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Saharan dust outbreaks frequently propagate over the tropical Atlantic, but only few in-situ and ground-based remote sensing observations exist over the region. Here, we document data from EXperiments with the Portable Observatory for aeRosol Transport ("EXPORT") conducted during the expeditions M207 and M208 aboard the German research vessel *R/V METEOR*.

5 The expedition M207 commenced on January 3, 2025, departing from Belém, Brazil, and concluded in Mindelo, Cabo Verde, on February 11, 2025. Expedition M208 both started and ended in Mindelo, Cabo Verde and lasted from February 15, 2025 until March, 17 2025. Throughout the expeditions, continuous measurements of aerosols and meteorological conditions were carried out. The data collection covers three distinct several-day long Saharan dust events, with the first plume over the tropical mid-Atlantic and the latter two dust plumes closer to the African continent.

Using an optical particle counter (OPC), we measured in-situ concentrations of particulate matter and size distribution information up to a diameter of $\sim 35 \mu\text{m}$. We further determined particle size distribution, elemental composition, and deposition rates derived from scanning electron microscopy coupled with energy-dispersive X-ray analysis (SEM-EDX). CALITOO and MICROTOPS sun photometers gave aerosol optical depth for several wavelengths. A Vaisala CL61 ceilometer allowed retrievals for fine-scale structure of aerosol layers including depolarization measurements. Moreover, we collected measurements from an optical disdrometer, a broadband radiation sensor, a wind lidar, and almost 90 launches of radiosondes to facilitate improved data interpretation. We here document the collected data sets from EXPORT including first comparison to reanalysis data sets and the ship's own meteorological sensors. Illustrative examples of the data focus on measurements during the three dust outbreaks over the tropical Atlantic.

The datasets presented in this study are publically available at <https://doi.org/10.1594/PANGAEA.983389> (Wahl et al., 2025a), <https://doi.org/10.1594/PANGAEA.983348> (Wahl et al., 2025b), <https://doi.org/10.1594/PANGAEA.983120> (Wahl et al., 2025c), <https://doi.org/10.1594/PANGAEA.995914> (Kanngießer and Wahl, 2026a), <https://doi.org/10.1594/PANGAEA.996258> (Wahl and Kanngießer, 2026a), <https://doi.org/10.1594/PANGAEA.983118> (Wahl et al., 2025d), <https://doi.org/10.1594/PANGAEA.983117> (Wahl et al., 2025e).



1594/PANGAEA.983121 (Wahl et al., 2025e), <https://doi.org/10.1594/PANGAEA.988728> (Wahl et al., 2026a), <https://doi.org/10.1594/PANGAEA.983119> (Wahl et al., 2025f), <https://doi.org/10.1594/PANGAEA.983388> (Wahl et al., 2025g), <https://doi.org/10.1594/PANGAEA.983350> (Wahl et al., 2025h), <https://doi.org/10.1594/PANGAEA.983128> (Wahl et al., 2025i), <https://doi.org/10.1594/PANGAEA.995915> (Kanngießer and Wahl, 2026b), <https://doi.org/10.1594/PANGAEA.996259> (Wahl and Kanngießer, 2026b), <https://doi.org/10.1594/PANGAEA.983126> (Wahl et al., 2025j), <https://doi.org/10.1594/PANGAEA.983129> (Wahl et al., 2025k), <https://doi.org/10.1594/PANGAEA.988729> (Wahl et al., 2026b), and dship.o2a-data.de (Universität Hamburg, Meteor, 2025).

30 1 Introduction

Dust aerosol is one of the most abundant aerosol components in the atmosphere by mass, contributing more than half of the total global aerosol burden (Textor et al., 2006). Mineral dust aerosol particles have direct effects on radiative transfer in Earth's atmosphere via the scattering and absorption of solar and terrestrial radiation (Di Sarra et al., 2011; Ryder et al., 2013) and indirect effects on cloud microphysical processes by acting as cloud condensation nuclei (CCN) and ice nuclei (IN) (Choobari et al., 2014; DeMott et al., 2003). Dust particles also play a role in biogeochemical cycles by providing nutrients to ecosystems, that are for instance relevant for the growth of phytoplankton in the ocean (Jickells et al., 2005; Mahowald et al., 2005). In addition, dust aerosols are known to affect air quality (Goudie, 2014; Morman and Plumlee, 2014).

The Sahara Desert is one of the largest and most active sources of atmospheric mineral dust in the world (Schütz et al., 1981). Under favourable meteorological conditions, North African dust particles can be uplifted and transported over a long distance including the tropical Atlantic (Rittmeister et al., 2017). It is known for some time that millions of tons of mineral dust are transported annually from the Sahara Desert across the Atlantic Ocean (Schütz et al., 1981; Goudie and Middleton, 2001). Mineral dust originating from North Africa can reach as far as the Caribbean Sea and the Amazon Basin (e.g., Yu et al., 2015b, a; Haarig et al., 2017a). An analysis by Yu et al. (2015a) of observations with the space-borne Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument between 2007 and 2013, suggest that 43 Tg of 182 Tg North African dust (dust at 15°W) reach the Caribbean (dust at 75°W). Prior studies, relying on observations and modelling, suggest a mean annual dust deposition over the Atlantic Ocean of $194.30 \pm 59.39 \text{ Tg yr}^{-1}$ (see Proestakis et al., 2025, and references therein) with considerable uncertainty, namely a range of 70 – 349 Tg yr⁻¹ (Kim et al., 2014; Proestakis et al., 2025). A recent investigation by Proestakis et al. (2025) of dust deposition based on a four-dimensional dust datasets, derived from 22 years of satellite observations and validated with sediment traps, suggests an annual dust deposition in the Tropical and North Atlantic of $243.93 \pm 23.89 \text{ Tg yr}^{-1}$. The spread in deposition estimates highlight the substantial uncertainty surrounding the magnitude of desert dust transport. This uncertainty underlines the necessity of observations over the tropical Atlantic — to better characterize and understand dynamics of dust transport.

Measurements of dust deposition and dust size distributions are rare over the oceans, but valuable to better understand the processes involved. The data from deposition measurements for instance provide insights into the rates at which mineral dust particles deposit, which can vary due to a range of factors, including meteorological conditions and particle characteristics.



Observational data from field campaigns and monitoring networks are supporting the development of deposition models, ultimately contributing to more accurate predictions of dust behaviour and its environmental impacts (Schulz et al., 2012; Waza et al., 2019; van der Does et al., 2024). Measuring aerosol size distributions permit insights into aerosol dynamics, sources, and atmospheric processes (Vu et al., 2015; Liang et al., 2020). Previous research (cf. Maring et al., 2003) has shown that aerosol properties such as size evolve significantly during atmospheric transport, yet key uncertainties remain — particularly regarding the influence of dynamic processes on particle modification and transport distances.

Past studies have characterized Saharan dust over the Atlantic Ocean using multiple platforms and sensors. Examples include ground-based instruments deployed on ships and moorings (e.g., Van Der Does et al., 2016; Rittmeister et al., 2017; Bohlmann et al., 2018; García et al., 2025; Ansmann et al., 2017) or located on islands (e.g., Ansmann et al., 2011; Haarig et al., 2017a, 2019; Marinou et al., 2023; Niedermeier et al., 2014; Waza et al., 2019; Ryder et al., 2018; Weinzierl et al., 2017), satellite observations (e.g., Prospero et al., 2002; Wang and Liu, 2014; Kim et al., 2014; Yu et al., 2015a; Proestakis et al., 2025), airborne measurements (e.g., Weinzierl et al., 2017; Ryder et al., 2018; Haarig et al., 2019) and model simulations (e.g., Wong et al., 2008; Kallos et al., 2006; Kim et al., 2014; Ansmann et al., 2017). Remote sensing instruments, operated at different locations and during several seasons, provide information on lofted aerosol plumes (cf., Rittmeister et al., 2017; Bohlmann et al., 2018; Ansmann et al., 2017; Haarig et al., 2017a, 2019; Weinzierl et al., 2017). The deployment of sediment traps along $\sim 12^\circ\text{N}$ allowed to study dust deposition and highlighted a modal dust particle diameter between $4 - 32\ \mu\text{m}$, which is higher than commonly used in models (Van Der Does et al., 2016). Furthermore, seasonal changes in particle sizes were found, with the largest average modal dust grain size being recorded during summer in the sediment trap closest to the African continent (Van Der Does et al., 2016). While remote sensing observations provide indications of the particle size distribution (Bohlmann et al., 2018; Haarig et al., 2017a; Ansmann et al., 2017; Rittmeister et al., 2017, e.g.), in-situ observations have provided more detailed information on particle size distributions, yielding a mode between $1 - 4\ \mu\text{m}$ (Ryder et al., 2018; Niedermeier et al., 2014; Weinzierl et al., 2017) with substantial giant mode particles ($d > 20\ \mu\text{m}$) reported from an aircraft campaign by Ryder et al. (2018). A comparison of dust aerosol profiles observed by lidar found good to reasonable agreement with dust forecasts with degrading forecast quality further away from dust source regions (Ansmann et al., 2017).

Despite past efforts, the understanding of long-range Saharan dust transport over the tropical Atlantic remains poor. In particular, in-situ observations of dust properties and deposition over the open ocean are scarce, which limits our ability to improve model simulations and understand the mechanisms governing dust transport and deposition. Especially, co-located measurements of atmospheric conditions are beneficial for assessing the meteorological drivers.

We present new measurements of aerosols and meteorological conditions during two expeditions as part of the *EXperiments with the Portable Observatory for aeRosol Transport* ("EXPORT") aboard the *R/V METEOR*. EXPORT aims to collect data to better understand the governing mechanisms for the transport, and deposition, as well as the effects of aerosols, here with focus on Saharan dust outbreaks to the tropical North Atlantic, including the upwelling regions off the West African coast. Specifically, data collected during EXPORT provides in-situ and remote sensing observations of aerosol particles and meteorological observations, e.g., radiation, precipitation, cloud base height, and winds. The primary purpose of this article is to document the



90 comprehensive dataset of EXPORT and provide a first analysis to support future research of aerosol transport and its driving mechanisms over the tropical Atlantic.

2 Data and methods

2.1 Portable Meteorological Observatory (PortMeteO)

PortMeteO has been designed for aerosol and meteorological measurements in the field, here for the usage on board of a
95 research vessel with the aim to collect co-located meteorological and aerosol data to better understand atmospheric dynamics involved in the trans-Atlantic transport of Saharan dust. In this regard, given the critical role meteorological factors play in dust transport (Tai et al., 2010; Schepanski et al., 2017; Dhital et al., 2020), understanding their influence is essential for analysing the spatiotemporal variability of dust events. A summary of the instruments used, and their corresponding measured parameters is provided in Table 1. Figure 1 shows the locations of the PortMeteO instruments on the fifth and sixth decks of
100 the *R/V METEOR*.



Table 1. Summary of instruments and their measured parameters

Instrument	Manufacturer	Measured Parameter(s)	Time Resolution	File Format
Vaisala CL61 Ceilometer	Vaisala Oyj, 00421 Helsinki, Finland	Cloud base height Attenuated backscattering coefficient (β_{par}) Linear volume depolarization ratio (δ_{par})	1 min	netCDF
Disdrometer (OTT Parsivel ²)	OTT Hydromet, 87437 Kempten, Germany	Size and speed of falling hydrometeors	1 min	netCDF
Broadband Radiation Station	Kipp & Zonen, 2628 XH Delft, The Netherlands	Shortwave (solar) and longwave (terrestrial) radiation	Approx. 10 second	ASCII
Calitoo Handheld Sun Photometer	Tenum, 31200 Toulouse, France	Aerosol Optical Depth (τ) and Ångström exponent	opportunistic	ASCII
Optical Particle Counter (OPC) "Environmental Dust Monitor (EDM 264)"	Grimm Aerosol Technik, 83404 Ainring, Germany	Dust mass fractions (TSP, PM ₁₀ , PM ₄ , PM _{2.5} , PM ₁ , PM _{coarse}); inhalable, thoracic, respirable PM; total concentration (TC); size distribution (31 bins)	1 min	ASCII
Radiosondes (Vaisala RS41-SGP)	Vaisala Oyj, 00421 Helsinki, Finland	Vertical profiles (e.g., wind speed and direction, and temperature) of atmospheric conditions	opportunistic	netCDF
MICROTOPS II handheld sun photometer	Solar Light, PA 19038, Glennside, USA	Aerosol Optical Depth, Ångström exponent, Precipitable Water Vapour	opportunistic	ASCII
Flat Plate Passive Sampler**	-	Aerosol chemical composition; deposition rate	Approx. 1 day	ASCII
Doppler Wind Lidar (Vaisala WindCube 2.0 WLS7) motion-corrected**	Vaisala Oyj, 00421 Helsinki, Finland	wind speed/direction Backscatter intensity (Carrier-to-Noise Ratio [CNR])	Approx. 1 sec, and 10 min	ASCII / netCDF

Note: Instruments marked with “**” have been provided by partners and are not part of PortMeteO.

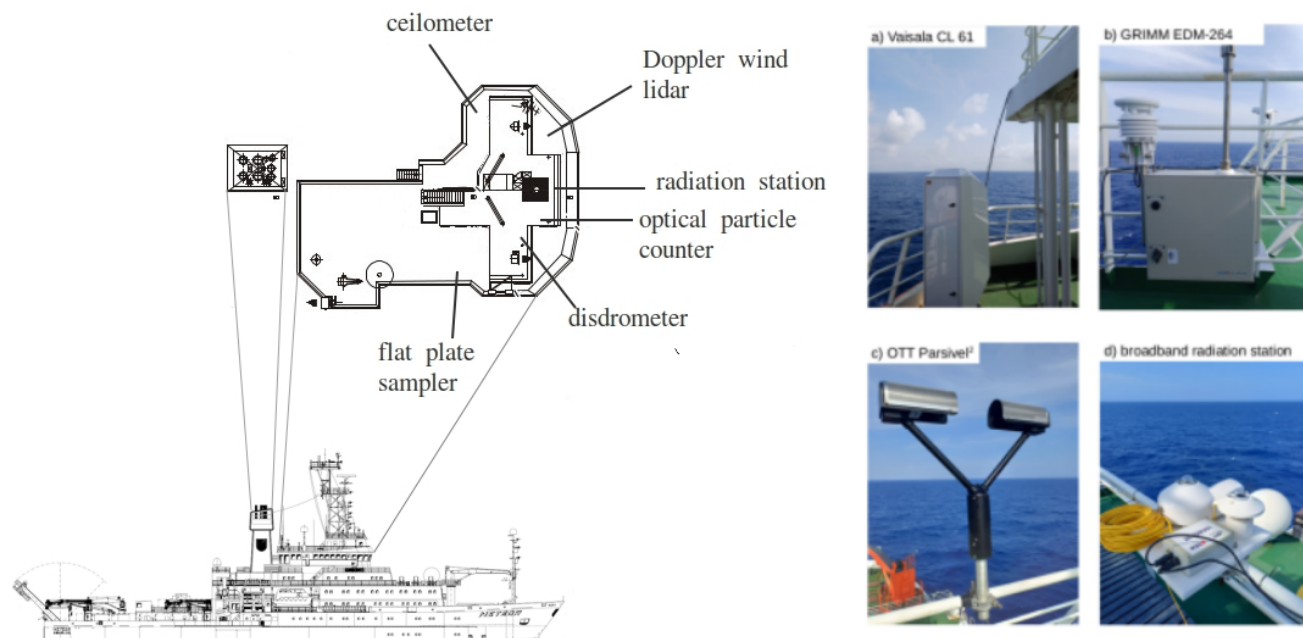


Figure 1. Locations of the instruments on the upper decks of R/V METEOR. Photos show the PortMeteO instruments. The Doppler wind lidar and the flat plate sampler, which were provided by Fraunhofer IWES and Technische Universität Darmstadt, respectively, are not shown. Schematic depiction on the left is modified with permission by German Research Fleet Coordination Center (Leitstelle Deutsche Forschungsschiffe). All photos were provided by F. Kanngießer.

2.1.1 Optical particle counter

We used the optical particle counter (OPC) "Environmental Dust Monitor" (EDM 264, see Fig. 1b) to continuously monitor surface concentrations of particulate matter. The OPC inlet was installed away from the exhaust outlet of the research vessel, positioned such that sampled air was not strongly affected by exhaust plumes but approximately represent ambient atmospheric conditions encountered during the expeditions. The instrument's aerosol spectrometer (11-DM) is housed in a weatherproof enclosure, along with electronics and pneumatics for controlling the air flow, a heated sampling system, and meteorological sensors for air pressure and internal temperature. The output of the instrument includes six particulate matter (PM) mass fractions: TSP (Total Suspended Particles), PM_{10} , PM_4 , $PM_{2.5}$, PM_1 , and PM_{Coarse} , which are calibrated against measurements from filter collectors with gravimetric mass determination. The data record of the instrument also contains inhalable, thoracic, respirable dust mass fractions and three PM fractions for indoor applications (not used here). Additionally, the instrument provides measurements of total particle concentration and particle number concentration (PNC) across 31 equidistant channels (Grimm Aerosol Technik Ainring GmbH & Co. KG, 2022).

The PM measurements allow to identify periods dominated by dust particles. The concentration of PM is a regulated air quality parameter that quantifies the mass of atmospheric aerosols, serving as an indicator of ambient air pollution. In this



context, previous studies — for example, those by Querol et al. (2009); Petroselli et al. (2024) — have utilized PM_{10} concentrations to assess the contribution of Saharan dust to background PM_{10} levels. Past studies have used thresholds of the daily mean PM_{10} concentrations ranging from $28\mu\text{g m}^{-3}$ to $50\mu\text{g m}^{-3}$ to indicate increased aerosol burden due to mineral dust (Prospero and Lamb, 2003; Wang et al., 2007; Euphrasie-Clotilde et al., 2020; Plocoste et al., 2022; Querol et al., 2009; Petroselli et al., 2024). For instance, Prospero and Lamb (2003) found that during substantial Saharan dust intrusions, PM_{10} concentrations typically exceed $45\mu\text{g m}^{-3}$. They used this threshold to distinguish between background and dust-affected conditions. In a similar context, studies of dust storms in China have found that PM_{10} concentrations often surpass $50\mu\text{g m}^{-3}$ during major dust events, with concentrations above $45\mu\text{g m}^{-3}$ serving as a threshold for detecting dust events (Wang et al., 2007). In the Caribbean, a $28\mu\text{g m}^{-3}$ threshold for PM_{10} has been identified as the lower limit for detecting African dust events, based on spatio-temporal analysis and back-trajectory validation (Plocoste et al., 2022). Alternatively, another assessment in the Caribbean Basin proposed a slightly higher threshold of $35\mu\text{g m}^{-3}$ to improve detection accuracy and account for regional variations in dust transport (Euphrasie-Clotilde et al., 2020). Here, we use a threshold of daily mean $\text{PM}_{10} > 30\mu\text{g m}^{-3}$ to detect the presence of mineral dust at surface level.

Moreover, the ratio of $\text{PM}_{2.5}/\text{PM}_{10}$ can be used as additional indicator for coarse dust particles. High (low) $\text{PM}_{2.5}/\text{PM}_{10}$ indicates an aerosol mixture dominated by fine (coarse) particles. Observations of Saharan dust over the Canary Islands and the Iberian Peninsula (Rodríguez and López-Darias, 2024), Saharan dust over Bulgaria (Evgenieva et al., 2024), and Asian dust in China (Filonchik et al., 2026) suggest typical $\text{PM}_{2.5}/\text{PM}_{10}$ values for dust occurrence at ~ 0.3 or below. Aerosol particles from anthropogenic sources, including traffic, industrial activity and biomass burning have been associated with $\text{PM}_{2.5}/\text{PM}_{10} > 0.5$ (Rodríguez and López-Darias, 2021; Xu et al., 2017; Gehrig and Buchmann, 2003; Rodríguez and López-Darias, 2024). Based on reported values, $\text{PM}_{2.5}/\text{PM}_{10} < 0.4$ was chosen here as dust identification criterion.

2.1.2 Sun photometer

Estimating the radiative effects of aerosols requires an understanding of aerosol optical properties. This includes the aerosol optical depth (τ). We collect measurements of τ in direct sunlight with four handheld sun photometers, which are manually operated on the fifth deck.

The MICROTOPS II hand-held multi-band Sun Photometer (SPM) was used to characterize the aerosol optical depth (τ) and the Ångström exponent (α) of atmospheric particles (Ichoku et al., 2002; Smirnov et al., 2002), provided by the National Aeronautics and Space Administration (NASA). To ensure high data quality two different instruments, specifically calibrated for the respective research cruise, were used; for M207 the instrument with the ID 28793 was used, and during M208 the instrument with ID 22499. Both instruments were calibrated before and after the expeditions, following the standard procedure described by Smirnov et al. (2009). The measurements with MICROTOPS contribute to NASA's Maritime Aerosol Network (MAN, e.g. Smirnov et al., 2009), as part of the Aerosol Robotic Network (AERONET, e.g., (Holben et al., 1998)). The instrument also measures precipitable water vapor (PWV) in the path of direct sunlight. The MICROTOPS II instruments used here have four channels for the wavelengths 380 nm, 440 nm, 675 nm, and 870 nm. Aerosol optical depth (τ) is often reported



for 500 nm (Voss et al., 2001; Xie et al., 2018; Gong et al., 2014). During data processing by the NASA MAN team, the
 150 Ångström exponent was being used to obtain τ at 500 nm. The Ångström exponent between two wavelengths is defined as:

$$\alpha = \frac{\log(\tau(\lambda_1)/\tau(\lambda_2))}{\log(\lambda_2/\lambda_1)}. \quad (1)$$

In the MAN dataset, α is reported based on a least-squares fit over the entire measured spectral range (Smirnov et al., 2011).

The τ data from the MICROTOS II are available with three processing levels: level 1.0, which is the original data without
 additional screening for cloud edges; level 1.5, which includes cloud screening; and level 2.0, which incorporates both cloud
 155 screening and additional quality assurance, such as evaluation of filter degradation and other potential instrument problems
 (Smirnov et al., 2009, 2011).

The spectral dependence of τ and hence α , allows us to infer information on the dominant particle size in the column
 (Schuster et al., 2006; Dubovik et al., 2002). A threshold of $\alpha = 0.6$ is often adopted in aerosol studies to distinguish dust-
 dominated conditions from those influenced by fine-mode particles. This value has been used in previous studies as a criterion
 160 for identifying mineral dust influence, particularly over arid and semi-arid regions, including Cabo Verde (cf. Schepanski et al.,
 2007; Dubovik et al., 2002; Cuevas et al., 2015; Basart et al., 2009), which is near to our expedition area.

In addition to the MICROTOS II sun photometer, three CALITOO sun photometers, were used to conduct further tests of
 the comparably low-cost instruments in marine conditions. These instruments were previously found to have a high calibration
 stability and strong agreement with ground-based AERONET observations, as well as satellite-borne MODIS observations and
 165 aerosol reanalysis (García et al., 2025). CALITOO sun photometers measure τ at wavelengths of 465 nm, 540 nm, and 619 nm
 and calculate the α as the regression slope of the measured τ analogously to MAN data (Tenum, 2020). We specifically used
 instruments with the IDs #443, #444, and #445 during M207, and the instruments with the IDs #443, and #444 during M208.

2.1.3 Ceilometer

Combining sun photometer measurements, which provide information on the entire atmospheric column, with activate instru-
 170 ments, yields more detailed information on the vertical structure and distribution of aerosol layers (cf. Sicard et al., 2015;
 Tsekeri et al., 2023). For this purpose, PortMeteO includes a lidar ceilometer CL61 with depolarisation capabilities (see Fig.
 1a). The CL61 operates at a wavelength of $\lambda = 910.55$ nm and provides profiles of the attenuated backscattering coefficient β_{vol}
 and the linear volume depolarisation ratio δ_{vol} (Vaisala Oyj, 2022). With the help of internal data processing, the CL61 provides
 cloud base height for up to five cloud layers and cloud coverage in okta, with some known measurement errors (Wagner and
 175 Kleiss, 2016)

Measured quantities of the ceilometer include signal contributions from both aerosol layers and air molecules. The parti-
 cles' signal contribution is extracted following the method outlined by Ansmann and Müller (2005). Specifically, the particle
 backscattering coefficient β_{par} is obtained by subtracting the molecular backscattering contribution, which is calculated fol-
 lowing the formulas reported by Bucholtz (1995) and taking pressure and temperature profiles from the 1976 US Standard
 180 Atmosphere (U.S. Committee on Extension of the Standard Atmosphere, 1976). The linear particle depolarisation ratio is cal-



culated following the approach by Freudenthaler et al. (2009), utilising the definition of the linear molecular depolarisation ratio as reported by Bates (1984); Bodhaine et al. (1999).

The linear particle depolarisation ratio provides useful information on particle microphysical properties (Tesche et al., 2019) and is often used for aerosol typing (e.g., Omar et al., 2009; Illingworth et al., 2015; Kim et al., 2018). So far, few observations
 185 of the depolarisation ratio of mineral dust aerosol at $\lambda = 910.55 \text{ nm}$ have been reported with $\delta_{\text{par}} \sim 0.25 - 0.35$ (Francis et al., 2023). However, mineral dust aerosol commonly has a linear particle depolarisation ratio of $\delta_{\text{par}} \sim 0.3$ at a wide spectral range (e.g., Shin et al., 2018; Kahnert et al., 2020; Floutsi et al., 2023b, a). While dried sea salt may possess similarly elevated values of δ_{par} (e.g., Kanngießer and Kahnert, 2021; Kahnert and Kanngießer, 2024, and references therein), it typically occurs in geometrically thin layers at the top of the marine boundary layer (Haarig et al., 2017b). Hence, if not limited to a geometrically
 190 thin layer, values of $\delta_{\text{par}} \sim 0.3$ are considered to pertain to mineral dust aerosol.

2.1.4 OTT Parsivel²

Wet deposition, i.e., dust aerosol removal with precipitation, is an important process for coarse mode particles (Bergametti and Forêt, 2014). Thus, monitoring rain, can provide information associated with wet deposition. In addition, a flat-plate passive sampler, introduced below, was used to collect aerosol particles for physico-chemical characterisation and to determine the
 195 (dry) aerosol deposition rate. As rain distorts these dry deposition measurements, rain observations are also required for the quality assurance.

We use the OTT Parsivel² disdrometer (see Fig. 1c) for rain measurements, in particular to measure the size and speed of hydrometeors, falling through the instrument's laser sheet (Löffler-Mang and Joss, 2000; Kim and Song, 2018). The instrument provides continuous measurements of one minute averages. The hydrometeor's size is determined from the maximum signal
 200 attenuation. The duration of the hydrometeor-induced signal attenuation, facilitates the fall speed measurement. Fall speed and particle size are classified into 32 separate velocity and size classes (Tokay et al., 2014). Despite being designed to avoid misclassifications by counting multiple smaller droplets as a single larger droplet, this cannot be ruled out (Tokay et al., 2014).

The OTT Parsivel² was previously found to provide droplet size distribution observations between diameters of 0.8 mm and 3.5 mm consistent with other sensor types (Park et al., 2017; Liu et al., 2019). For size bins below 0.8 mm the size distribution
 205 is underestimated due to instrument sensitivity, whereas for size bins above 3.5 mm horizontal movement within the beam introduces an overestimation. Agreement between droplet size distributions observed by OTT Parsivel² disdrometers and other instruments decreases during heavy rainfall, i.e., for rain rates with $R > 10 \text{ mm h}^{-1}$ (Park et al., 2017). Strong winds may further introduce misclassifications of droplet size and fall speed, for example by droplets no longer traveling the shortest distance through the laser sheet (Friedrich et al., 2013).

210 2.1.5 Broad-band radiation station

By interacting with electromagnetic radiation, mineral dust affect short-wave and long-wave radiation transfer in the atmosphere (e.g., Buseck and Pósfai, 1999; Nousiainen and Kandler, 2014; Noreen et al., 2024). We measured short-wave and long-wave radiation fluxes at the surface with a broad-band radiation station. This station consists of a Kipp & Zonen CMP21



pyranometer, a CGR pyrgeometer, and a Kipp & Zonen LogboxSE datalogger (see Fig. 1d). The pyranometer measures irradiance from both diffuse and direct radiation within the wavelength range of 0.28 to 2.8 μm , while the pyrgeometer measures radiation within 4.5 to 42 μm . The radiation station was placed on deck 6 with partial shading by the ship's mast during some times during the day. The high frequency of data gaps during M207 (see Fig. 4) and the subsequent need for maintenance and inspection, prevented installing the radiation station at the mast.

To assess the PortMeteO radiation data, we opted to use measurements from the ship's weather station, which are documented in detail by the German Meteorological Service (Deutscher Wetterdienst, 2023, Deutscher Wetterdienst, DWD, see). The ship's broadband radiation sensors are installed at the highest point of the vessel and are largely unaffected by shading. They were further mounted on gimbals, thus passively adjusted for potential deviations from a horizontal plane due to the ship's movement. However, the DWD sensors were only infrequently inspected for cleanliness during M207. We use data from the ship's weather station to apply a simple filtering for effects of shading on the radiation measurements, which is introduced in Sec. 3.4. We provide direct observations in the original 10s temporal resolution and 1 minute averaged data, filtered for shading.

An observation is considered shaded if the relative difference in observed short-wave radiation between the PortMeteO pyranometer and the ship's radiation sensor exceeds 20% (see also Fig. 12). The ship's radiation sensor is located on the mast's top platform (cf. Fig. 1) and can be considered unshaded. As expected, due to the chosen filtering method based on relative differences, the values are well correlated with Pearson correlation coefficient r of $r = 0.9971$ for M207 and $r = 0.9958$ for M208 (Fig. 2). Similarly expected due to filtering by relative difference, the spread of the values increases with increasing magnitude. The corresponding coefficients of determination (R^2) are $R^2_{\text{M207}} = 0.9884$ and $R^2_{\text{M208}} = 0.9892$, and the root-mean-square error (RMSE) between the two sensors are $\text{RMSE}_{\text{M207}} = 34.81 \text{ W m}^{-2}$ and $\text{RMSE}_{\text{M208}} = 38.75 \text{ W m}^{-2}$. Fig. 2 also shows the distribution of recorded measurements. Here, we only considered value pairs with SW radiation_{PortMeteO} $\geq 10 \text{ W m}^{-2}$, excluding low values, such as night-time observations for which we do not expect any shading effects. For simplicity, we consider this as day-time conditions. The respective measures for the day-time short-wave radiation are $r_{\text{M207}} = 0.9932$, $R^2_{\text{M207}} = 0.9730$, and $\text{RMSE}_{\text{M207}} = 50.41 \text{ W m}^{-2}$ for M207 and $r_{\text{M208}} = 0.9892$, $R^2_{\text{M208}} = 0.9719$, and $\text{RMSE}_{\text{M208}} = 51.48 \text{ W m}^{-2}$ for M208.

2.1.6 Flat-plate Passive Sampler for Aerosol SEM-EDX Analysis

A flat-plate passive sampler (Waza et al., 2019) was used to collect atmospheric aerosol particles by dry deposition for subsequent laboratory analysis of the particles' physico-chemical properties. The design consists of two round brass plates: a top plate with a diameter of 203 mm, and a bottom plate with a diameter of 127 mm, both with a thickness of 1 mm. These plates are separated by a 16 mm gap. Samples were collected on pure carbon adhesive substrates (Spectro Tabs, Plano GmbH, Wetzlar, Germany) mounted to standard SEM aluminium stubs. All adhesive samples were stored in standard SEM storage boxes (Ted Pella Inc., Redding, CA, USA) in dry conditions at room temperature.

The collected samples were analysed via scanning electron microscopy. Individual particle analysis by automated scanning electron microscopy (SEM) (FEI ESEM Quanta 400 FEG, FEI, Eindhoven, The Netherlands) coupled with energy-dispersive

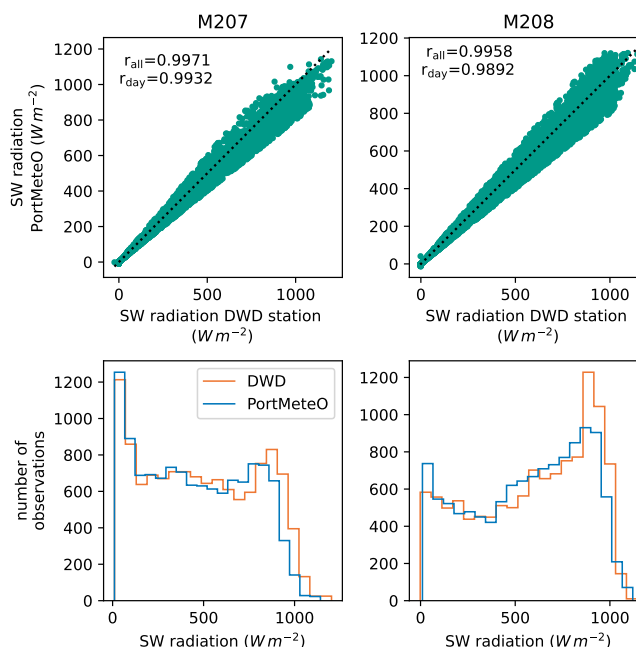


Figure 2. Comparison between filtered shortwave radiation measurements from the PortMeteO radiation station and the DWD-operated ship radiation station for M207 (left) and M208 (right). The top row shows the PortMeteO-values as a function of the corresponding DWD-values. The bottom row shows the distribution of the measured values for day-time conditions, defined as $SW\ radiation_{PortMeteO} \geq 10\ W\ m^{-2}$.

X-ray analysis (EDX) (Oxford X-Max 120, Oxford Instruments, Abingdon, United Kingdom) was used to determine particle size distribution, size-resolved elemental composition, and mixing state of inorganic aerosol particles. This method has been employed in previous research (Kandler et al., 2018, 2007; Ryder et al., 2018; Chou et al., 2008; Kandler et al., 2020). A magnification of 1600 $\times$ (equalling 160 nm per pixel) and an acceleration voltage of 12.5 kV were used. Particles were segmented from the substrate background using the backscatter-electron (BSE) image. The recognized features were then measured for their size and composition, controlled by the system software Oxford Aztec 6.3 (for details refer to Kandler et al. (2018)).

2.1.7 WindCube Vertical Profiling Doppler Wind Lidar

Winds play a critical role in understanding the long-range transport and deposition of aerosols across the North Atlantic by influencing the vertical placement, speed, and direction of aerosol-laden air masses (Dunjon and Velden, 2004). The WindCube 2.0 vertical profiling lidar was placed on deck 5 (see Fig. 1) to measure horizontal wind speed and direction profiles from 40 m to about 300 m, depending on the aerosol backscatter. This pulsed Doppler lidar was continually measuring in DBS (Doppler-Beam-Swinging) mode, where 4 lines of sight measured each cardinal direction at a 28° angle to obtain the horizontal wind components, and a 5th line of sight measuring the vertical wind speed. The recordings of the lidar device are combined with those of a motion measurement setup, comprising an Inertial Measurement Unit (IMU) and a satellite compass that provide



motion data in all six degrees of freedom. Motion data are applied to obtain the corrected wind profile data both with a 1-sec and 10-min temporal resolution – i.e., the correction/processing step is applied at the high-frequency level, and the motion-corrected measurements are then averaged to 10-min mean values.

265 The correction that was applied to the Doppler lidar data is further detailed in Rubio and Gottschall (2022) and uses the vessel's velocity and heading data (course and speed over ground of the vessel) collected by the motion sensors – i.e., an inertial measurement unit and a satellite compass – installed together with the lidar profiler.

For the first part of the campaign, until 2025-02-01, the lidar was set up to measure at 12 levels up to 200m height. After that the maximum measurement height was adjusted to 290m. The reported Carrier-to-Noise (CNR) level is used to control
 270 the quality the measurement, typically leading to a lower data availability at higher altitudes. The reported data comprises the processed 10-min wind time series, including mean horizontal wind speed and direction, at all available height levels AMSL. Additionally reported parameters are the mean CNR in dB and an availability parameter (in %) that indicates the percentage amount of valid height-frequency data points within a 10-min period. Validity is defined based on a threshold for CNR as given by the instrument manufacturer – a typical value for this is -23 dB as lower threshold.

275 During the second half of the M208 cruise, the Trimble satellite compass installed together with the lidar profiler stopped operation until the end of the cruise. As fall-back solution, we used instead the ship's internal navigation data from the Seapath 320 system, accessed via the DSHIP interface, to correct the lidar profiler data for motion impact. To verify this approach, data have been analysed for an overlapping period of five days (starting from 2025-02-22) for which both correction approaches could be applied – see Fig. 3. Deviations between the two corrected wind speed data sets are only marginal, so that the motion-
 280 corrected from both periods can be used without further differentiation.

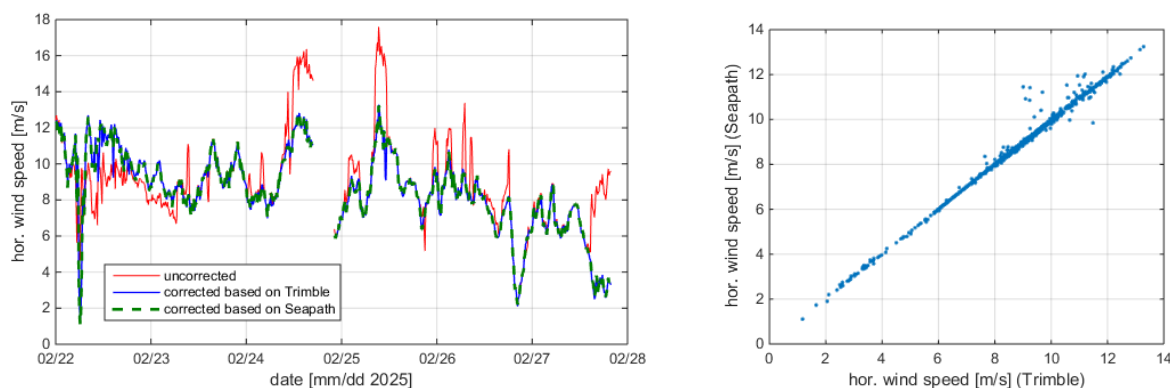


Figure 3. Left: Time series of 10-minute averaged horizontal wind speed measured by Doppler lidar (WLS7) at 100 m AMSL – uncorrected (red) and corrected using either the motion data from Trimble (blue) or Seapath (green, dashed) system. Right: Correlation between the two corrected lidar wind datasets for period of five consecutive days.

For further details on the setup, refer to Gottschall et al. (2018); Rubio et al. (2022, 2025), where the same system setup was used.



2.2 Expeditions M207 and M208

EXPORT aims to collect measurements to study the transport and deposition of aerosols. Measurements of EXPORT were per-
 285 formed during the expeditions M207 and M208 of the German research vessel R/V METEOR. Expedition M207 commenced
 on January 3, 2025, departing from Belém (1.4563° S, 48.5013° W), Brazil, and concluded in Mindelo (16.8840° N, 24.9874°
 W), Cabo Verde on February 11, 2025. The combined track of cruises M207 and M208 (see below) is shown in Fig. 5.

Instruments for automated measurements recorded data continuously, whereas measurements with the sun photometers and
 radiosonde launches were opportunistic depending on the weather conditions. On January 9, 2025, R/V METEOR called the
 290 port of Recife (8.0556° S, 34.8911° W), Brazil, leading to a data gap in all automated measurements between 11:00 UTC and
 19:40 UTC. The flat plate sampler was deployed after leaving the Brazilian Exclusive Economic Zone (EEZ), sampling began
 on January 28, 2025 at 07:45 UTC. The German Weather Service performs daily radiosonde launches within the framework of
 the Automated Shipboard Aerological Programme (Deutscher Wetterdienst, 2023). In addition to these launches, Vaisala RS41-
 SGP radiosondes were launched as part of EXPORT. Eight radiosonde launches were performed during the M207 transect at
 295 7°N. An overview over the data collection periods and instrument specific data gaps during M207 is provided in Tab. 2. The
 radiation station encountered frequent data gaps of different durations. The data availability of the PortMeteO radiation station
 during M207 is documented in Fig. 4.

Instrument	data collection period	comments
1 Ceilometer (Vaisala CL61)	2025-01-06 - 2025-02-11	
1 Wind lidar (Vaisala WindCube2.0 WLS7)	2025-02-16 - 2025-02-09	due to differences in measurement height data is split into period 1 (until 2025-02-01 10:40 UTC) and pe- riod 2 (from 2025-02-01 11:00 UTC)
1 Disdrometer (OTT Parsivel ²)	2025-01-06 - 2025-02-11	
1 Optical particle counter (GRIMM EDM 264)	2025-01-06 - 2025-02-11	data gap on 2025-01-16 between 03:58 - 10:44 UTC
8 Radiosondes (Vaisala RS41-SGP)	2025-01-27 - 2025-01-30	data gap during ascent on 2025-01-27 on 12 UTC launch
1 Flat plate sampler	2025-01-28 - 2025-02-10	
3 Sun photometers (CALITOO)	2025-01-28 - 2025-02-10	
1 Sun photometer (MICROTOPS)	2025-01-08 - 2025-02-10	data processed by and provided via NASA, instru- ment ID 28793
1 Radiation station (CMP21, CGR4)	2025-01-06 - 2025-02-11	frequent data gaps, see Fig. 4 for data availability

Table 2. Overview of data collection during M207. Comments do not include the data gap due to stay in port of Recife, Brazil on 2025-01-09. An overview over performed sensor cleaning is provided in Tab. 4. Links to the individual datasets are provided in the section Data Availability.

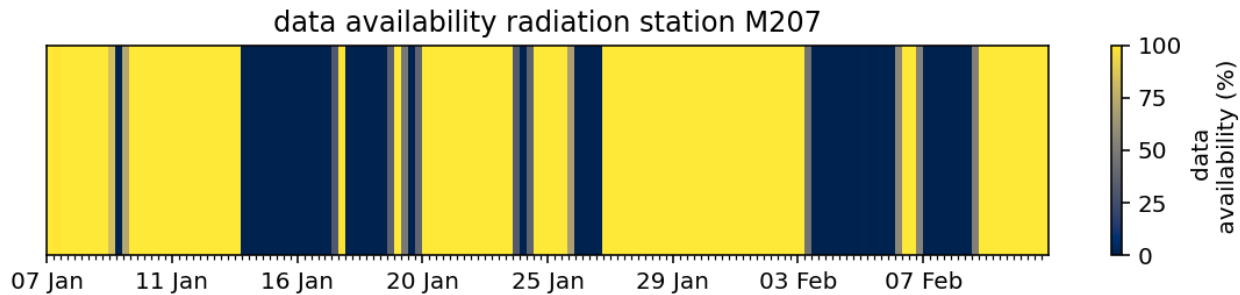


Figure 4. Data availability of radiation data during M207 in six hourly intervals, starting from 2025-01-07, 00:00 UTC until 2025-02-11, 23:59 UTC. Note, the data gap due to calling the port of Recife, Brazil on 2025-01-09 is included.

Expedition M208 started on February 14, 2025 and ended on March 17, 2025. Mindelo acted as both start and end point. Data collection was interrupted due to entering ports and crossing Senegal’s EEZ. Specifically, on February 21, 2025 between 08:00 and 17:00 UTC no data was collected due to entering the port of Mindelo, Cabo Verde. No data was collected on February 24, 2025 16:55 UTC - 22:10 UTC and between February 27, 19:50 UTC and March 1, 02:25 UTC due to crossing Senegal’s EEZ. During M208, in total 80 radiosonde launches were performed at least daily, if the distance to land was sufficiently large. Multiple launches per day with a frequency of up to every three hours were performed between 2025-02-23 – 2025-03-02, and 2025-03-07 – 2025-03-15, with interruptions due to proximity to land and crossing EEZs. Tab. 3 provides an overview of the instrument-specific data collection periods and data gaps.

Instrument	data collection period	comments
1 Ceilometer (Vaisala CL61)	2025-02-16 - 2025-03-15	
1 Wind lidar (Vaisala WindCube2.0 WLS 7)	2025-02-15 - 2025-03-14	motion correction after 2025-02-27 performed with ship’s inertial navigation system, see Sec. 3.2
1 Optical particle counter (GRIMM EDM 264)	2025-02-15 - 2025-03-15	
80 Radiosondes (Vaisala RS41-SGP)	2025-02-16 - 2025-03-15	no launch during 2025-03-03 - 2025-03-06, 2025-03-12
1 Flat plate sampler	2025-02-15 - 2025-03-13	
2 Sun photometers (CALITOO)	2025-02-16 - 2025-03-14	no data collection with CALITOO #445
1 Sun photometer (MICROTOPS)	2025-02-22 - 2025-03-14	data processed by and provided via NASA, instrument ID 22499
1 Radiation station (CMP21, CGR4)	2025-02-15 - 2025-03-15	

Table 3. Overview over data collection during M208. Comments do not include the data gaps in port of Mindelo, Cabo Verde on 2025-02-21, and crossing Senegal’s EEZ on 2025-02-24 and 2025-02-28/2025-03-01. An overview over performed sensor cleaning is provided in Tab. 4. Links to the individual datasets are provided in the section Data Availability.



Deposition of dust and sea spray onto optical sensors may degrade the detected signal. Thus, in Tab. 4, we report the times during which the sensors of the Vaisala CL61 ceilometer and the OTT Parsivel² disdrometer were cleaned. Note, for the disdrometer we only report cleaning periods during M207 since there was no rain during M208.

instrument	time
Ceilometer	2025-01-29 10:09 UTC, 2025-02-03 11:33 UTC, 2025-02-05 08:51 UTC 2025-02-07 17:56 UTC, 2025-02-08 15:14 UTC, 2025-02-15 12:00 UTC, 2025-02-17 12:05 UTC, 2025-02-18 11:55 UTC, 2025-02-19 11:17 UTC, 2025-02-22 15:10 UTC, 2025-02-23 11:00 UTC, 2025-02-24 11:00 UTC 2025-02-25 14:05 UTC, 2025-02-26 09:52 UTC, 2025-02-28 10:00 UTC, 2025-03-03 10:00 UTC 2025-03-04 13:00 UTC, 2025-03-06 13:20 UTC, 2025-03-10 15:13 UTC, 2025-03-11 13:15 UTC
Disdrometer	2025-01-31 12:47-12:52 UTC, 2025-02-07 17:51 -17:56 UTC, 2025-02-10 14:23 - 14:25 UTC
Radiation sensor	2025-02-07 17:51 - 17:53 UTC, 2025-02-09 10:03 UTC, 2025-02-17 12:05 UTC, 2025-02-22 15:10 UTC, 2025-02-23 11:00 UTC, 2025-02-24 11:00 UTC, 2025-02-26 09:52 UTC, 2025-02-28 10:00 UTC, 2025-03-03 10:00 UTC, 2025-03-06 13:20 UTC, 2025-03-10 15:13 UTC, 2025-03-11 13:15 UTC

Table 4. Overview of manually performed sensor cleaning during both cruises. In case of the disdrometer sensor cleaning induces a respective data gap.

The cruise tracks of both M207 and M208 is shown in Fig. 5 as blue line. The location of the research vessel during the dust plumes (see Section 3.5 for the duration and definition) are marked by colour. Fig. 5 also shows the 20-year mean of dust optical depth (τ_{dust}) at 550 nm averaged over January, February, and March in 2003–2022. Mean values of τ_{dust} were obtained from the reanalysis product of atmospheric composition provided by the Copernicus Atmospheric Monitoring Service (CAMS, Inness et al., 2019b, a). This 20-year mean further indicates the prevalence of mineral dust transport across the Atlantic Ocean, introduced above.

Alongside the measurements obtained from the PortMeteO instruments, additional meteorological data are collected from the ship’s sensors, including relative humidity, temperature, solar radiation, air pressure, visibility, wind speed, and wind direction. The data is collected, combined, and stored by the DAVIS-SHIP (DSHIP) system. DSHIP, developed by WERUM Software & Systems AG (21337 Lüneburg, Germany), also collects navigational data, such as latitude, longitude, heading, and orientation angles. Long-term access to the full DSHIP database is provided via Universität Hamburg, Meteor (2025).

2.3 Analysis Strategy

2.3.1 Aerosol Deposition Rate

The deposition rate is estimated by counting and sizing particles that have been deposited on the surface of the substrate of the flat plate sampler. As suggested by Kandler et al. (2009), a correction for the analysis window, denoted as C_w , was applied.

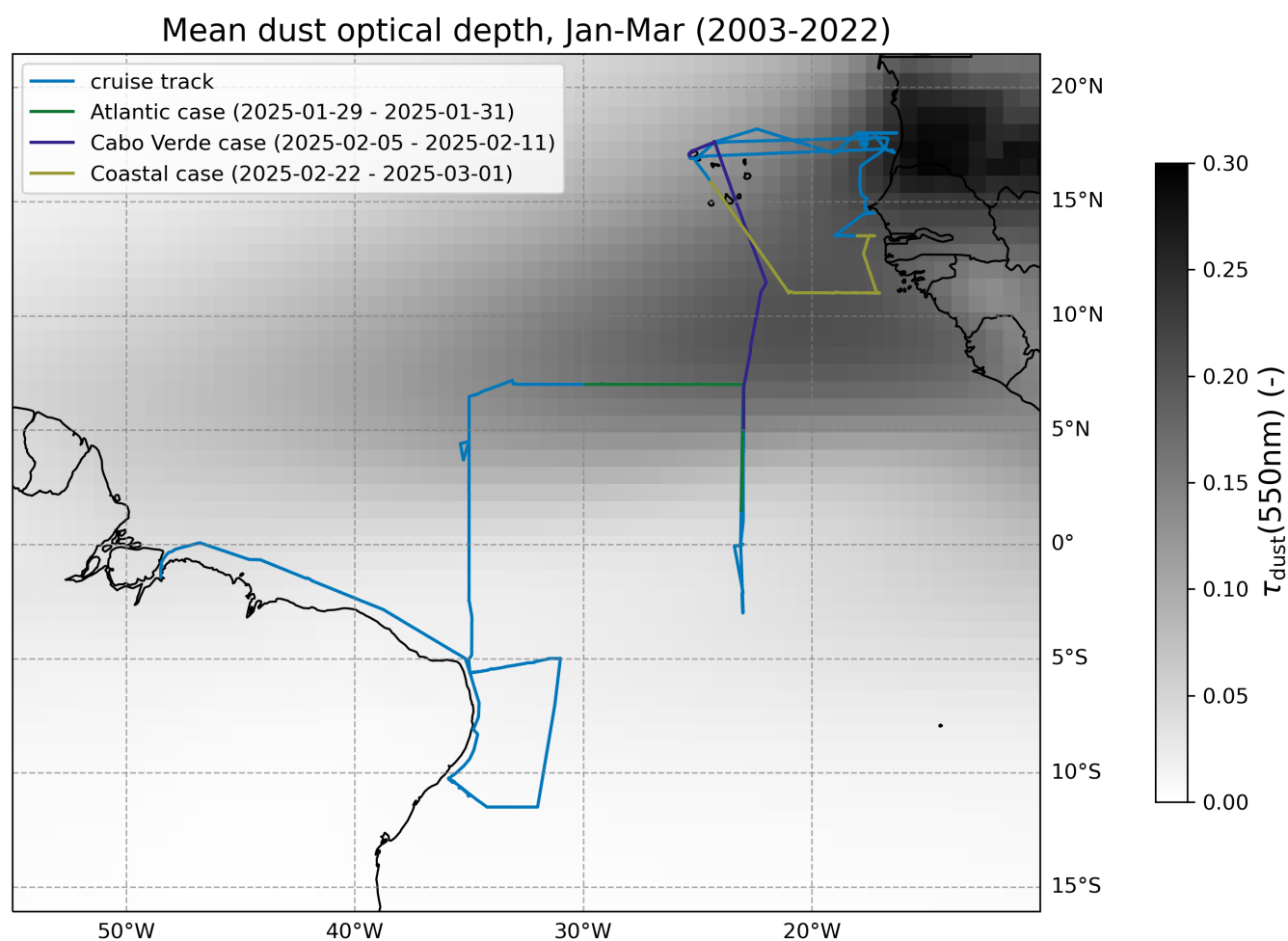


Figure 5. Ship tracks for *R/V METEOR* cruises M207 and M208 started from Belem, Brazil, on 3 Jan 2025 and arrived at Mindelo, Cabo Verde, on 15 March 2025. The track was superimposed on the 20-year averaged dust aerosol optical depth for January to March for 2003–2022, obtained from CAMS reanalysis.



The correction factor is used to account for particles that touch the border of the analysis frame and are thus omitted from the analysis area (Kandler et al., 2009), effectively reducing the analysis area as a function of particle size.

While, in general, the particle sizes of dust aerosol vary between $0.1 \mu\text{m}$ and $100 \mu\text{m}$ in diameter subjected to meteorological conditions and soil characteristics (e.g., Schulz et al., 2012), in this work, the SEM analysis is confined to particles between 1 and $64 \mu\text{m}$ for reasons of counting statistics.

The number deposition contribution of each particle were calculated using

$$C_{w,k} = \frac{w_x w_y}{(w_x - d_g)(w_y - d_g)} \quad (2)$$

where w_x and w_y are the dimensions of the analysis rectangle and k is the index of the particle.

Total mass deposition rates were estimated from the number deposition contribution as

$$M = \frac{\pi}{6} \cdot \frac{1}{t A_t} \sum_k \rho_{p,k} d_{v,k}^3 C_{w,k} \quad (3)$$

where A_t is the total analysed area, t is the sample collection time, and $\rho_{p,k}$ the material density of the particle, estimated from its composition. As apparent from Equation 3, an accurate estimation of the deposition rate relies on knowledge of the particle size $d_{v,k}$, which besides determining the settling velocity plays a key role in estimating the particle mass.

2.3.2 Particle Size Measurement

The image analysis integrated into the SEM-EDX software determines the size of particles as a projected area diameter, a diameter of a circle having the same area as the projected area of the particle in consideration.

$$d_g = \frac{\sqrt{4B}}{\pi} \quad (4)$$

where B is the area covered by the particle on the sample substrate and d_g the projected area diameter. For the volume estimation however a volume-equivalent diameter is required, which is – following Ott et al. (2008) – estimated using a shape factor as

$$d_v = \frac{d_g}{S_v} \quad (5)$$

with the volumetric shape factor calculated as:

$$S_v = \frac{P^2}{4\pi B} \quad (6)$$

where P is the perimeter.



2.3.3 Particle Classification and Chemical Composition

Based on single-particle composition quantification, an elemental index $R(X)$ for element X is defined as the atomic ratio of
 350 its concentration to the sum of all quantified elemental concentrations (Kandler et al., 2007; Li et al., 2018):

$$R(X) = \frac{X}{\text{Na} + \text{Mg} + \text{Al} + \text{Si} + \text{P} + \text{S} + \text{Cl} + \text{K} + \text{Ca} + \text{Ti} + \text{Cr} + \text{Fe}} \quad (7)$$

Based on the values of $R(X)$, for illustration here the particles are classified into six different groups (Table 5). Five groups
 are defined by a set of rules; the last group 'Other' is assigned to particles that fall outside the defined criteria. The latter
 particles are mostly mixtures and gypsum. More sophisticated rule sets or machine-learning approaches can be employed for
 355 in-depth analyses.

Table 5. Classification based on elemental ratios

$R(\text{Ca})$	$R(\text{Ca} + \text{Mg})$	$R(\text{Al} + \text{Si})$	$R(\text{Fe})$	$R(\text{Na} + \text{Cl})$	$R(\text{Cl})$	$R(\text{S})$	Other	Group/class
< 0.3		> 0.3			< 0.3	< 0.3		Silicate/dust
	> 0.6	< 0.3			< 0.3	< 0.3	$R(\text{Mg})/R(\text{Ca}) < 1$	Carbonate/dust
< 0.3		< 0.3	> 0.5		< 0.3	< 0.3		Fe-oxide/dust
< 0.3		< 0.3		> 0.3		< 0.3	$R(\text{S})/R(\text{Cl}) < 1$	Sea-salt
< 0.3		< 0.3			< 0.3	> 0.3	$R(\text{S})/R(\text{Cl}) > 1$	Sulfate

2.4 Climatological and Synoptic Context from Reanalysis

To put our measurements in their climatological context, as well as to provide synoptic context for selected times during the
 cruise, we used reanalysis products produced by the European Centre for Medium-range Weather Forecasts (ECMWF). Specif-
 ically, we used ERA5 reanalysis (Hersbach et al., 2020, 2018) and the CAMS global reanalysis (Inness et al., 2019b, a), which
 360 was already introduced above. Reanalysis products combine numerical model forecasts with various operational observations
 to provide a consistent representation of the atmospheric state (Inness et al., 2019b; Hersbach et al., 2020). ERA5 has a spatial
 resolution of 0.25° on a regular latitude/longitude grid (~ 31 km) and a temporal resolution of one hour. This reanalysis spans
 the period from January 1940 onward (Hersbach et al., 2018, 2020). CAMS reanalysis is provided with coarser resolution than
 ERA5, i.e., a spatial resolution of 0.7° (~ 80 km) and a temporal resolution of three hours (Inness et al., 2019a, b) from January
 365 2003 onward.

To compare the recorded measurements to the climatological distribution as obtained from the respective reanalysis dataset,
 we selected the reanalysis grid box corresponding to the position of the ship. After spatial sampling, we selected the corre-
 sponding day and time. Each spatial grid box was only sampled once for the respective time of day. For example, given the
 position of the ship on 29th of January 2025 at 12 UTC (shown in Fig. 13), the respective reanalysis grid box was identified,
 370 and all values pertaining to 29th of January, 12 UTC during the entire climatological period in this grid box were used for the
 comparison. In case of ERA5 variables, i.e., temperature and wind speed, we use the WMO 1991-2020 reference period as cli-



matological comparison. CAMS reanalysis does not cover the same period, hence we consider the period between 2003–2022 as our climatological reference. In addition, we use reanalysis data to provide synoptic context.

2.5 Air mass source estimation

375 Backward trajectory calculations are commonly employed in remote sensing studies to investigate the pathway of air parcels at a certain location (e.g., Haarig et al., 2017a, 2019; Bohlmann et al., 2018; Rittmeister et al., 2017; Radenz et al., 2021). Here, we assume if a trajectory passes a certain surface type or a certain region below the reception height, the air mass takes the aerosol characteristics associated with that surface type/region. With increasing cumulative residence time below the reception height, the more dominant the associated aerosol properties are (Radenz et al., 2021).

380 We performed air mass source estimates using the Lagrangian transport and dispersion model FLEXPART (FLEXible PARTicle dispersion model, version 10.4) (Pisso et al., 2019) according to the framework proposed and implemented by Radenz (2021); Radenz et al. (2021). The US National Centers' for Environmental Prediction Final Operational Model Global Tropospheric Analyses (NCEP-FNL) with a horizontal resolution of 1° by 1° served as input (National Centers for Environmental Prediction, National Weather Service, NOAA, U.S. Department of Commerce, 2000; Chen et al., 2019; Hazelton et al., 2018).

385 Our calculations considered two different reception heights, 2 km, which is widely used and considered to be applicable to a wide range of climates and surfaces (Radenz et al., 2021), and the mixing depth (MD) as derived from the meteorological input. The mixing depth, also mixing layer height, is connected to the planetary boundary layer, and commonly linked to aerosol dispersion (Julaha et al., 2025). Surfaces types are based on simplified Moderate Imaging Spectrometer (MODIS) land cover classifications (cf., Radenz et al., 2021) and include the following types: forest, urban, snow/ice, and grass/cropland, barren, 390 savanna/shrubland, and water. Backward FLEXPART calculations were performed 10 days into the past with a starting height of 250 m above ground and a vertical resolution of 250 m up until a height of 12000 m above ground, following Radenz et al. (2021); Haarig et al. (2022), but with increased vertical resolution.

3 Results

The data collected during the two expeditions highlights three multi-day dust outbreaks from North Africa over the tropical 395 Atlantic. The different instruments used for dust detection provide indications for dust-dominated aerosol plumes, as indicated in Fig. 6. If we define dust plumes based on elevated daily means of near-surface PM_{10} concentrations, exceeding $30 \mu\text{g m}^{-3}$, we get three dust episodes as follows. The first event was detected during the west-to-east transect between January 28 and 31, 2025, and is referred to Atlantic case hereafter. The second outbreak occurred near Cabo Verde from February 5 to 11 (Cabo Verde case), and the third and most intense dust event occurred near the African coast between February 24 and March 1, 2025 400 (Coastal case, see Fig. 5). Considering a dust plume definition based on the daily mean ratio between $\text{PM}_{2.5}$ and PM_{10} below 0.4, yields three distinct plumes on January 30, from February 5 to February 11, and between February 22 and February 28. These two definitions are based on in-situ observations performed with the GRIMM-EDM264 optical particle counter.



With the help of remote sensing observations, lofted dust layers, which may not be seen in near-surface measurements, can additionally be detected. Using MICROTOS II sunphotometer observations of aerosol optical depth and Ångström exponent, allows us to identify absorbing coarse mode aerosol, which is assumed to be dust. Sun photometer observations suggest the presence of the three larger dust plumes, with the Atlantic case being first detected on January, 28, 14:00 UTC and present until January 29, 19:00 UTC. The Cabo Verde case lasts from February, 6, 13:00 UTC until February, 10, 12:00 UTC, and the coastal case from February, 23, 13:00 UTC until March 1, 14:00 UTC. Note, however, that no sun photometer measurements were performed during February 27 and 28. Sun photometer observations suggest additionally shorter sub-daily dust-dominated aerosol layers on January 10, between 15:00 and 18:00 UTC, during January 15, 10:00 UTC until January, 16, 17:00 UTC, and on March, 5.

Inferring dust presence from ceilometer observations, i.e., assuming a geometrically thick layer with a linear particle depolarisation ratio of ~ 0.3 pertains to dust, confirms the occurrence of the three multi-day dust plumes with slightly different timing. The Atlantic case is seen from January, 27, 16:00 UTC until January, 31, 00:00 UTC, the Cabo Verde case from February 6, 09:00 UTC until February, 10, 15:00 UTC, and the Coastal case from February 22, 05:00 UTC to March 3, 09:00 UTC. Note, however, that observations of the coastal case had to be partially interrupted due to crossing an EEZ (see Sec. 2.2). The following sections present the meteorological and aerosol data collected during expeditions with focus on the three main dust events.

3.1 Meteorological overview

The measurements on board of *R/V METEOR* for near-surface wind speed and direction, temperature, humidity, pressure, irradiance, and visibility are shown in Fig. 7 and show aspects typical for the region and season. The maximum wind speed reached approximately 25 m/s. Easterly winds were prevailing, as typical for the trade wind region (e.g., Krishnamurti, 2013). During the expedition, the highest recorded atmospheric temperature reached approximately 34.6°C , while the lowest was 17.0°C . The mean air temperature was 20.3°C . Temperature and wind speed were further compared to the range in the WMO 1991–2020 reference period as obtained from ERA5 reanalysis along the cruise track to evaluate the representativeness of the measurements from a climatological perspective. Observed near-surface concentrations of PM_{10} were compared analogously against CAMS reanalysis between 2003–2022 (see Fig. 8). The observed temperatures and wind speeds resemble the climatological range, although measured mean winds are higher during both expeditions. PM_{10} observations overlap with the full climatological range, however during M208 the majority of PM_{10} observations, indicated by the 95th percentile, was below the climatological median along the cruise track.

3.2 (Short-range) Doppler Lidar Observations

Figure 9 shows the temporal evolution of horizontal wind speed measured by the Doppler lidar (WLS7) at up to 12 heights (58 m, 72 m, 86 m, 100 m, 114 m, 128 m, 142 m, 156 m, 170 m, 184 m, 198 m, and 218 m) AMSL, together with ERA5 reanalysis data at 100 m for the period 27 January–1 February 2025. For simplicity, the middle heights were shown in the same colour, as the time series are visually indistinguishable.

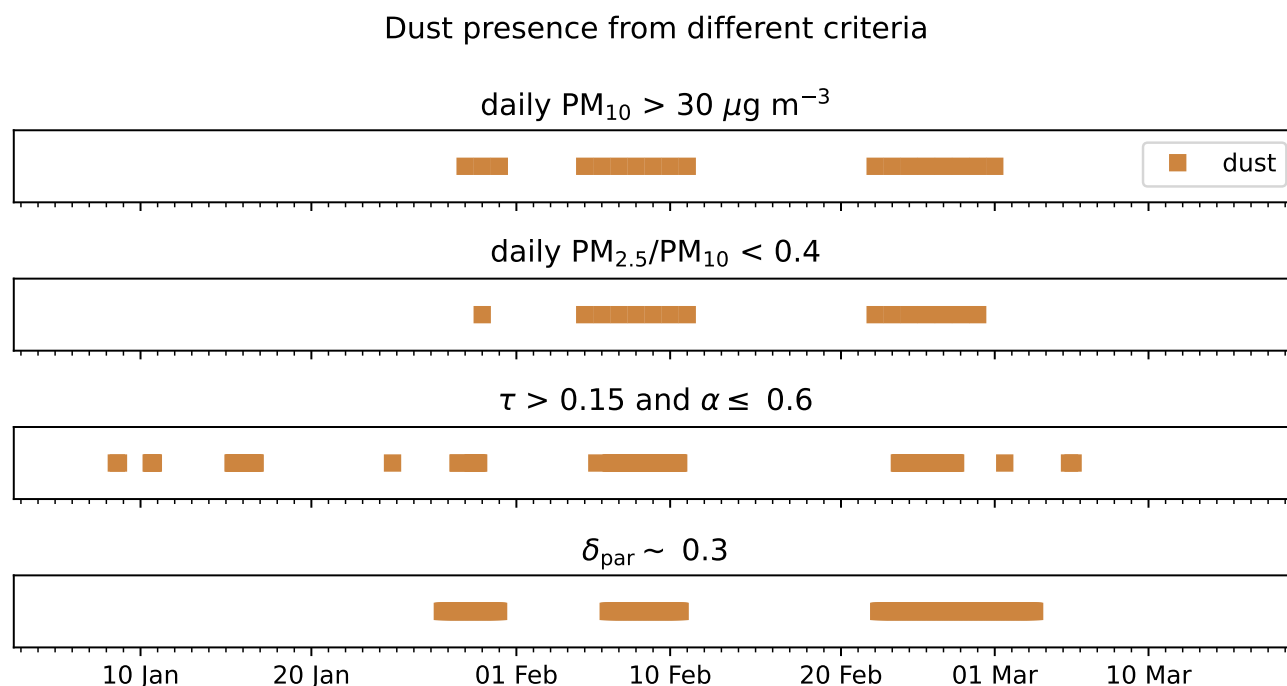


Figure 6. Presence and duration of dust plumes inferred from different criteria. For the remainder of this manuscript, dust plumes are defined according to the first criterion, i.e., days with daily mean $\text{PM}_{10} > 30 \mu\text{g m}^{-3}$. PM observations were obtained from the GRIMM EDM-264 optical particle counter, observations of τ and α from MICROTOPS II sun photometers, and δ_{par} was observed with the Vaisala CL61 ceilometer. Sun photometer observations were resampled to hourly resolution, smaller data gaps in photometer observations due to clouds and/or night-time are not resolved in this figure.

Figure 10 shows similar data for a second period, 5–9 February 2025, for which the measurement heights of the lidar profiles had been adjusted to another set of height levels that cover also higher altitudes (58 m, 83 m, 100 m, 123 m, 146 m, 169 m, 192 m, 215 m, 238 m, 261 m, 284 m, and 308 m) AMSL, which were then kept for the rest of the campaign.

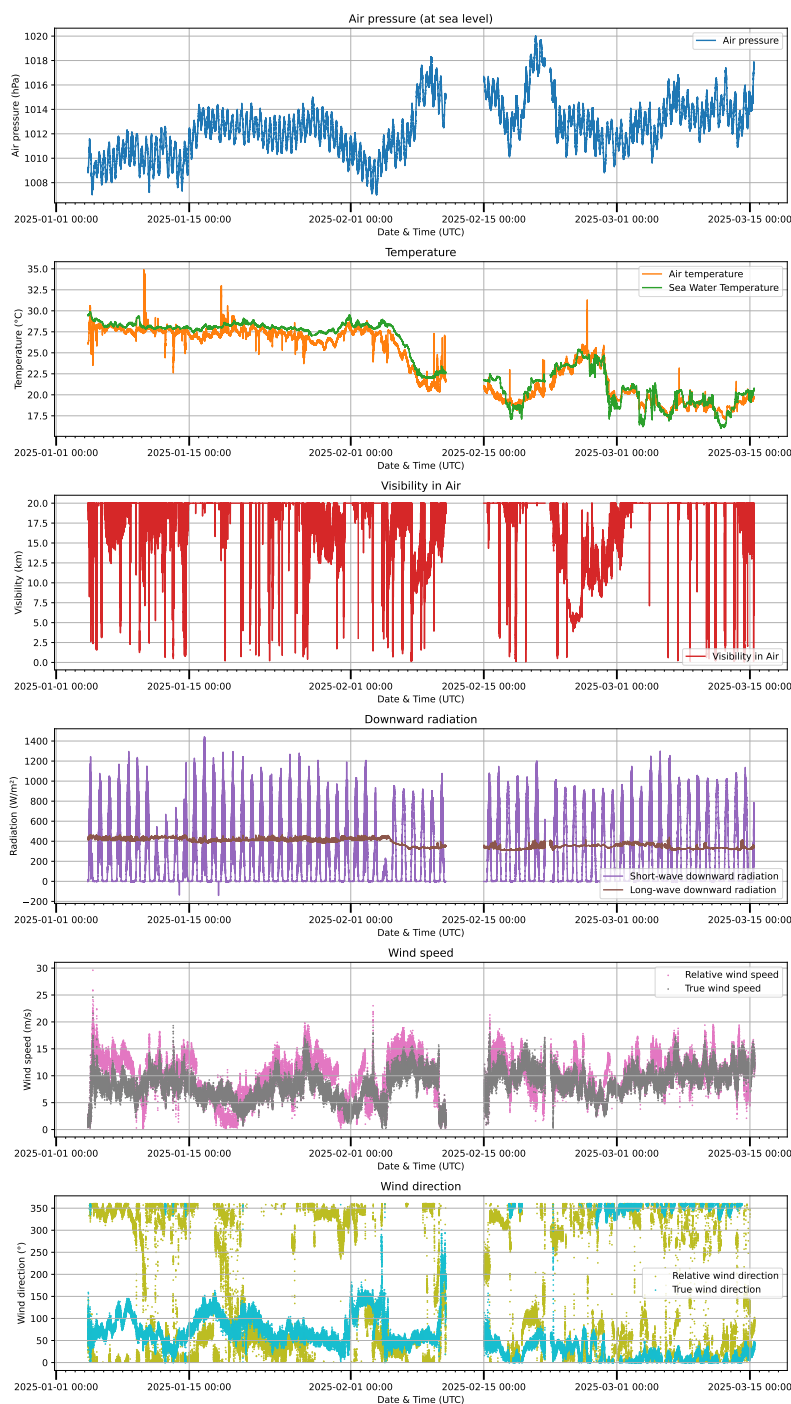


Figure 7. Meteorological data recorded by the ship’s own weather sensors from the 4th of January 2025 to 15th of March 2025 during the M207 and M208 expeditions, provided via DSHIP (Universität Hamburg, Meteor, 2025).

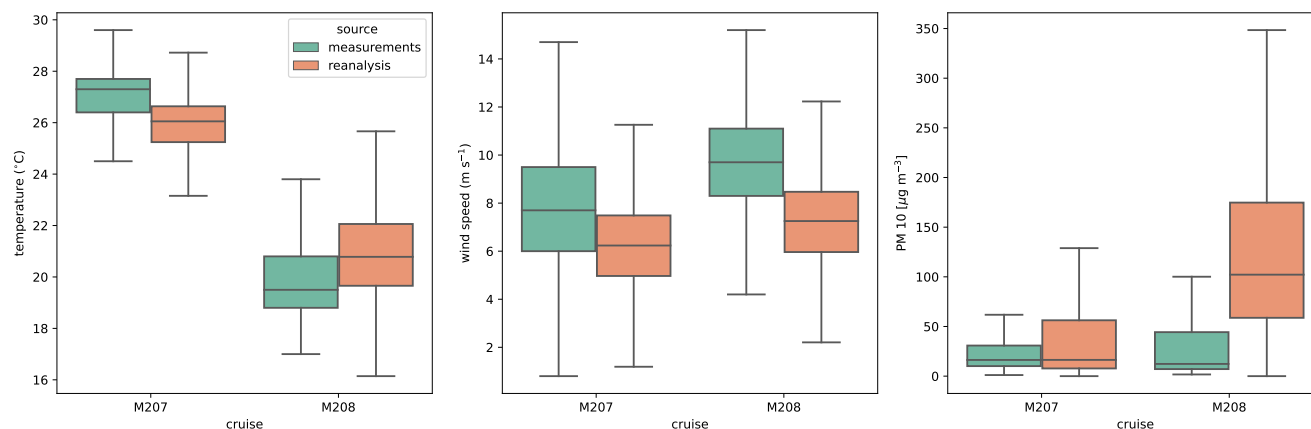


Figure 8. Comparison of measurements (green) to climatological values (orange) for air temperature (left), wind speed (centre), and PM_{10} (right). Air temperature and wind speed sensors are permanently installed on the ship's mast, approximately 42 m above sea level. PM_{10} measurements were performed on Deck 6 (approximately 34 m above sea level) at starboard. Air temperature and wind speed climatology refers to the WMO 1991-2020 reference period. PM_{10} climatology refers to the period 2003-2022.

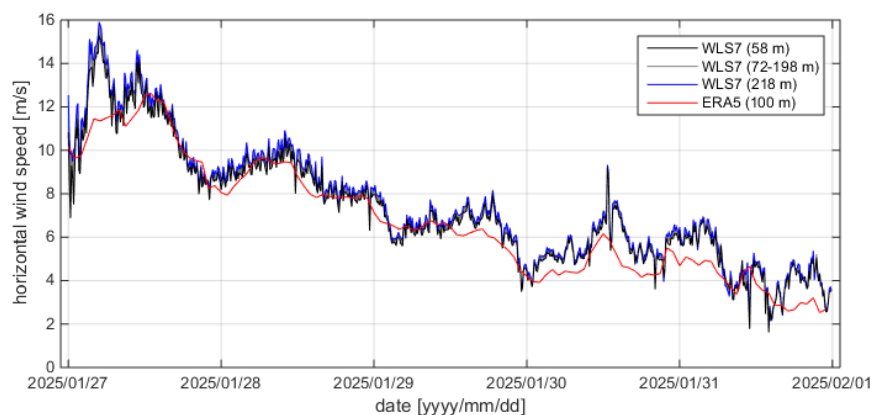


Figure 9. Time series of 10-minute averaged horizontal wind speed measured by Doppler lidar (WLS7) at in total 12 height levels (58 m, 10 levels within 72–198 m, and 218 m), compared with ERA5 reanalysis data at 100 m, for the period 27 January–1 February 2025, which includes the Atlantic case.

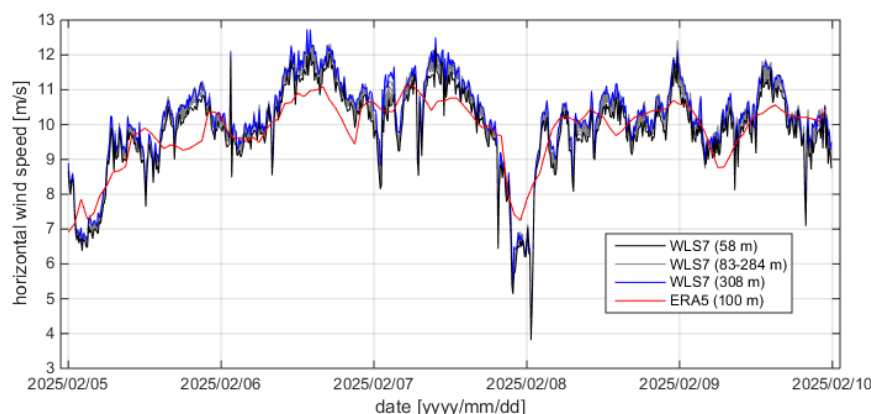


Figure 10. Time series of 10-minute averaged horizontal wind speed measured by Doppler lidar (WLS7) at in total 12 height levels (58 m, 10 levels within 83–284 m, and 308 m), compared with ERA5 reanalysis data at 100 m, for the period 5–9 February 2025, i.e. a subset of the Cabo Verde case.

These periods illustrate the wind profiles during two of the three Saharan dust outbreaks recorded during EXPORT, the Atlantic case and the Cabo Verde case. In each case, the presence of elevated dust layers coincides with discernible modifications of the lower-tropospheric wind structure. The first episode, as shown in Fig. 9, is characterised by weakened near-surface winds and stronger flow aloft, indicative of enhanced static stability and reduced boundary-layer mixing near the surface. The second episode (Fig. 10) exhibits stronger vertical wind shear. This is consistent with intensified synoptic forcing and dust-driven radiative stabilization. The presented wind lidar observations could be used to investigate this effect in more detail. For both periods, we find a reasonable agreement of our measurements with ERA5 reanalysis data, broadly consistent with previous studies of motion-corrected ship-based Doppler lidar wind data (Gottschall et al., 2018; Rubio et al., 2022, 2025).

3.3 Disdrometer-based rain observations

Figure 11 shows the diameter-velocity spectrum of rain droplets during M207. In general, larger drops have a higher fall velocity. In general, the drops follow the calculated size-dependent terminal fall velocity according to Atlas et al. (1973), which is shown as grey line. There are numerous particles of various size classes with a fall speed of $v < 1 \text{ ms}^{-1}$. These low-velocity particles could be attributed to aerosol generated by sea spray aerosols instead of hydrometeors or caused by high wind speeds. High wind speeds are known to introduce anomalously low droplet fall speeds, as droplets no longer fall vertical through the laser sheet (cf. Friedrich et al., 2013).

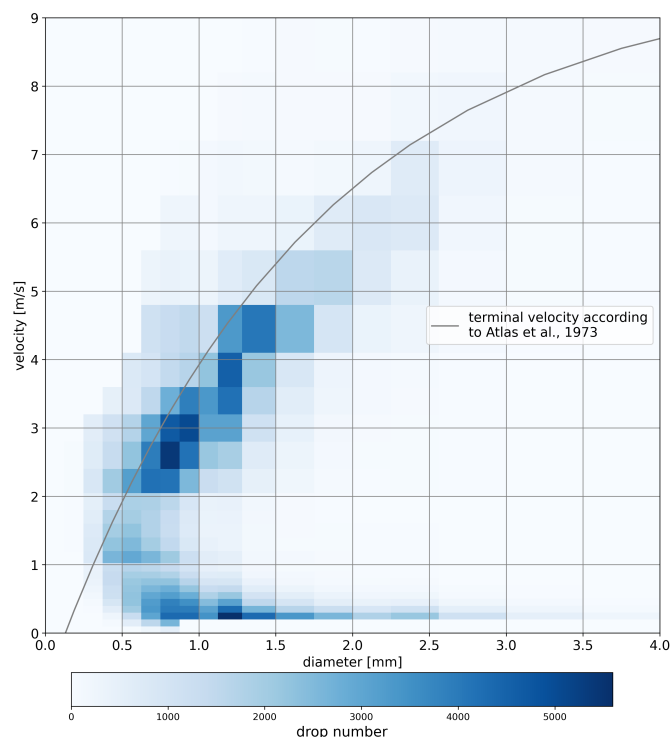


Figure 11. Diameter-velocity spectrum of all rain events during M207. No rain was detected during M208. Colour represents the number of particles observed in the respective diameter/velocity bins.

3.4 Atmospheric radiation measurements

Figure 12 presents shortwave radiation measurements taken at 1-minute intervals using a CMP21 pyranometer for selected days during two of the dust plume cases (28 January and 28 February 2025). For comparison, we also show 27 January 2025, which was characterised by rain until 08 UTC, as detected by the Parsivel² disdrometer, and the on-set of the dust plume after ~ 16 UTC as detected by the CL61 ceilometer (see Figs. 6, 20). Fig. 12 also shows cloud cover as detected by the CL61. The first dust day, during the Atlantic case, was characterised by low clouds and the strong presence of dust, as can also be seen in Fig. 20. The fluctuations in the shortwave radiation measurements during 28 January 2025 are consequently caused by clouds and dust. For the second dust day, during the Coastal case, we see radiation fluctuations in absence of clouds, which are likely caused by variable dust concentrations. The comparison with 27 January 2025, which until local noon can be considered dust-free, shows that broken clouds leave a stronger and more noticeable imprint in shortwave radiation than variations in dust concentration. Thus, effects of clouds on shortwave radiation during 28 January 2025 masked the attenuation and fluctuations associated with dust aerosols. Additional data during the three dust plumes are presented next.

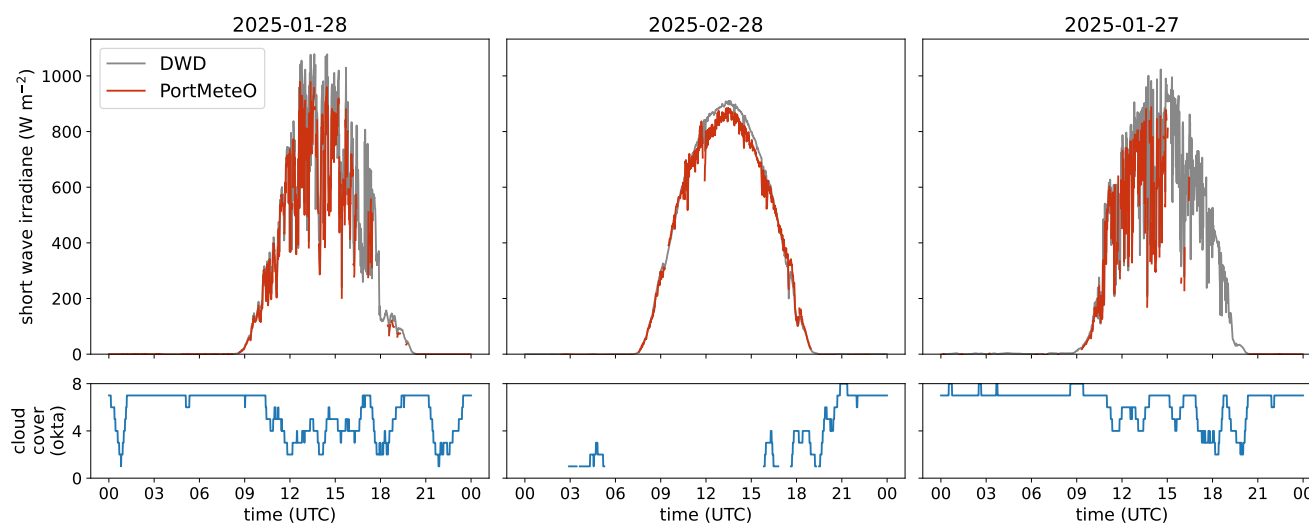


Figure 12. Shortwave irradiance obtained with a CMP21 pyranometer at 1-minute resolution. Shown are incoming shortwave radiation for one selected day (left to right) during the two dust cases on 28 January and 28 February 2025, and the rainy day of 27 January 2025. Grey colour indicates values from the DWD-operated sensors, red shows measurements from the PortMeteO sensors, for which the relative difference to the DWD data was below 20%. The bottom panels show the cloud cover in okta as detected by the CL61.

3.5 Dust Plumes

3.5.1 Meteorological conditions

During the cruises M207 and M208, three Saharan dust plumes were encountered, also seen by reduced visibility (Fig. 7). To provide synoptic context, Fig. 13 shows the mean sea level pressure and the dust aerosol optical depth as obtained from CAMS reanalysis during the beginning of each plume. The mean sea level pressure in all three cases is characterised by weak gradients with a particularly weak gradient during 2025-01-29, 12 UTC, which suggests low surface winds. In addition, the cruise track and the local of R/V METEOR at the time corresponding to data shown in Fig. 13 are shown.

Figure 14 shows temperature and relative humidity data measured during the three dust plumes, here inferred from daily mean PM_{10} concentrations. Especially during the Cabo Verde case, temperature decreases during the passage of the dust plumes. Namely, the air temperature decreases from above 25°C to nearly 20°C in both cases. This could result from the attenuation of solar radiation by suspended dust particles (cf., Sec. 3.4), which limits surface heating. Prior to the increase of surface PM_{10} associated with the Atlantic case, a small decrease in temperature was measured, e.g., due to dust arriving in some distance to the surface before it is influencing surface-level dust concentration. Indeed, the sun photometers and ceilometer suggest an earlier arrival of lofted dust during the Atlantic case (see Fig. 6). In this case, the lofted plume might cause near-surface cooling, despite the dust not yet being detected in-situ at the surface.

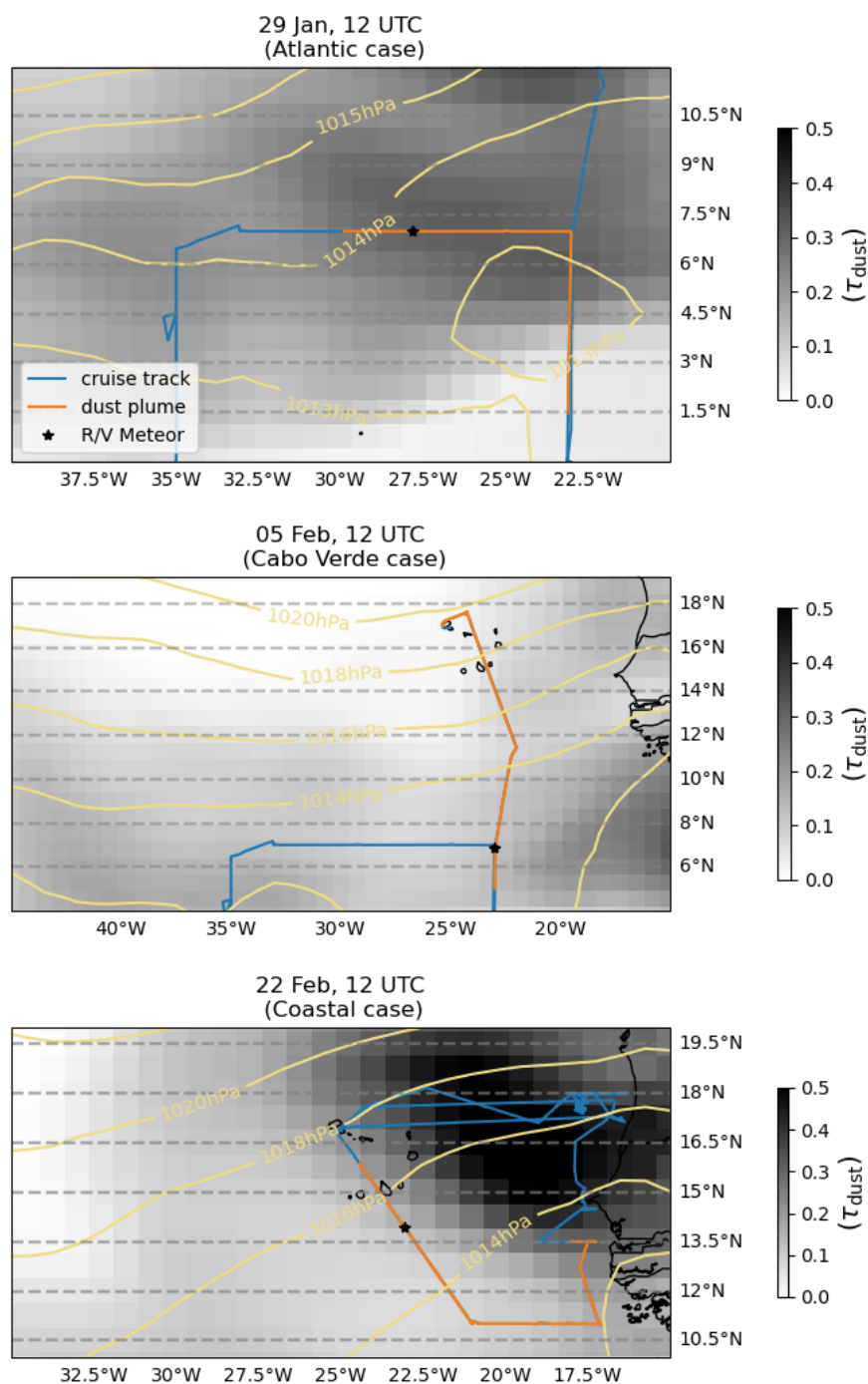


Figure 13. Dust aerosol optical depth (τ_{dust} , shading) and mean sea level pressure (yellow lines) from CAMS reanalysis at the beginning of each dust plume. The blue lines show the cruise track, the section of the cruise track during the respective dust plume is marked in orange, and the star indicates the position of R/V METEOR during the indicated time.

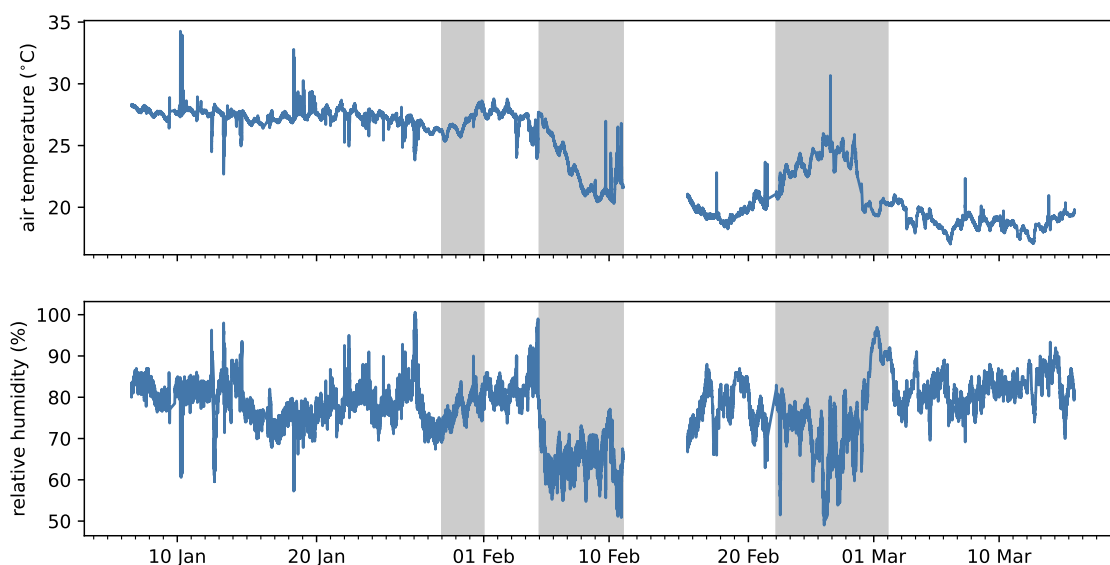


Figure 14. Time series of observed air temperature (top panel) and relative humidity (bottom panel). Grey shading indicates dust plumes as defined by daily mean PM_{10} with the locations marked in Figs 5 and 8.

Relative humidity (RH) also shows similar developments across the dust events. For the Cabo Verde case and just before the near-surface arrival of the Atlantic case's dust plume, RH decreases noticeably, consistent with the advection of relatively drier air masses, as expected for desert air. The most significant decrease of RH occurs during the Cabo Verde case with a minimum around 55%, contrasting with the higher values above 80% prior to the dust event. These measurements document
 485 that dust plumes can be associated with both reduced near-surface temperature and relative humidity, consistent with earlier reports on dust transport across the Atlantic by Barreto et al. (2022). In contrast, lofted air containing mineral dust, also known as Saharan Air Layer (SAL), is typically dry but warm (Schepanski et al., 2009; Ben-Ami et al., 2009; Barreto et al., 2022), although in some instances elevated moisture levels have been reported within the SAL (Gutleben et al., 2019). Typically, the SAL's vertical structure is less clearly distinguishable in the Western tropical Atlantic, i.e., with increasing distance from the
 490 North African dust source regions (Ben-Ami et al., 2009). For column integrated humidity information in form of precipitable water vapour (PWV), please also see Fig. 17. In general, values of PWV during cruise M207 are, with exceptions during the Cabo Verde dust case, higher than during for M208. In particular, PWV during M207 tends to be lower during the dust plumes than during non-dust days.

We document the origin and transport path of the dust-laden air measured at the location of R/V METEOR with an ensemble
 495 of backward trajectories (Fig. 15). Each column shows normalised residence times for a dust plume. The high normalised residence times of air parcels above surfaces classified as either barren or grass/cropland support the identification of aerosol plumes as mineral dust plumes. As an example, the FLEXPART particle positions for the Coastal case, 23 Feb., 12 UTC are



500 shown in Fig. 16. The map shows the positions 7 days, 3 days and one day before they reach the location of the ship (marked with a red star) at a height of 800–1200 m AGL. The maps indicate the simplified MODIS land cover classifications according to Radenz et al. (2021). The maps exemplify the high residence time of the air masses over the Sahara, further supporting the aerosol plumes identification as dust plumes.



Air mass source estimates during dust plumes

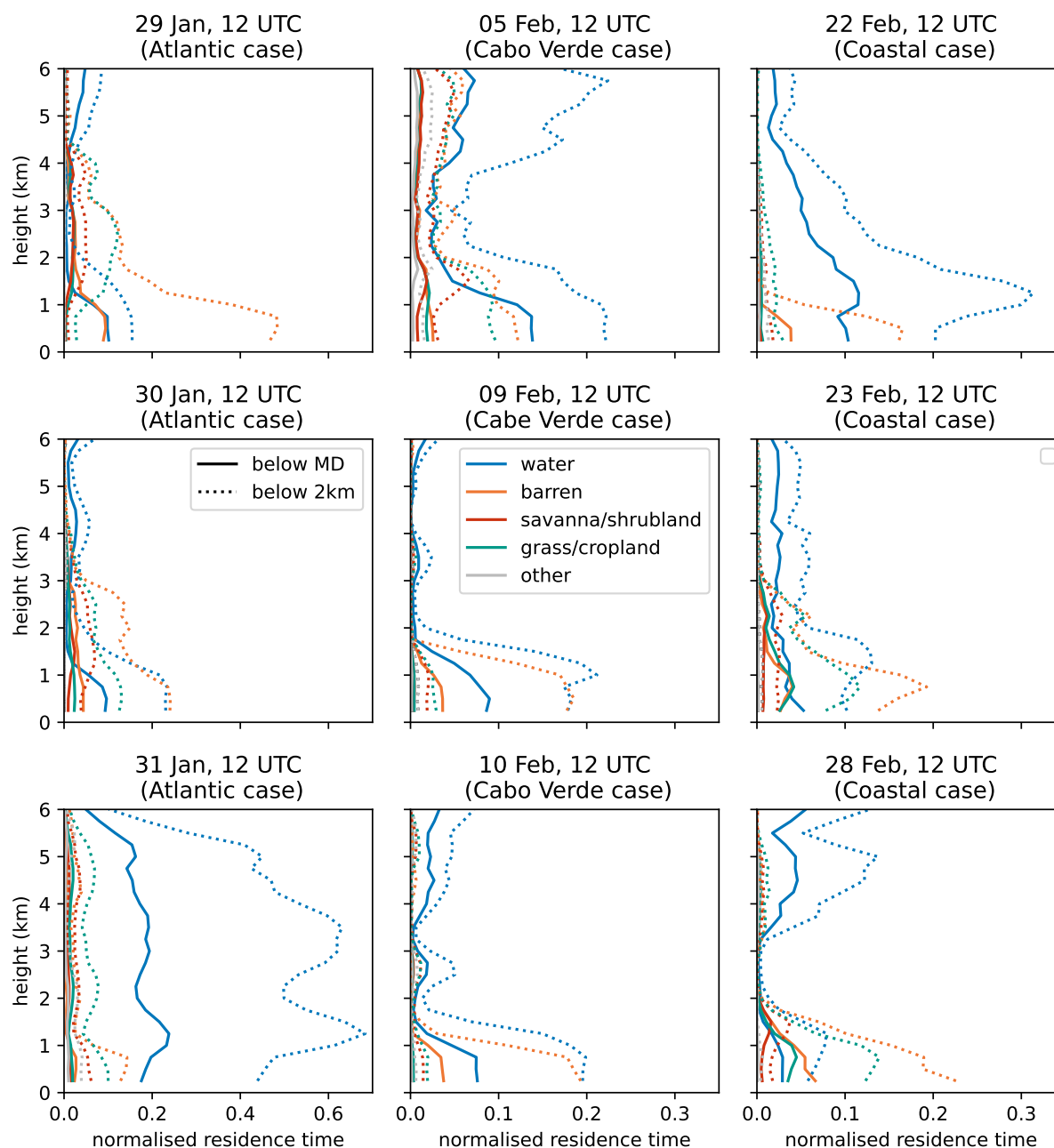


Figure 15. Air mass source estimate from FLEXPART backward trajectory calculations for the dust plumes. Backward trajectories were computed 10 days into the past with a starting height of 250 m above ground and a vertical resolution of 250 m until a height of 12000 m. At each height level 500 trajectories were computed. The top row shows results for 12 UTC during the first day of each plume. Results for the second to last day at 12 UTC for the Cabo Verde case and the Coastal case and the last day for the Atlantic case, during which the dust plume criterion (daily mean $\text{PM}_{10} > 30 \mu\text{g m}^{-3}$) was fulfilled. The middle row pertains to the remaining days of each dust plume with the highest value of daily mean PM_{10} . Colours indicate the surface type, blue pertains to water, orange to barren surfaces, red to savanna or shrubland, green to grass or cropland and grey to the remaining types (see Sec. 2.5). Solid lines indicate the mixing depth as reception height, and dashed lines a static reception height of 2 km.



Flexpart results for plume 3
 2025-02-23 12UTC, height: 800-1200m

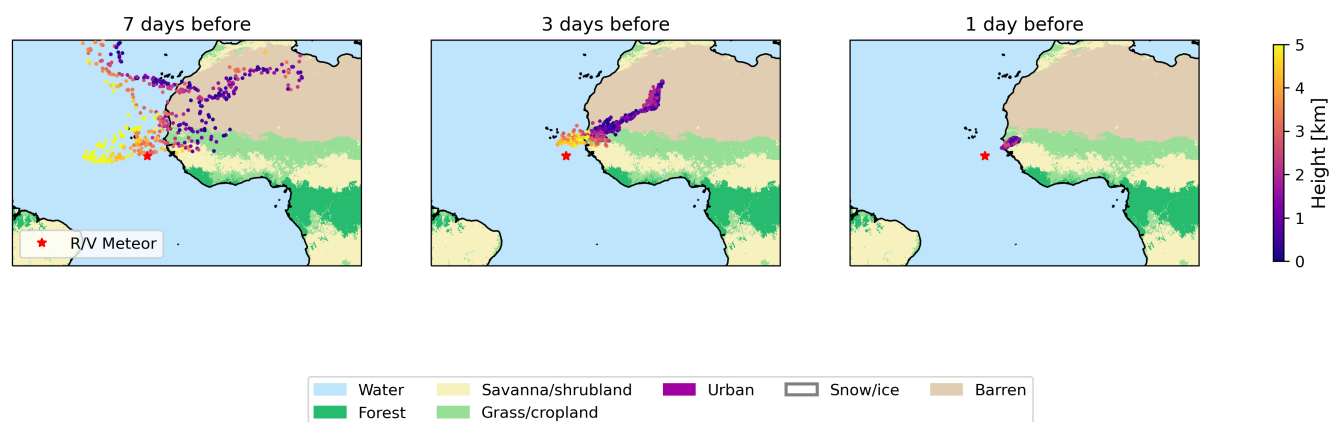


Figure 16. FLEXPART particle positions for the plume during the Coastal case (2025-02-23, 12 UTC), 7 days (left panel), 3 days (middle panel), and 1 day (right panel) before the indicated time. The maps indicate the simplified surface classes defined by Radenz et al. (2021). Points show the positions of the traced air parcels. The colour indicates the height above ground. The position of *R/V METEOR* at 12 UTC on 2025-02-23 is marked in red.



3.5.2 Column-integrated aerosol properties

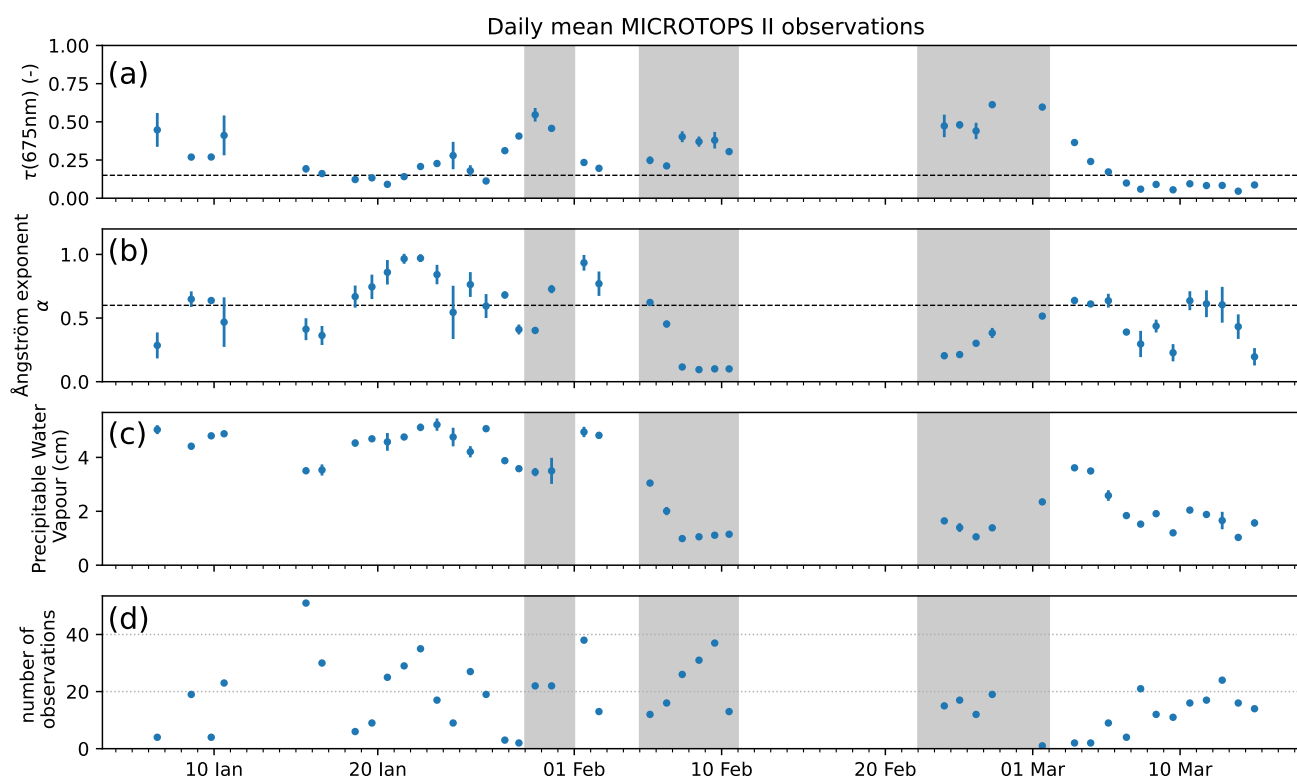


Figure 17. Level 2 daily mean aerosol optical depth (τ , (a)) measurements at the 675 nm wavelength channel and the associated Ångström exponent (α , (b)). Grey shading indicate the dust plumes defined by daily mean PM_{10} . The horizontal dashed lines indicate the alternative dust identification criteria ($\tau > 0.15, \alpha < 0.6$). The daily mean precipitable water vapour (PWV) is shown in panel (c). Vertical lines show the standard deviation across the measurements for each day. Panel (d) shows the number of observations during each day.

A key characteristic of daily mean τ is its significant variability in the course of the expeditions. Sun photometer observations provide column-integrated information on extinction by aerosol particles, i.e., the aerosol optical depth τ . An increase in aerosol extinction and, thus, τ can be related to an increase in aerosol number concentration, an increase in aerosol particle size, an increase in aerosol absorption or combinations thereof. The spectral changes of τ , quantified by the Ångström exponent, provides information on the dominant mode of the aerosol particle size distribution. Figure 17 shows Level 2, i.e., cloud-screened and quality assured, data of aerosol optical depth (AOD, τ) at 500 nm and the corresponding Ångström exponent (α) obtained from the MICROTOPS II sun photometer during both expeditions.

During the dust plume events, elevated values of τ ($\tau > 0.5$) are observed, along with high dust concentrations in the atmosphere (Fig. 17). This observation is consistent with previous studies conducted in the region, which have documented similar increases in aerosol optical depth due to Saharan dust transport (Prospero et al., 2002; Tegen and Fung, 1994). As can



be inferred from the sign of the Ångström exponent (see Eq. 1), τ decreases with increasing wavelength. This wavelength dependence often reflects variation in the size and composition of the aerosol particles (Bayat et al., 2011; Schuster et al., 2006). The dominance of coarse particles (e.g., dust, sea salt) and particularly Saharan desert dust particles during the plumes is evident from low α values (< 1.0). Precipitable water vapour, which was also recorded by the MICROTOPS II instruments (see Section 3.5.1), decreases during the Saharan dust plumes, which is consistent with relatively dry Saharan air masses. Our data are in agreement with an earlier study (Balarabe et al., 2015), which identified that approximately 79% of the observed α values in the dust belt region were below 1, indicating the prevalence of coarse-mode aerosols such as dust. Conversely, α values above 1 indicate fine mode particles in the atmosphere.

When recording τ using the CALITOO instruments at least three measurements were performed within a short period of time of approximately up to five minutes (Level 1.0). Data processing to Level 1.5 included the filtering for cloud contamination, identifying obvious errors, such as pointing errors, etc., following the manufacturer's guidance (Tennum, 2020). When considering multiple Level 1.0 observations with a given observational interval of approximately up to five minutes, only the lowest value of τ was retained in the Level 1.5 data set. In addition, values related to rapid changes in τ , which can often be attributed to the occurrence of thin clouds or close to edges of clouds, were not retained in the Level 1.5 data.

Figure 18 shows the inter-comparison of τ (Level 1.5) as obtained from the three different CALITOO instruments. The measurements of τ from the three instruments exhibit a strong correlation, with a correlation coefficient (r) of approximately 0.99, indicating strong consistency across the three instruments. Similarly, Fig. 19 illustrates the comparison between Level 1.0 (blue) and Level 1.5 (orange) observations of τ at the wavelength $\lambda = 465\text{nm}$ and α collected during M207 and M208 using the CALITOO instrument (#443). In addition to the data shown here, observations at $\lambda = 540\text{nm}$ and $\lambda = 619\text{nm}$ are available from the CALITOO sun photometers.

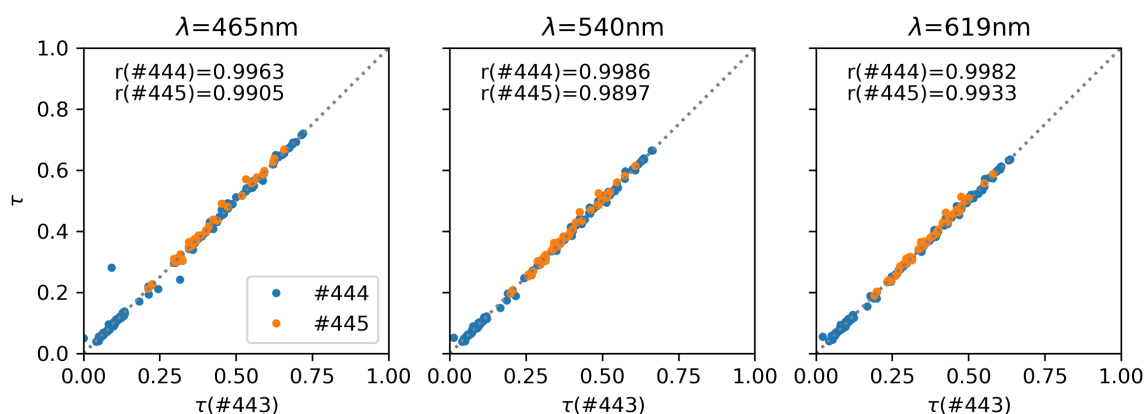


Figure 18. Inter-comparison of hourly averaged τ (Level 1.5) as obtained from the three different CALITOO instruments with respect to the instrument with ID #443.

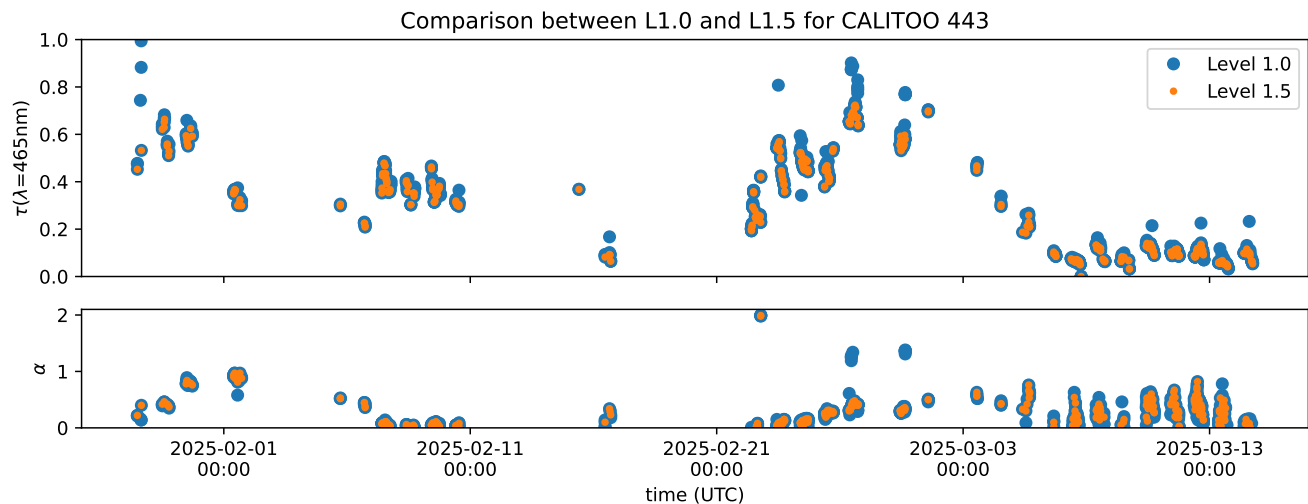


Figure 19. Comparison between Level 1.0 (blue) and Level 1.5 (orange) observations of τ at a wavelength of $\lambda = 465\text{ nm}$ and α during M207 and M208 as obtained from CALITOO instrument # 443. Level 1 contains raw observations, whereas Level 1.5 observations were processed, e.g. filtered for cloud contamination and pointing errors (see Section 3.5.2). Note, that Level 1.0 data points exceeding $\tau = 1.0$ are not shown. There were no Level 1.5 observations with $\tau > 1.0$.

3.5.3 Vertical structure of dust plumes

CL61 observations provide height-resolved values of the attenuated backscattering coefficient β_{att} and the linear depolarisation ratio δ_l . Similar to τ , increases in β_{att} can pertain to increases in particle size, in particle number concentration, and particle composition. However, δ_l is independent of the particle number concentration and encodes information on particle shape, composition, and size.

The presence of the dust layer is indicated by elevated values of β_{par} between 1200 and 3000 m AGL (Fig. 20). Values of $\delta_{\text{par}} \sim 0.3$ for this vertically thick layer indicate the presence of mineral dust, consistent with other measurements on board. Fig. 20 shows the 20 minute running mean of β_{par} (top) and δ_{par} (bottom). The signal is only indicated for altitudes with $\beta_{\text{par}} > 2.5\beta_{\text{mol}}$ to reduce noise in the depolarisation signal associated with a low backscattering signal. The Atlantic dust case was influenced by several clouds with base heights between 500 m and partly more than 3000 m AGL. The transported dust is partly above the cloud base height and intermittent cloudiness resulted in challenging conditions for sun photometer measurements. The dust layer can be clearly distinguished from 2025-01-27, 17:00 UTC until 2025-01-31, 10:00 UTC. Increasing values of δ_{par} within the marine boundary layer from 2025-01-28, 12:00 UTC onwards and even more pronounced from 2025-01-30, 06:00 UTC indicate the surface deposition of dust. This gradual increase of dust in the boundary layer explains the earlier onset of this dust plume as detected by CL61 and MICROTOPS II sun photometers compared to the GRIMM EDM-264 (see Fig. 6).

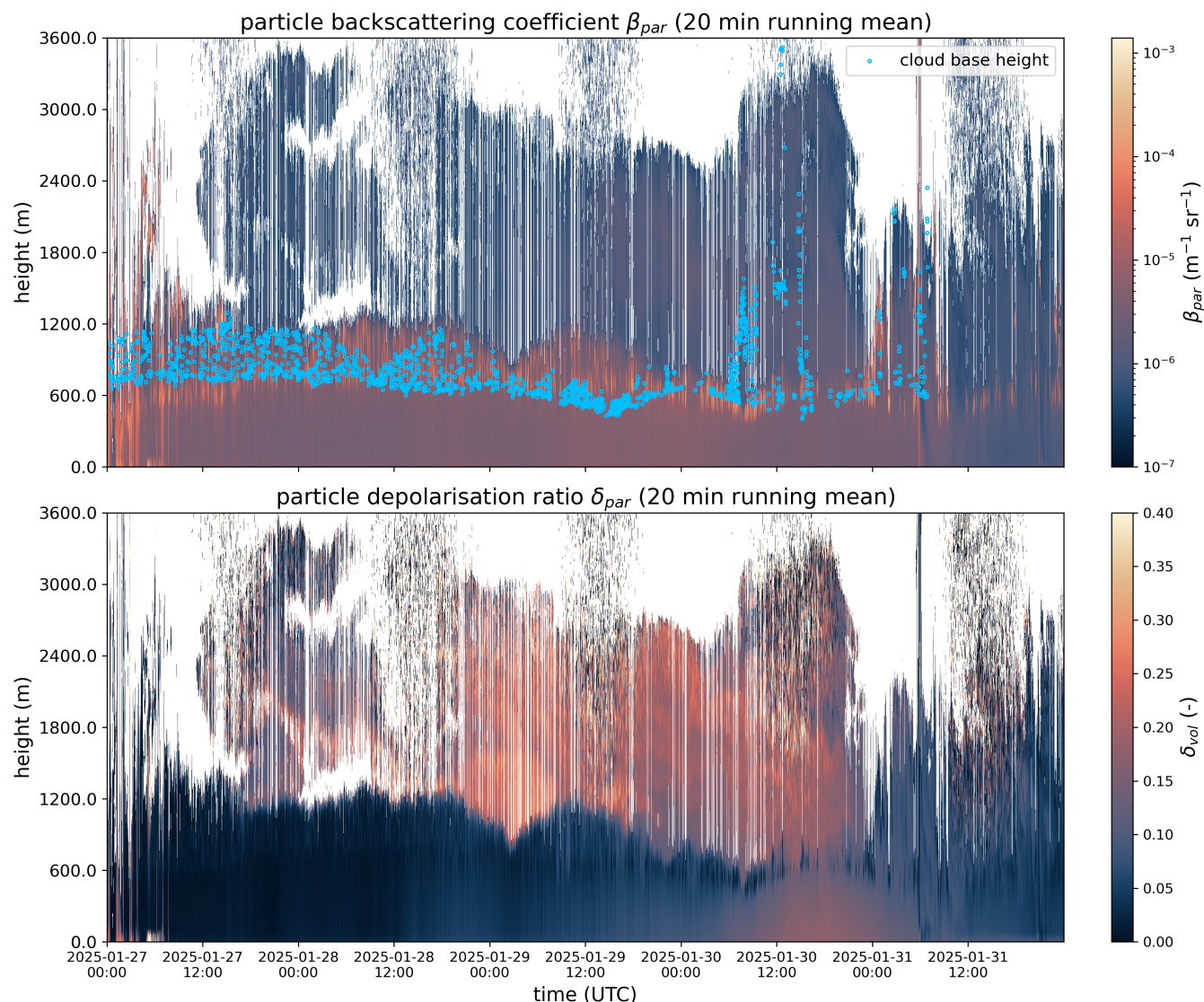


Figure 20. Observations of particle backscattering coefficient (top) and linear particle depolarisation ratio (bottom) for the Atlantic case from 2025-01-27 00:00 UTC to 2025-01-31 23:59 UTC (M207) with the ship track during the Atlantic case marked in Figs. 5 and 8. Blue dots mark the cloud base height as determined by the CL61's internal processing software.

As an example for dust during M208, CL61 observations between 2025-02-24, 22:20 UTC and 2025-02-27, 19:48 UTC are shown in Fig. 21. For operational reasons the CL61 had to remain switched off before and after this shown time window. The aerosol layer, which is characterized by elevated values of β_{par} and values of $\delta_{\text{par}} \sim 0.3$, reaches from the ground to altitudes of 1200 m in the beginning to more than 2600 m AGL. Due to this combination of large vertical extent and the values of the linear particle depolarisation ratio, the aerosol layer is considered to consist of mineral dust aerosol. No low clouds were detected during this time allowing easy measurements with the sun photometers.

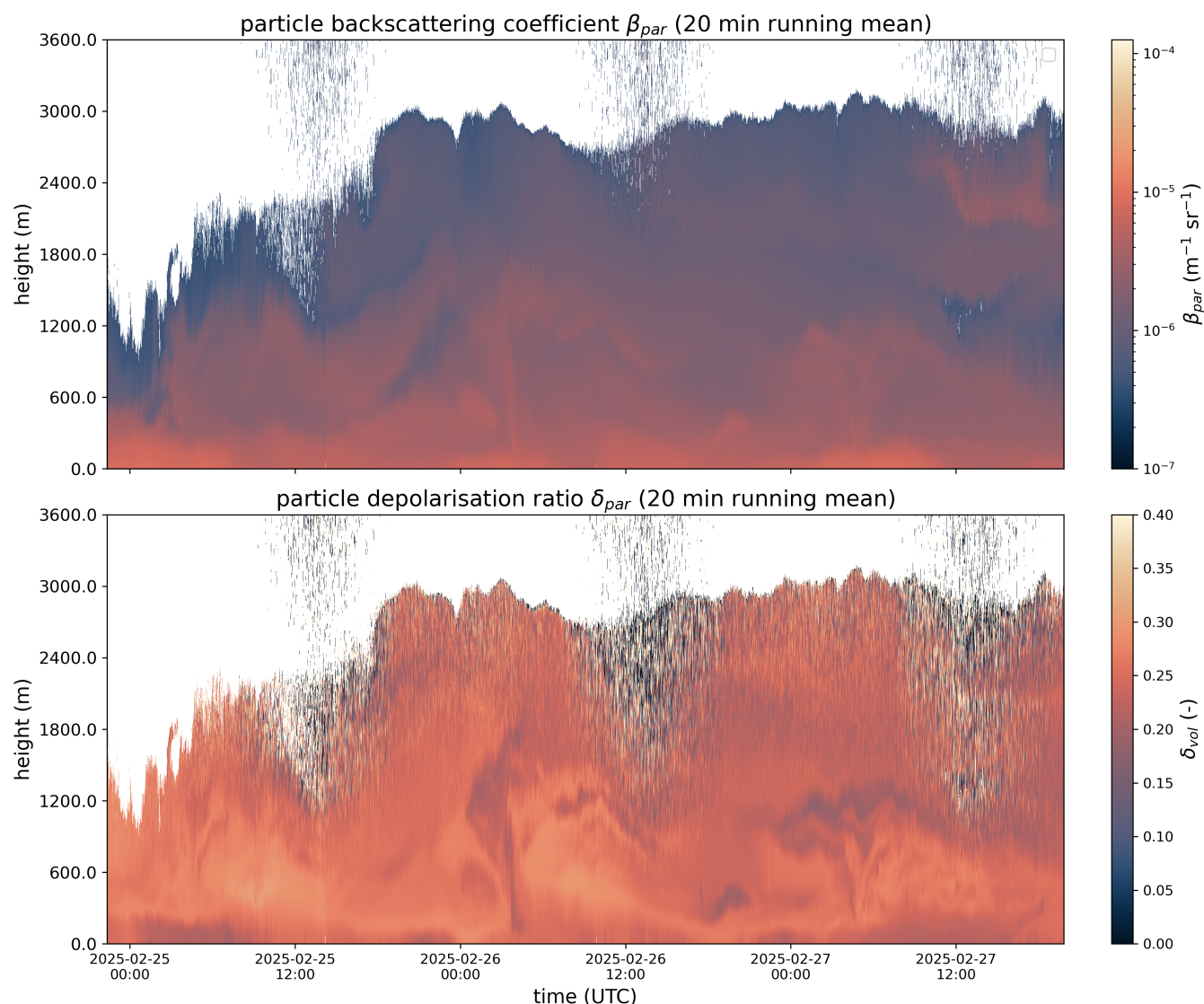


Figure 21. As Fig. 20, but during the Cabo Verde case, specifically the time from 2025-02-24 22:20 UTC to 2025-02-27 19:48 UTC (M208). The ship track during the dust plume is shown in Figs. 5 and 8.

3.5.4 Near-surface PM_x Concentrations and Particle Size Distributions

555 Near-surface aerosol particle mass concentrations were detected using the in-situ GRIMM EDM-264 OPC. The PM_{10} (particles with a diameter of $10 \mu\text{m}$ or less) and $\text{PM}_{2.5}$ (particles with a diameter of $2.5 \mu\text{m}$ or less) concentrations, along with the ratio $\text{PM}_{2.5}/\text{PM}_{10}$ (defined as the proportions of $\text{PM}_{2.5}$ mass concentrations to PM_{10} mass concentrations), measured between January 4th, 2025, and March 15th, 2025, during the M207 and M208 expeditions, are shown in Figure 22. The PM_{10} and $\text{PM}_{2.5}$ concentrations (in $\mu\text{g m}^{-3}$) are shown on the left y-axis, while the $\text{PM}_{2.5}/\text{PM}_{10}$ ratio is shown on the right y-axis.



560 As can be seen, the PM exhibited notable temporal variations, with higher concentrations of PM_{10} ($378.40 \mu\text{g m}^{-3}$) and $\text{PM}_{2.5}$ ($67.00 \mu\text{g m}^{-3}$) observed during dust storm events. The impact of Saharan dust plumes on PM_{10} and $\text{PM}_{2.5}$ levels during the first expedition, particularly on January 28–29, is clearly visible. The dust plume reappeared during the second expedition, notably between February 21 and March 1, 2025, as shown in Fig. 22. Moreover, it is evident that the PM_{10} and $\text{PM}_{2.5}$ graphs display closely matching patterns, indicating a strong correlation between the two particulate matter concentrations.

565 The PM_{10} and $\text{PM}_{2.5}$ concentrations, along with the ratio of $\text{PM}_{2.5}$ to PM_{10} ($\text{PM}_{2.5}/\text{PM}_{10}$), measured between January 4th, 2025, and March 15th, 2025, during the M207 and M208 expeditions, are shown in Fig. 22.

When applying the threshold of $30 \mu\text{g m}^{-3}$ to the daily mean concentrations of PM_{10} (see Fig. 22), we identify 18 days of North African dust plumes during the EXPORT expeditions. Specifically, the maximum particle mass exceeded background conditions by more than eightfold, as shown in Fig. 22. Moreover, the $\text{PM}_{2.5}/\text{PM}_{10}$ ratio during the dust plumes was at or
 570 below 0.3, i.e., below the threshold of 0.4, indicating a dominance of coarse particulate matter.

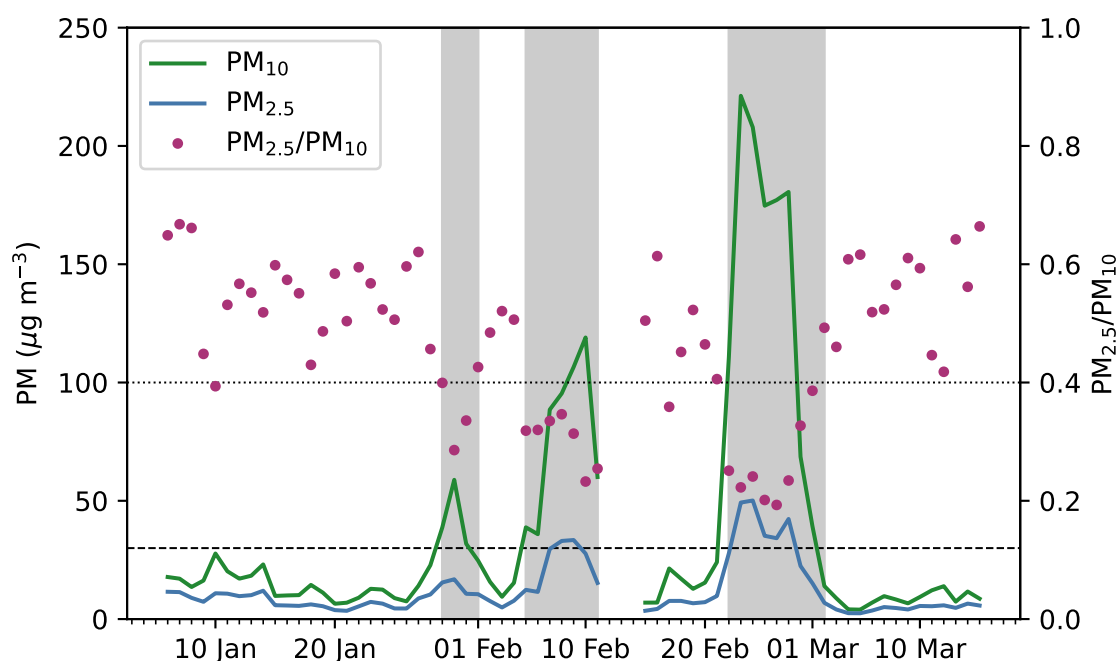


Figure 22. Aerosol measurements shown are the time series of daily mean PM_{10} (green), and $\text{PM}_{2.5}$ (blue) concentrations (left axis), as well as $\text{PM}_{2.5}/\text{PM}_{10}$ ratios (purple, right axis) measured from the 4th of January 2025 to 15th of March 2025 during the EXPORT expeditions. The horizontal dashed line shows the African dust detection threshold estimated at $30 \mu\text{g m}^{-3}$, used for identification and definition of dust plumes. The horizontal dotted line indicates $\text{PM}_{2.5}/\text{PM}_{10}$ ratio of 0.4, an alternative dust identification criterion. See Section 2.1.1 for the justification of these thresholds.



Figure 23 presents wind rose plot illustrating the distributions of wind speeds alongside PM_{10} concentration classes with corresponding wind directions as detected by the ship's weather station, during the individual dust plumes, defined by daily mean PM_{10} near-surface concentrations. The recorded wind direction is always a local measurement, thus, conclusions on large scale atmospheric circulation cannot be inferred from these values. However, during the dust plumes northeasterly winds dominated with increased variation during the Coastal case, which is consistent with trade wind circulation on the Northern Hemisphere. Mean sea level pressure isobars in ERA5 reanalysis at the beginning of each plume, as shown in Fig. 8, also indicate north-easterly winds and, thus, also point towards dust transport from North African sources via the trade wind circulation. This is also supported by the air mass source estimates (see Fig. 16). Both during the Coastal case and M208 in general, show a higher fraction of northerly winds, than during the other dust cases or M207 as a whole (see also Fig. 7). Notably, the highest fraction of PM_{10} values with $PM_{10} < 100 \mu g m^{-3}$ during the Coastal case is associated with north-northwesterly winds.

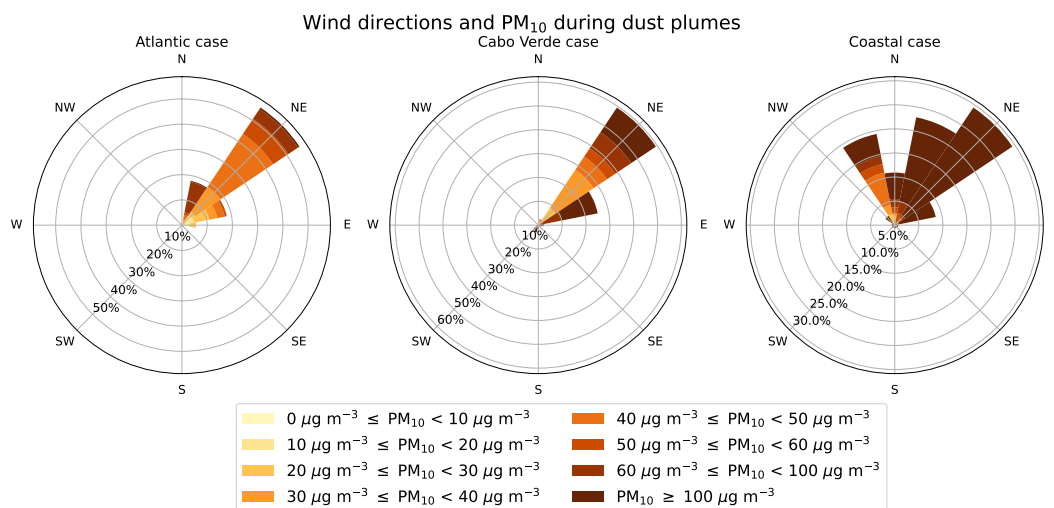


Figure 23. Wind roses of measured wind direction and PM_{10} concentration classes for all recorded PM_{10} observations during the three dust plume cases. As stated above dust plumes are defined as days with daily mean $PM_{10} > 30 \mu g m^{-3}$.

The GRIMM-EMD264 additionally provides size distribution information. In Fig. 24, we present daily mean particle size distributions for the different dust plumes (green for the Atlantic case, blue for the Cabo Verde case, and yellow for the Coastal case) and non-dust (red) days. Dust plume days are characterised by higher mass concentration for channels with $> 0.4 \mu m$ than non-dust days. The highest mass concentration during dust plumes was observed for particle diameters between $2 - 4 \mu m$. For non-dust days, the particle size distribution's maximum is between $1 - 3 \mu m$.

3.5.5 SEM-EDX Characterization of Aerosol Particles

In this section, we present the SEM-EDX analyses of individual dust particles, collected during two expeditions. A total of 56,484 particles from 39 usable samples were analysed. There were 13 samples from M207 and 26 samples from M208.

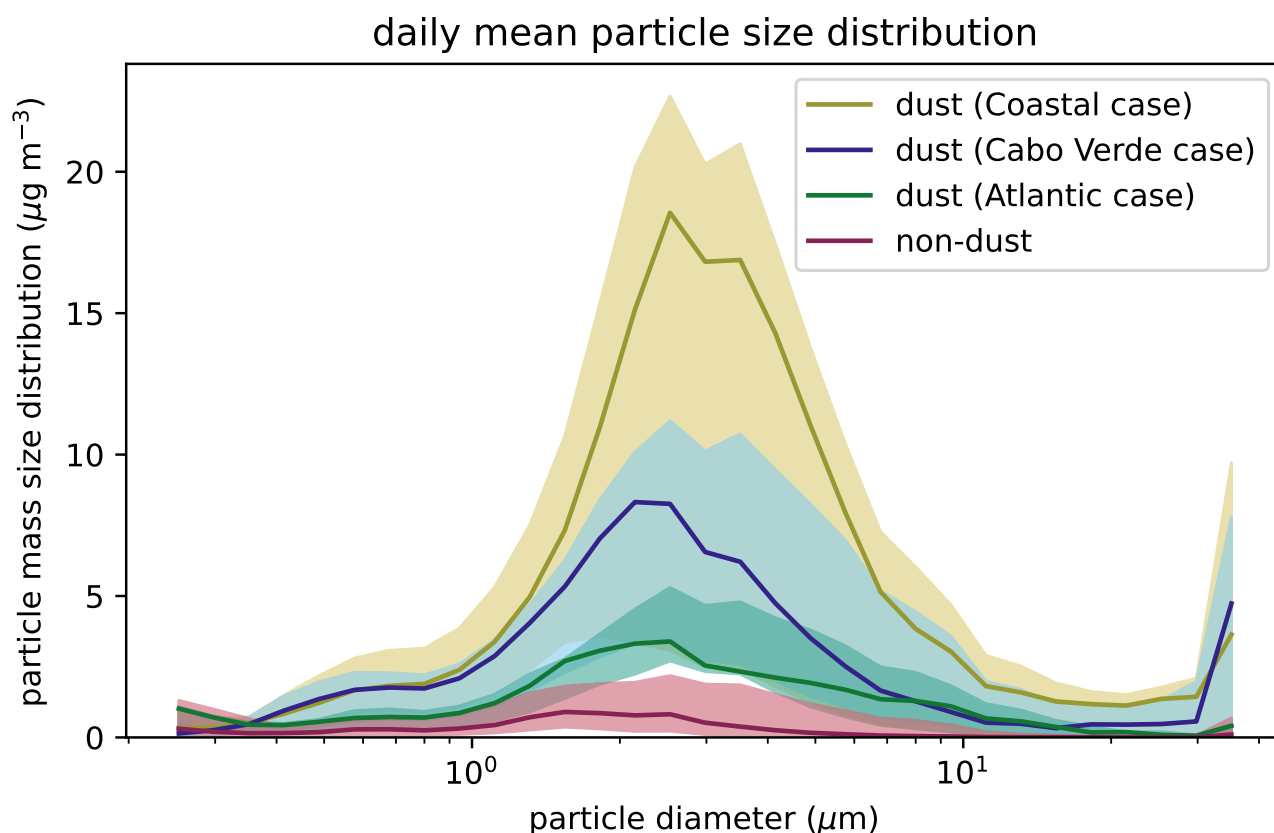


Figure 24. Daily mean particle size distributions for the three different dust plumes and non-dust (red) days recorded by the GRIMM EDM-264, as defined by daily mean PM_{10} . The line indicates the median during the plumes and all non-dust dust days, whereas the shaded area indicates the full spread.

Using a simple classification of the observed particles, Fig. 25 shows the mean number deposition rates for the three dust events encountered and the marine background conditions. From the deposition rates of dust, i.e., the sum of Fe-oxides, silicates and carbonates, the plume during the Atlantic case shows the lowest values, consistent with the longest transport distance from the continent and the associated transport losses. The Cabo Verde case and the Coastal case show a similar intensity of deposition rates, while the Cabo Verde case has slightly coarser dust particles. This might be related to the more northerly sources in more arid regions, which potentially produce less fine material. Dust during the Atlantic case has nearly no carbonate in contrast to plumes during the other two cases. This is also inline with the potential source compositions showing a gradient in carbonate contribution decreasing from north to south (Kandler et al., 2007; Scheuvens et al., 2013). Compared to the marine background, the dust deposition rates are one order of magnitude higher during dust events. However, in nearly all samples at least a small amount of dust was detected.



The sea-salt deposition during the Cabo Verde case is similar to the marine background (see. Fig. 25), whereas the Coastal case despite the similar dust deposition has a considerable lower sea-salt deposition. The sulfate deposition is very low in general, e.g., compared to similar measurements of transported dust by Kandler et al. (2018), owing probably to the comparatively pristine setting. It occurs mainly as small particles, pointing to a gas phase source, e.g. marine dimethylsulfide conversion (cf., Luria et al., 1989; Zheng et al., 2021; Wollesen de Jonge et al., 2026).

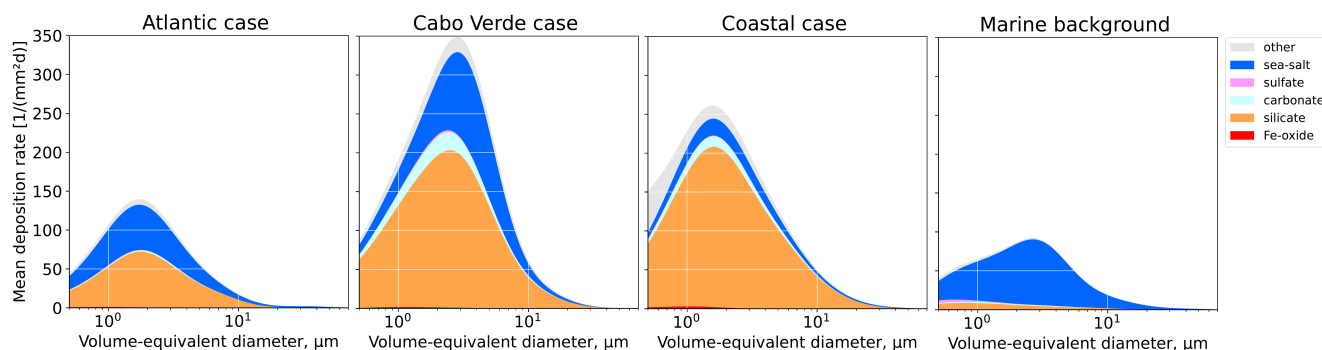


Figure 25. Comparison of size-resolved mean relative number deposition rates of major particle types during three dust periods and the marine background phase, as obtained from the analysis of individual particles in deposited aerosol. The plots are based on kernel density estimates (bandwidth 0.15) of the normalized number concentration densities $dN/d\log d$, with N the number deposition rate and d the diameter.

Fig. 26 shows the sea salt number deposition rate as a function of mean wind speed. The wind speed, recorded by the ship's weather station, was resampled by calculating the mean during the respective sampling period of the flat plate sampler. The Pearson correlation of $r_{\text{pearson}} = 0.539$ and the Spearman rank correlation of $r_{\text{spearman}} = 0.584$ indicate a monotonic, non-linear relationship between mean wind speed and sea salt deposition rate. Note, correlations between sea salt deposition rate and median ($r_{\text{pearson}} = 0.555, r_{\text{spearman}} = 0.594$) and maximum wind speed ($r_{\text{pearson}} = 0.549, r_{\text{spearman}} = 0.588$) are only marginally different. Thus, a high abundance of sea salt particles can be partially attributed to observed wind speeds.

Finally, Fig. 27 shows the dust number deposition rate as a function of mean aerosol optical depth reported at a wavelength of 500 nm (left) and as function of PWV (right). Here only days, during which MICROTOPS II measurements were performed are included. As for Fig. 26, MICROTOPS II values, as included in the MAN database, of τ and PWV were resampled by calculating the mean during the flat plate sampler's corresponding sampling period. The Pearson ($r_{\text{pearson}} = 0.475$) and Spearman rank correlation $r_{\text{spearman}} = 0.642$ indicate a positive monotonic, yet non-linear relationship between τ and dust number deposition rate. Sampling periods with high dust number concentration tend to coincide with mean values of $\tau \gtrsim 0.2$. The relationship between dust number deposition rate and PWV is negative, as also emphasised by the negative Pearson and Spearman rank correlations. In other words, high values of dust number deposition rate are associated with drier atmospheric columns, as expected for air masses originating over North Africa.

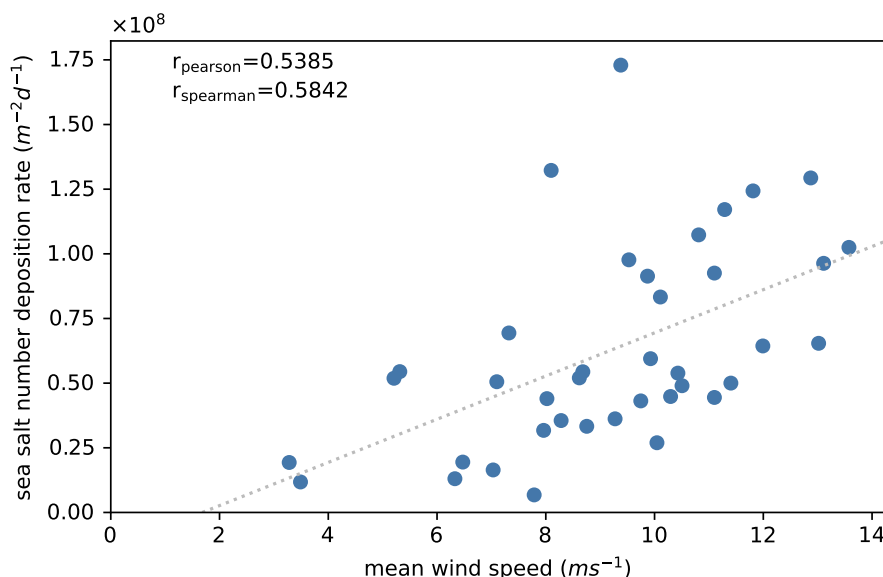


Figure 26. Relationship between sea salt number deposition rate and mean wind speed. The dotted line indicates the curve fit obtained by using linear regression.

4 Summary and conclusions

620 The primary objective of this study was to document observational datasets collected during the first two *EXperiments with the Portable Observatory for aeRosol Transport* during the research cruises M207 and M208. Measurements were collected onboard the German research vessel *R/V METEOR* from January to March 2025 in the tropical Atlantic. It was the first several-month long deployment of the Portable Meteorological Observatory (PortMeteO) on board of a research vessel, which has the aim to improve our understanding of the meteorological processes driving the transatlantic transport of Saharan dust particles.

625 First data analyses highlight three distinct outbreaks of dust-laden air from North Africa between January and March 2025. The collected data highlight (1) the vertical extent and fine-scale structure arising from turbulent mixing in the dust aerosol plumes using a ceilometer, (2) vertical profiles of meteorological conditions including winds from a lidar as well as temperature, humidity and winds from over 85 radiosonde launches, (3) column-integrated information on aerosols in form of aerosol optical depth and Ångström exponent, recorded from 4 sun photometers, (4) the chemical composition and size of deposited aerosol

630 particles derived from approximately 56,400 single-particle analyses in laboratory measurements of collected samples, and (5) particulate matter mass fractions and particle size distributions, observed with an in-situ optical particle counter. The EXPORT dataset presented here allows us to address knowledge gaps for dust transport across the tropical Atlantic by combining high-resolution aerosol and meteorological measurements. This co-located dataset is an opportunity to investigate the physical drivers and characteristics of cross-Atlantic transported Saharan dust in future studies.

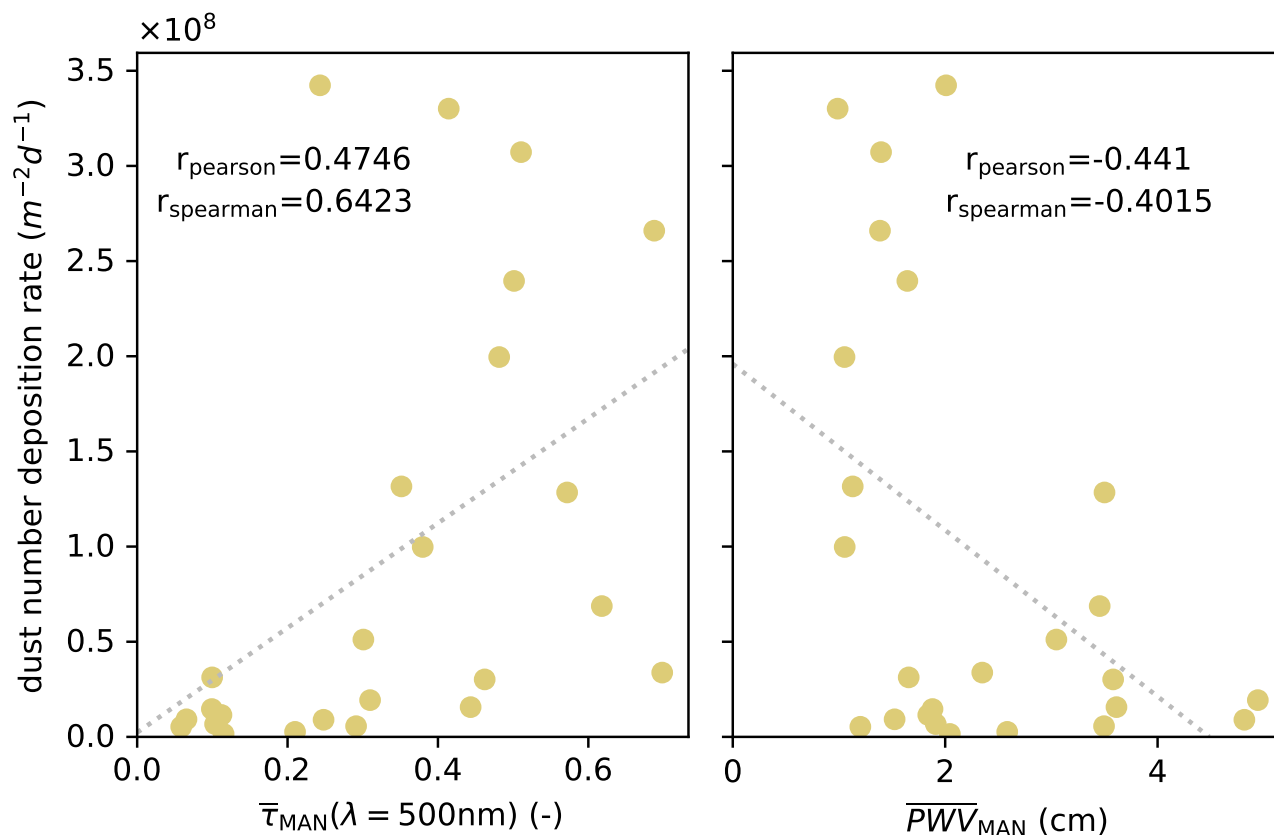


Figure 27. Relationship between dust number deposition rate and mean τ (left) and mean PWV (right). Values of τ at 500 nm and PWV are taken from MICROTOPS II observations, as included in the MAN database. The dotted lines represent the curve fit obtained by using linear regression.

635 5 Data availability

The datasets collected during the research cruises M207 and M208, presented in this publication, are freely available from the PANGAEA data repository. The respective citations are listed in Tabs. 6 (M207) and 7 (M208). Ship sensor data, including observations from the ship's weather station, are publicly available under Universität Hamburg, Meteor (2025). Furthermore, three auxiliary datasets were used. To provide climatological context both CAMS (Inness et al., 2019a) and ERA5 (Hersbach
 640 et al., 2018) reanalysis data were used. CAMS reanalysis can be obtained via <https://ads.atmosphere.copernicus.eu/> and ERA5 reanalysis via <https://cds.climate.copernicus.eu/>. Air mass source estimates relied on NCEP FNL Operational Model Global Tropospheric Analysis (National Centers for Environmental Prediction, National Weather Service, NOAA, U.S. Department



of Commerce, 2000), which can be obtained via <https://gdex.ucar.edu/>. Access to these three auxiliary (re-)analysis datasets require registration.

instrument	reference
GRIMM EDM-264	Wahl et al. (2025a)
Flat plate sampler	Wahl et al. (2025b)
CALITOO sun photometers	Wahl et al. (2025c)
MICROTOPS II sun photometer	Kanngießer and Wahl (2026a)
Radiation observations	Wahl and Kanngießer (2026a)
CL61 ceilometer	Wahl et al. (2025d)
Radiosondes	Wahl et al. (2025e)
Wind lidar	Wahl et al. (2026a)
OTT Parsivel ²	Wahl et al. (2025f)
DWD ship weather station	Universität Hamburg, Meteor (2025)

Table 6. Overview of presented datasets for research cruise M207

instrument	reference
GRIMM EDM-264	Wahl et al. (2025g)
Flat plate sampler	Wahl et al. (2025h)
CALITOO sun photometers	Wahl et al. (2025i)
MICROTOPS II sun photometer	Kanngießer and Wahl (2026b)
Radiation observations	Wahl and Kanngießer (2026b)
CL61 ceilometer	Wahl et al. (2025j)
Radiosondes	Wahl et al. (2025k)
Wind lidar	Wahl et al. (2026b)
DWD ship weather station	Universität Hamburg, Meteor (2025)

Table 7. Overview of presented datasets for research cruise M208

645 *Author contributions.*

AW conducted the field measurements, analysed data, and wrote the first draft of the manuscript. KK carried out the SEM analyses and performed data processing. FK conducted the field measurements, assisted with data analysis, performed auxiliary calculations, and revised the manuscript. JG performed wind lidar data processing. NS, AL, SS, and SW conducted the field measurements and assisted with data analysis. WH assisted with data analysis. SF designed and supervised the entire



650 experimental program, provided guidance on data analysis, revised and edited the manuscript. All authors contributed to the manuscript preparation.

Competing interests.

The authors declare that they have no conflict of interest.

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