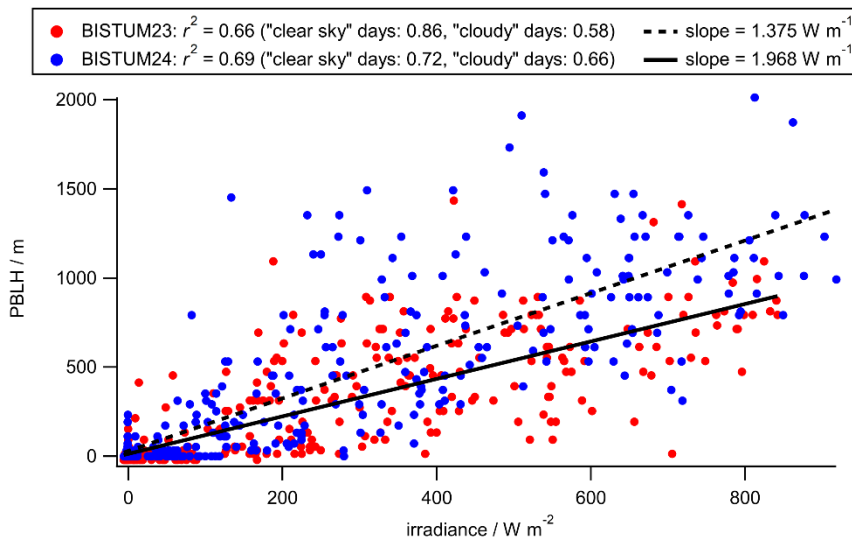


Figure S8: The modeled planetary boundary layer height (PBLH) versus the irradiance show a linear relationship for BISTUM23 (red) and BISTUM24 (blue). The respective Pearson's correlation coefficients r^2 are higher for only "clear sky days compared to when solely "cloudy" days are considered.

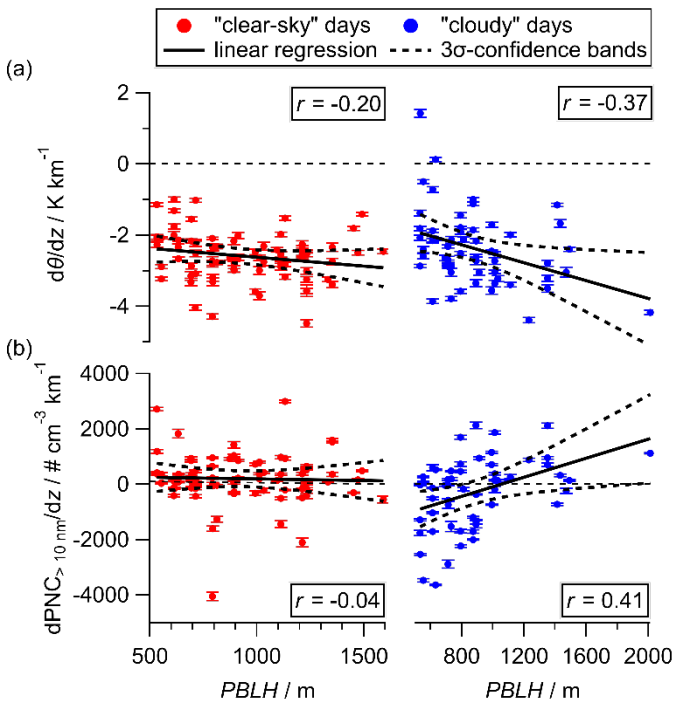


Figure S9: Gradients of the potential temperature θ (a) and the particle number concentration $\text{PNC}_{>10 \text{ nm}}$ (b) in the lowermost 500 m in a mixed PBL from both campaigns versus the non-logarithmic planetary boundary layer height (PBLH, in m). Linear regression and its 3 σ -confidence bands are depicted in solid and dotted lines.

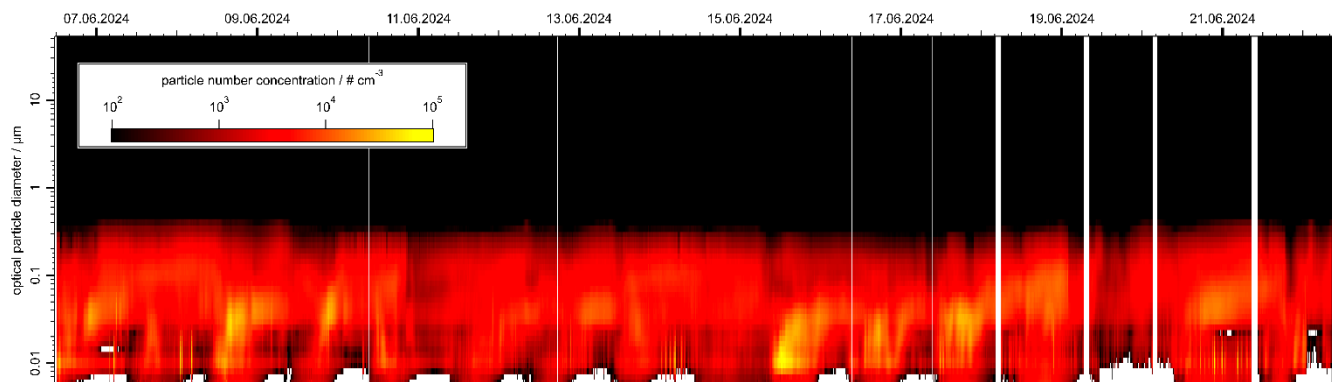


Figure S10: Throughout BISTUM24, the merged particle size distribution (described in Pikmann et al., 2024) shows new particle formation events almost daily. New particle formation is indicated by the growth of sub-10 nm particles after noon and is further described in Kulmala et al. (2004).

55

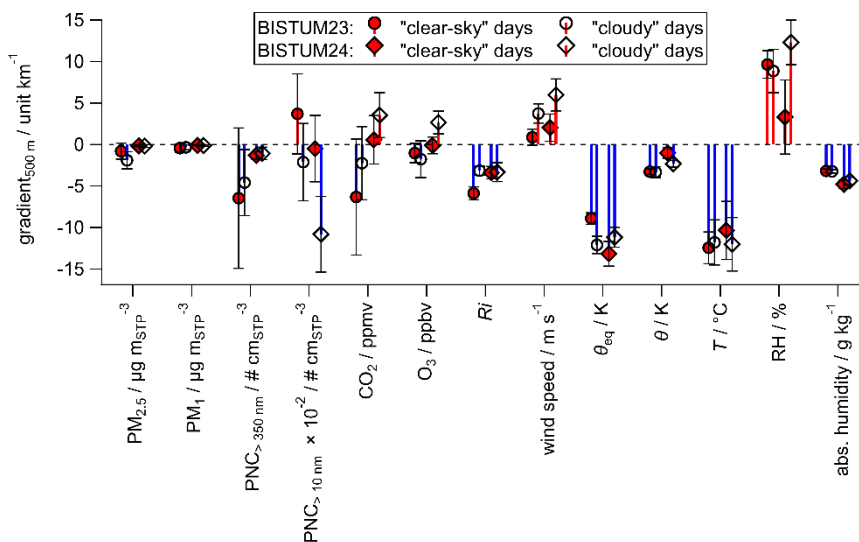


Figure S11: Vertical gradients in the lowermost 500 m in a mixed PBL for meteorological and trace matter variables during two campaigns (circles and diamonds) for “clear-sky” and “cloudy” days (red and white filled markers, respectively). Blue bars show negative, red bars positive gradients, and error bars represent the overall uncertainty, mainly due to day-to-day variability.

60

References

- Drewnick, F., Böttger, T., von der Weiden-Reinmüller, S. L., Zorn, S. R., Klimach, T., Schneider, J., and Borrmann, S.: Design of a mobile aerosol research laboratory and data processing tools for effective stationary and mobile field measurements, *Atmospheric Measurement Techniques*, 5, 1443-1457, <https://doi.org/10.5194/amt-5-1443-2012>, 2012.
- 65 Kulmala, M., Vehkamäki, H., Petäjä, T., Dal Maso, M., Lauri, A., Kerminen, V. M., Birmili, W., and McMurry, P. H.: Formation and growth rates of ultrafine atmospheric particles: a review of observations, *Journal of Aerosol Science*, 35, 143-176, <https://doi.org/10.1016/j.jaerosci.2003.10.003>, 2004.
- Moormann, L., Böttger, T., Schuhmann, P., Valero, L., Fachinger, F., and Drewnick, F.: The Flying Laboratory FLab: development and application of a UAS to measure aerosol particles and trace gases in the lower troposphere, *Atmos. Meas. Tech.*, 18, 1441-1459, <https://doi.org/10.5194/amt-18-1441-2025>, 2025.
- 70 Pikmann, J., Drewnick, F., Fachinger, F., and Borrmann, S.: Particulate emissions from cooking: emission factors, emission dynamics, and mass spectrometric analysis for different cooking methods, *Atmos. Chem. Phys.*, 24, 12295-12321, <https://doi.org/10.5194/acp-24-12295-2024>, 2024.