Responses to Review #1

The author would like to thank the reviewer for his valuable comments which helped in improving the quality of the manuscript. My point-by-point responses to the reviewer's comments appear in bold below.

General Comments

1. I found the article quite difficult to read, with numerous errors (some but not all highlighted below). I found the introduction in particular lacked coherence, and this needs a significant rewrite to ensure that the context and novelty of the research is clearer to the reader. The author should go through the full article to improve readability.

   Clarifications have been made throughout the article, particularly in response to the reviewer's comments. The introduction was indeed rather too general and did not focus sufficiently on the article's objective. I have therefore revised and simplified it to make this clearer.

   Section 2 now contains a more detailed description of the FENNEC field campaign, partly based on the original introduction. Mentioning FENEC in such detail in the old introduction somewhat detracted from the article's focus.

   New introduction:

   Modelling is essential for characterising aerosol types and providing the most accurate possible assessment of their impacts on climate (Giorgi and Lionello, 2008; IPCC, 2022; Nabat et al., 2015; Flamant et al., 2015), as well as on meteorology and air quality (Wang et al., 2013, 2014a; Benedetti et al., 2009; Huneeus et al., 2012; Fourrié et al., 2019). This process relies on the validation of model-derived estimates against relevant observations. However, identifying aerosol types from observations remains a challenging and active area of research. In particular, the ability to characterise aerosols as a function of altitude and time is crucial not only for model validation but also for the interpretation and validation of spaceborne observations.

   Significant progress on aerosol typing has been achieved with the advent of satellite missions carrying lidar instruments, such as the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) (Winker et al., 2009). Dedicated field campaigns were conducted both to support the development of the mission and to validate its products. These efforts notably relied on polarised and multispectral lidar measurements to discriminate between different aerosol types and their potential mixtures (Burton et al., 2012). The recent launch of the Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) satellite mission (Wehr et al., 2023) has underscored the need for robust validation methods to accurately identify the different aerosol types. This need is particularly critical given that the mission relies solely on polarised channels at 355 nm in order to optimise the performance of the high-spectral-resolution atmospheric lidar (ATLID). Consequently, aerosol typing must primarily rely on the lidar ratio (LR) and the linear particle depolarisation ratio (PDR). Although the operational algorithm

accounts for a range of aerosol types, significant overlaps between classes may still occur.

The aim of this study is to present an approach based on a straightforward N_2–Raman lidar technique to retrieve aerosol optical properties at 355 nm with high spatial resolution in the troposphere, with the objective of performing aerosol classification. The study investigates the temporal evolution of aerosol optical properties during the FENNEC (https://africanclimateoxford.net/projects/fennec/: last access 4 April 2026) ground-based field campaign conducted from mid-June to the end of August 2011, with a particular focus on identifying aerosol types (e.g. dust, carbonaceous, and soluble particles). The resulting optical apportionment is compared with mesoscale simulations of aerosol chemical composition from the Copernicus Atmosphere Monitoring Service (CAMS; https://atmosphere.copernicus.eu/: last access: 8 February 2026) (Inness et al., 2019). Unlike spaceborne lidar observations, for which few coincidences are available due to satellite revisits, this method offers the possibility of significant statistical overlap. Hence, the reliability of the CAMS reanalysis of aerosols can be studied, which is important for understanding the impact of aerosols on the climate and air quality. This is also part of the long-term vision to use modelling data alongside ATLID products.

Subsection 2.1

The FENNEC airborne component was conducted from June to July 2011 (Ryder et al., 2015; Marsham et al., 2013) and was extended to include ground-based measurements from mid-June to the end of August 2011. These measurements focused primarily on the contribution of Saharan dust to the atmospheric particle load. During this extended summer period, the vertical distribution of aerosols was monitored from a ground-based remote sensing station located in San Pedro Alcántara, southern Spain (36°29′11″ N, 4°59′33″ W), between Gibraltar and Marbella in Andalusia. The complex topography of the Mediterranean coastline at this site generates contrasting air masses in the lower and middle troposphere (Rodríguez et al., 2001). These air masses transport a variety of aerosol types, the physicochemical and optical properties of which are closely linked to their source regions (e.g. the Sahara area) (Gallero et al., 2006).

It is worth noting that the FENNEC ground-based experiment follows the Mediterranean Dust Experiment (MEDUSE) (Hamonou et al., 1999; Dulac and Chazette, 2003) and predates the Chemistry-Aerosol Mediterranean Experiment (ChArMEx), conducted between 2013 and 2014 (Chazette et al., 2016b; Di Girolamo et al., 2020; Chazette et al., 2019; Mallet et al., 2015). The latter notably included contributions from the European Aerosol Research Lidar Network (EARLINET) (Barragan et al., 2017; Navas-Guzmán et al., 2013). Compared with these campaigns, FENNEC provided an exceptionally long and continuous lidar sampling of the troposphere.

2. The calculation of vertical profiles of aerosol extinction for the reanalysis may be overly simplistic and the author only verifies that the calculation reproduces the model AOT. In particular, using a single value for the specific cross section for each aerosol

type neglects any dependence on humidity or the aerosol species within the type that is included in the reanalysis. Indeed neglecting the impact of increasing humidity near the surface could explain the underestimate of the extinction. More recent versions of the model used for the reanalysis do output aerosol extinction, so I would suggest checking that the method works well for extinction at the same location for a more recent period when the extinction is available.

Indeed, this section of the article requires further discussion. In the model, aerosol optical thicknesses (AOT) take relative humidity (RH) into account, but this is based on several assumptions. The main assumptions are that aerosols do not change bin during growth with RH, and that for highly hydrophilic sea salt aerosols, only RH = 80% is considered for both the AOT and mixing ratio (see https://www.ecmwf.int/sites/default/files/elibrary/112024/81630-ifs-documentation-cy49r1-part-viii-atmospheric-composition.pdf). Therefore, the impact of RH on the modelling is based on strong assumptions.

Therefore, I would say that the hypotheses put forward in this article are fairly well supported for sea salts (which are highly hydrophilic) and dust particles (which are slightly hydrophilic). Furthermore, the model accounts for dependence on RH via the AOTs.

Normally, the wet AOT should be calculated more accurately using an equation of the form:

$$AOT_W(z) = \int_{ground}^{z} \overbrace{M_D(z') \cdot \underbrace{\left(1 + \mu(z') \cdot \frac{RH(z')}{(1 - RH(z'))}\right) \cdot \sigma_W(z')}_{C}}^{\alpha_{CAMS}} \cdot dz'$$

In the article, I assumed that C is constant in order to derive Eq. 11.

- **µ is the aerosol mass increase coefficient (e.g. Hänel, 1976)**
- **M_D is the dry matter mass, and $M_W = M_D \cdot \left(1 + \mu \cdot \frac{RH}{(1-RH)}\right)$ is the wet matter mass (e.g. Hänel, 1976)**
- **σ_W is the wet specific cross-section**

It turns out that, when hydrophilic aerosols are present in high concentrations in the model (below 1 km), the relative humidity (RH) remains stable at altitude with a certain degree of repetition from one night to the next in the lower layers. Values between 50% and 80% are observed (see the figure below, derived from the ERA5 reanalysis). This therefore minimises the impact of RH on calculations. It could be said that the cross-section retrieved here is a pseudo-wet cross-section. Please note that the model's hypothesis also involved the use of a pseudo-wet cross-section, and that below the deliquescence point (RH between 50% and 70%, 76.8% for sea salt), the hygroscopicity effect is low (see McMurry and Stolzenburg, 1989; Randriamiarisoa et al., 2006).

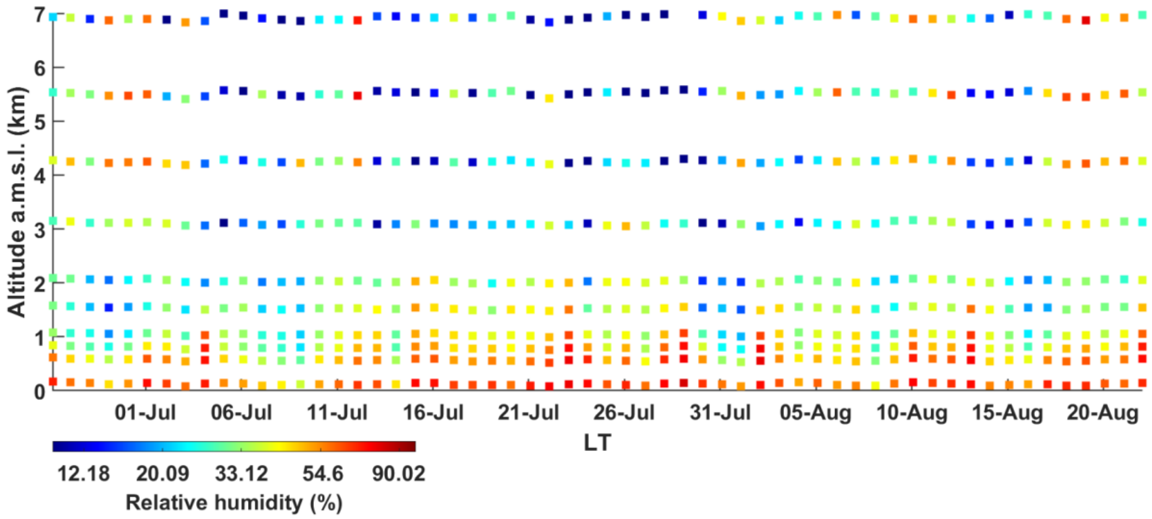

Table 2 provides a comparison of the AOT from the model with those recalculated based on my assumptions. The bias in the total AOT is very small (5.65 × 10^3), particularly when dust is present. I have updated this table to present the same type of results for the three types of aerosols considered. There is an excellent match for dust and carbonaceous aerosols. The correlation is slightly weaker for soluble aerosols but still shows a correlation of 0.82 with a very small bias.

Table 1: Specific cross sections σ_{spec} assessed for each aerosol compound using the CAMS data. The statistical parameters of the comparison between the AOTs provided by CAMS and those recalculated are also given: Mean bias (MB), root mean square error (RMSE) and corelation coefficient (COR).

	Dust	**Carbonaceous**	**Soluble**	**Total**
σ_{spec} at 550 nm (m^2 g^{-1})	**0.93**	**4.16**	**2.25**	**-**
Statistical parameters on AOT at 550 nm				
MB	**+5.06 10^{-3}**	**-8.10 10^{-5}**	**+6.74 10^{-4}**	**+5.65 10^{-3}**
RMSE	**1.47 10^{-2}**	**6.51 10^{-3}**	**1.61 10^{-2}**	**2.41 10^{-2}**
COR	**0.98**	**0.95**	**0.82**	**0.97**

Therefore, I think that the AOTs recalculated using the hypothesis set out in the article are in very good agreement with the ones provided directly by CAMS. This suggests that we are not far off the extinction profiles we are looking for, particularly given that the soluble and carbonaceous components are primarily found in the lower part of the profiles, below ~1 km. Therefore, the loss of significant correlation in the lower layers (see Table 4) does not necessarily indicate that hygroscopicity was not adequately considered in my calculations. It should be noted that the model is primarily validated using AOTs, which it also assimilates. The vertical profiles derived from the model are therefore adjusted accordingly.

A more precise comparison of the model's reliability can be made once all the hygroscopicity information is available in the database. In particular, the mass increase coefficients and wet densities of the aerosols would be useful to know.

Unfortunately, the aerosol extinction coefficient profiles are not available. I have looked for recent data, but cannot find any. If these profiles are calculated, they should be included for all products, enabling users to assess the consistency of the dataset.

I propose including all these explanations in Section 3.2 of the article.

3. The “RMSE” used in this article is more typically called the centred root mean square error (e.g. Taylor, 2001) I appreciate that the terminology used in this article is used by some authors, but I think RMSE is more widely understood to mean the error including the bias (i.e. what is called RMSD in this article). I think it would be better to adopt the more widely used terminology, which is less likely to cause confusion. In addition, while the appendix was useful for highlighting that a non-standard definition of the RMSE is used, I think it is unnecessary if the more widely used terminology is used.

   Ultimately, it comes down to definitions. The key point is that they are clearly stated. We have consistently used these definitions when comparing measurements and models, and they are also found in numerous publications. While I am not certain which definitions are the most widely used, I do not believe that this is particularly important. Maintaining consistency with our previous work seems more valuable.

   Note that RMS is calculated on a centred variable and reflects statistical noise. I believe the appendix is helpful for readers who may be less familiar with this type of calculation, as it can provide additional clarity.

4. I appreciate that there may be non-scientific reasons, but am puzzled by the long delay between collection of the data and the submission of this paper. I expect other readers will be too. It would be good to highlight how this older dataset remains relevant and important given the availability of more recent observations and more sophisticated instruments.

   Although the dataset is old, it remains entirely relevant. It is the longest continuous dataset available from our lidars. Furthermore, I can confidently state that lidar technology has not changed significantly since 2011. LAASURS is a French lidar system that remains operational and uses proven technology employed in recent developments and field campaigns (Laly et al., 2024). The FENNEC dataset has the additional advantage of having been collected during a period of low cloud cover in southern Spain. This provided sufficient nights for meaningful statistical analysis, following a robust inversion process.

   I explained this in subsection 2.2.2.

   “LAASURS (Erreur ! Source du renvoi introuvable.**b) itself is described in detail and validated in Royer et al. (2011a) and Chazette et al. (2019b) and it has been used in numerous field campaigns, such as the journey from Paris to Lake Baikal (Dieudonné et al., 2015). LAASURS is a French lidar system that remains operational and uses proven technology that has been employed in recent developments and field campaigns (Laly et al., 2024). ”**

> **Another important point is the need to create databases to preserve records of observations for reuse years after they were collected, both in Europe and elsewhere. The same applies to model outputs. These datasets will remain relevant in the decades to come and must be used. It is better to focus on the relevance of the data than on its age.**

Specific Comments

P1, L10: Expand FENNEC acronym.

This is not an acronym; it is the name of the project.

P2, L32: This should be *after* the Mediterannean dust experiment?

Yes, this paragraph has been moved to section 2.1.

P5, L20: This is incorrect. Aeronet observations are not assimilated into the model

Yes, the reviewer is correct. AERONET data are used for validation. The correction has been made.

"In particular, AOTs derived from satellite observations, such as those of the Moderate Resolution Imaging Spectroradiometer (MODIS) (Remer et al., 2005), are directly assimilated into the model. Ground-based measurements from permanent AERONET stations are also used as a validation dataset. However, vertical aerosol profiles are not assimilated and are rarely considered for validation purposes."

P13, L9: During *the* day…

The correction has been done.

P16, L10: No need for upper case The.

The correction has been done.

Fig. 9: Can you add ticks to the axis with the same orientation as the lines that show constant values for that aerosol to make it clear which lines correspond to which aerosol?

I have used different colours to mark the projections for the three types of aerosols because it was unclear when adding the ticks. This makes the ternary diagram easier to read.

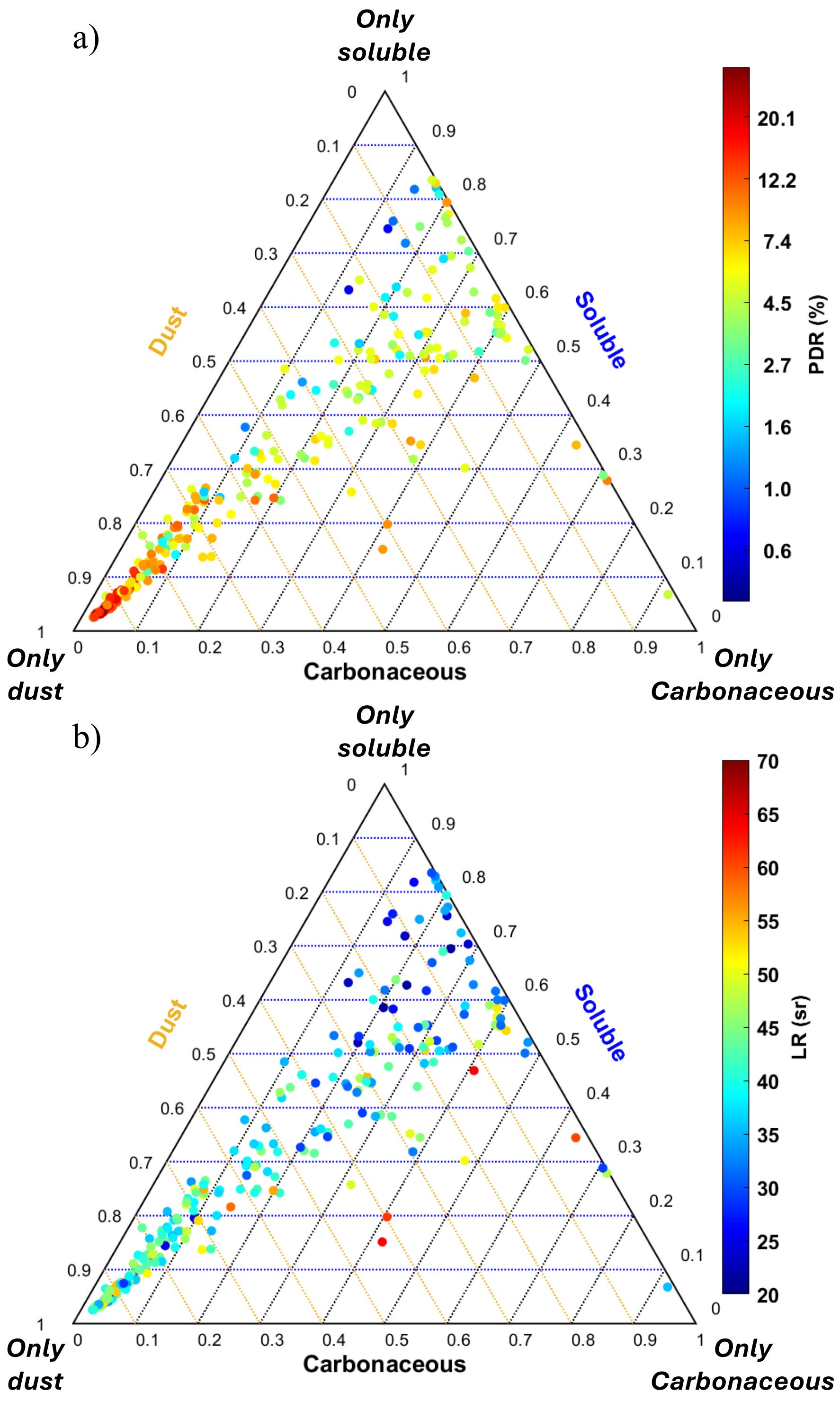

Figure 1. Ternary diagram established from the aerosol compounds derived from CAMS: dust, carbonaceous and soluble compounds. Each colour dot corresponds to lidar-derived optical properties: a) particulate depolarization ratio (PDR) and b) lidar ratio (LR). The projections onto the sides of the equilateral triangle are colour-coded as follows: orange for dust aerosols, blue for soluble aerosols, and black for carbonaceous aerosols.

P19 L 23: expends should be extent?

The correction has been done.