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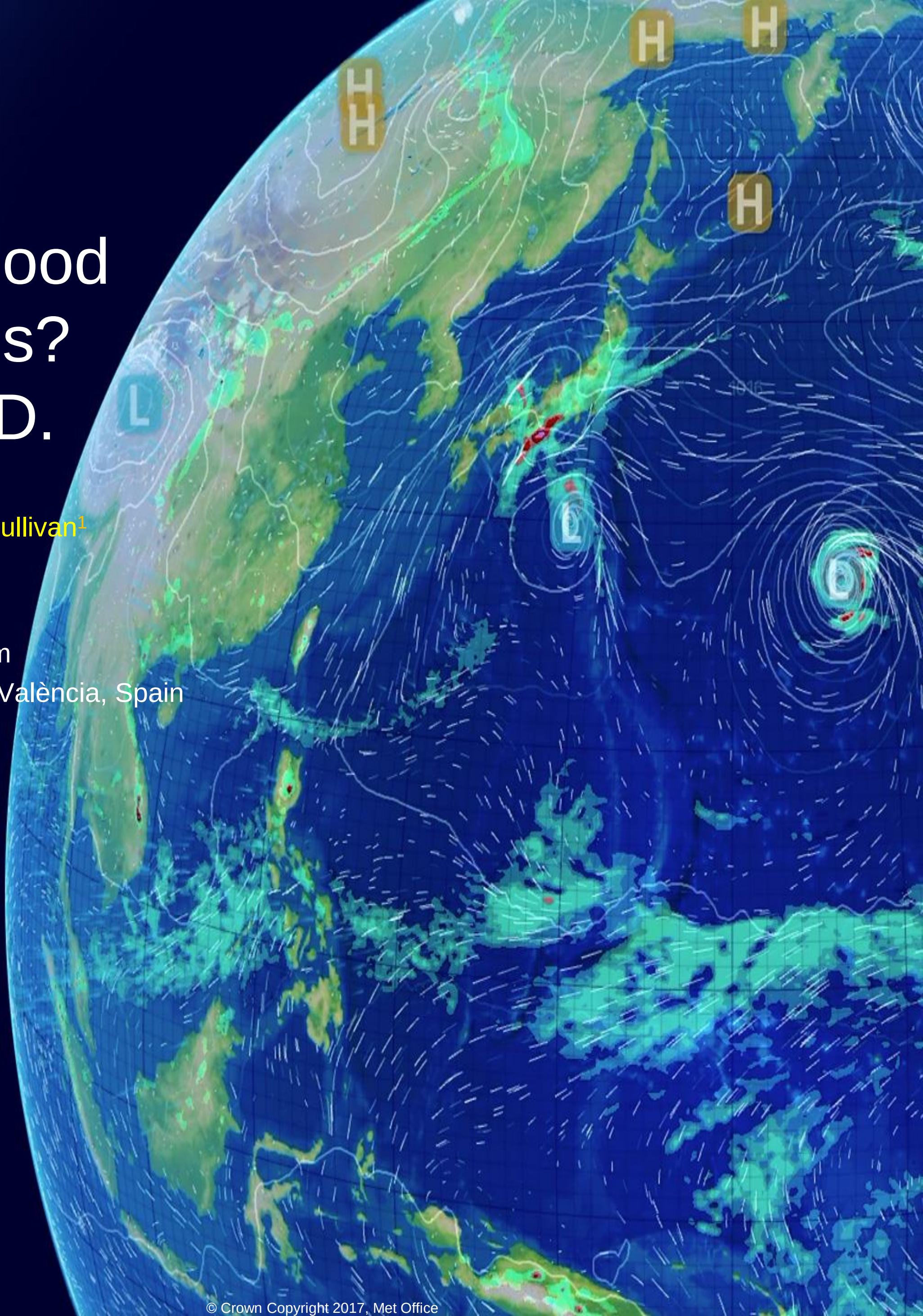
Is Aerosol Optical Depth a good metric to map dust properties? Lessons learned from AER-D.

Franco Marenco[1], Claire L. Ryder[2], Victor Estellés[3] and Debbie O'Sullivan[1]

[1]Met Office, Exeter, United Kingdom
[2]Department of Meteorology, University of Reading, United Kingdom
[3]Department de Física de la Terra i Termodinàmica, Universitat de València, Spain



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Is Aerosol Optical Depth a good metric to map dust properties? Lessons learned from AER-D.

The main observable quantity used on a global scale to map aerosols is aerosol optical depth (AOD), from ground-based and satellite remote sensing. It is at the same time an optical property and a vertically integrated quantity, and it is commonly used as the main metric towards which to pull aerosol models, through data assimilation, verification, and tuning. ***Here we introduce a few reflections on how to better constrain our knowledge of the Saharan Air Layer and its associated mineral dust***, following results from the AER-D campaign.

AER-D was a small field experiment in the Eastern Atlantic during August 2015, based on the opportunity given by the simultaneous ICE-D experiment. The purpose of AER-D was to investigate the physical properties of the Saharan Air Layer, and to assess and validate remote sensing and modelling products. The FAAM atmospheric research aircraft was used as a flying laboratory, and it carried a full set of instruments aimed at both in-situ sampling and remote sensing.

A broad distribution of particle sizes was consistently observed, with a significant giant mode up to 80 μm, generally larger than what was observed in previous experiments: we ascribe this to the set of instruments used, able to capture the full spectrum. We discuss the representation of the particle size in operational models, and we show that despite predicting an extinction coefficient of the correct order of magnitude, ***the particle size is generally underestimated***. We will also discuss the implication of the giant particles for the ground-based remote sensing of columnar size-distributions from the SKYNET and AERONET networks (Sunphotometer Airborne Validation Experiment, which was a component of AER-D).

We present the vertical structure of the Saharan Air Layer, and the comparison with the operational models shows that ***they can predict a correct AOD, despite missing the vertical distribution.***

These findings lead to a series of reflections on how to better constrain our knowledge of the Saharan Air Layer and its representation in operational models. ***Size-resolved properties and the vertical distribution are essential companions of the global AOD observations commonly used operationally***.

Aerosol Optical Depth (AOD)

- Extinction is an **optical property**, measuring visibility (how much light is attenuated over a path of 1 m):

$$\alpha[\mathrm{m}^{-1}] = \rho[\mathrm{g\ m}^{-3}] \cdot K_{\mathrm{ext}}[\mathrm{m}^2\mathrm{g}^{-1}]$$

α = Extinction coefficient
ρ = Aerosol concentration
K_{ext} = Specific extinction

- Aerosol Optical Depth (AOD) is **integrated over the column** (how much light is attenuated from the surface to the top of the atmosphere):

$$\tau = \int_0^\infty \alpha(z)dz$$

τ = Aerosol Optical Depth

- Light **transmittance** through the atmosphere is computed from AOD:

$$T = e^{-\tau}$$

T = Transmittance

- Direct measurements of AOD are obtained from the surface with sun-photometers (e.g. AERONET, SKYNET).
- Global measurements of AOD are obtained from satellite platforms such as MODIS, VIIRS, etc.

Limitations of AOD-only observations

- AOD is a total-column quantity $\tau = \int_0^\infty \alpha(z)dz$
- Useful for 2-D mapping, but no information on **vertical distribution** (VD)
- Moreover, no information on **particle size-distribution** (PSD)
- Dust transport depends on wind speed and direction (altitude-dependent)
- Dust residence affected by VD and PSD
- Dust gradient downstream of sources likely affected by these properties

Is it sufficient to constrain models mainly through AOD ?

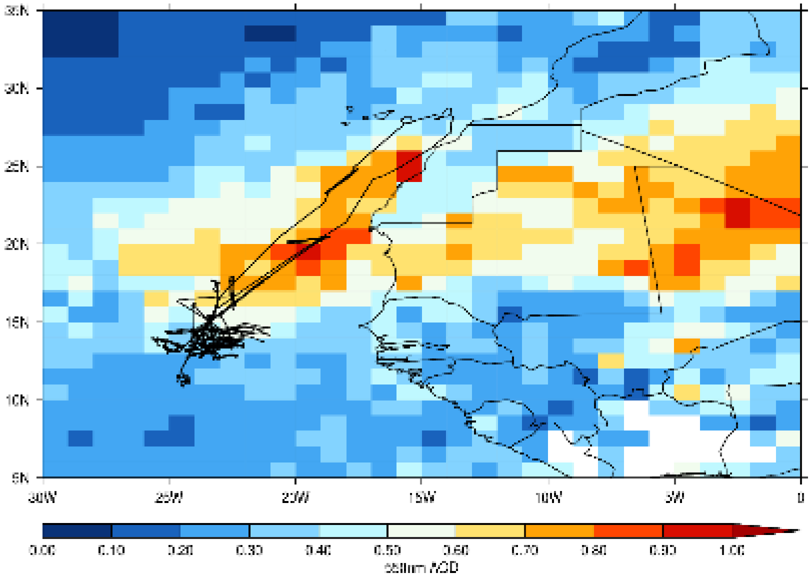
(through data assimilation, model verification, model tuning, etc.)

AER-D Campaign

AERosol properties - Dust

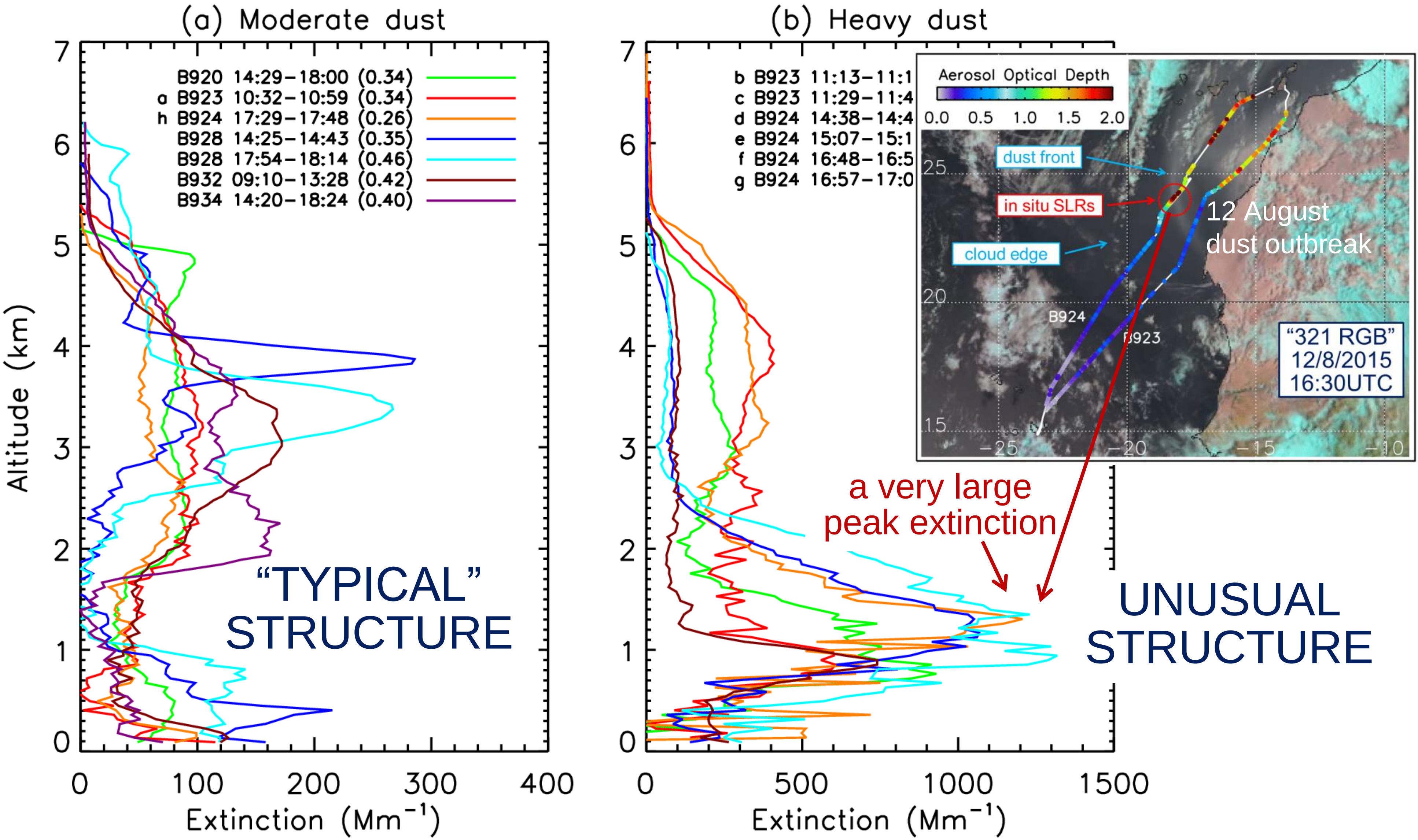
Cape Verde, 6–25 August 2015

- Insight on dust properties and processes
- Verify/validate operational dust predictions
- Verify/validate novel satellite dust retrievals
- Verify/validate the CATS space lidar
- SAVEX-D: validation of AERONET/SKYNET sunphotometer measurements of dust properties (size distribution, optical properties)



MODIS Aqua Combined Product AOD during ICE-D/AER-D and flight tracks 6-25 Aug 2015

AER-D campaign findings (1) Vertical Distribution



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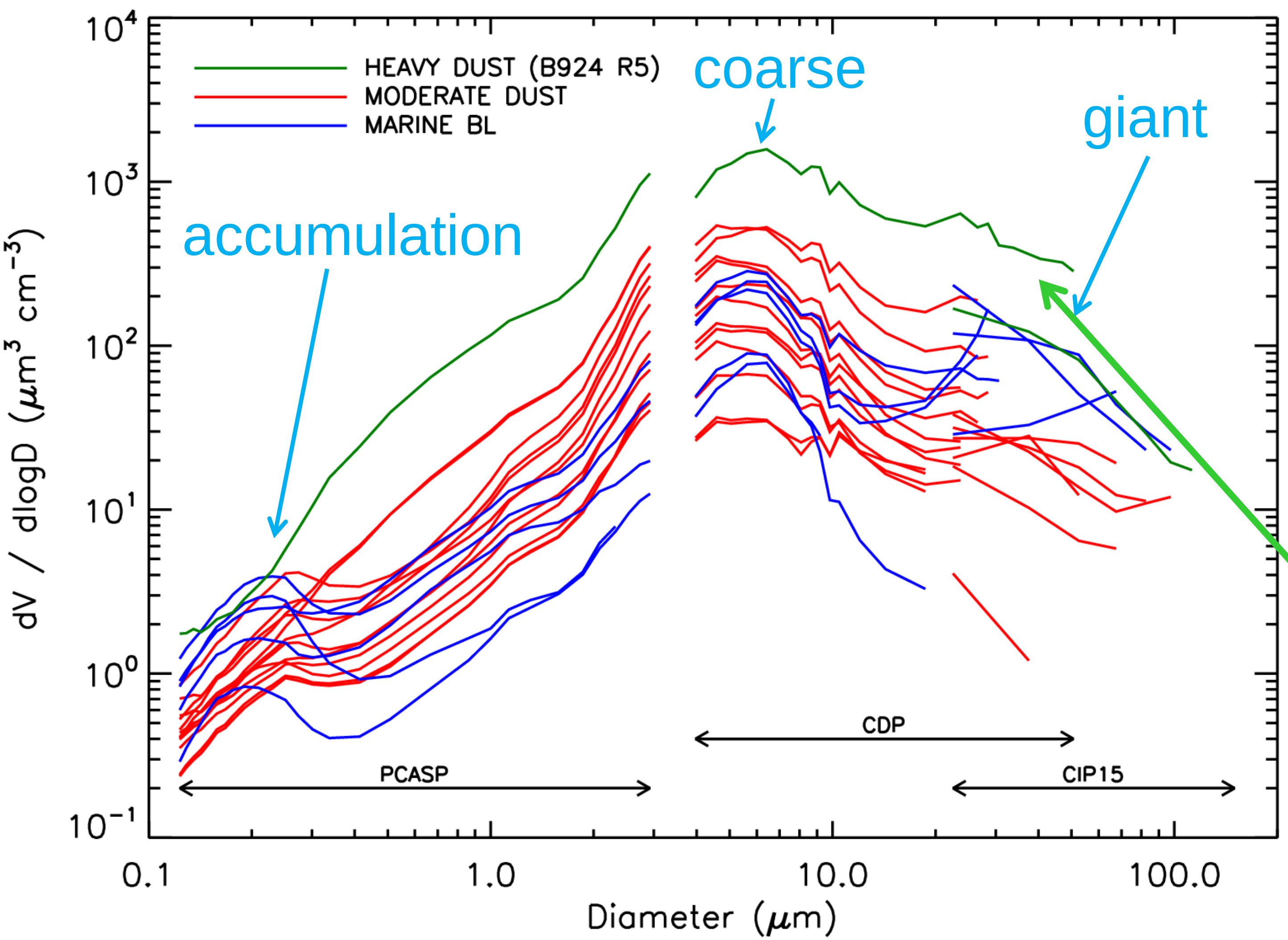
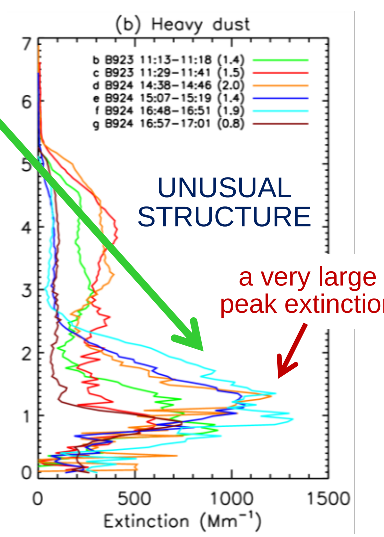
AER-D campaign findings
(2) Particle Size Distribution

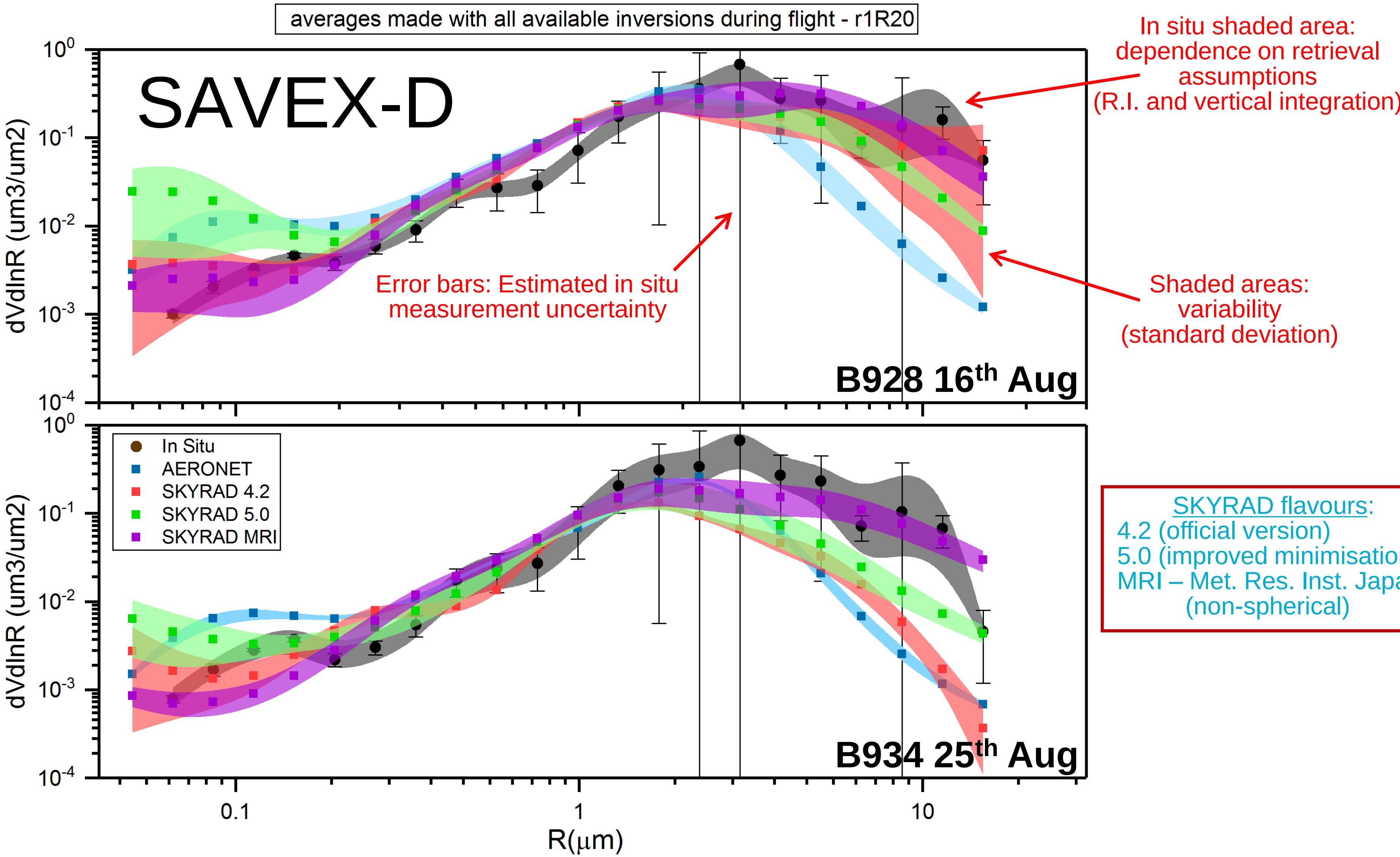


- Dominated by coarse mode
- MBL exhibits pronounced fine mode and less particles in coarse mode
- Giant particles in SAL and MBL
- Dust falling from above in MBL?



courtesy of Martyn Gallagher and Gary Lloyd

AER-D campaign findings (3) Sun-photometer validation



SKYRAD flavours:
4.2 (official version)
5.0 (improved minimisation)
MRI – Met. Res. Inst. Japan (non-spherical)

AER-D campaign findings (4) Model comparisons

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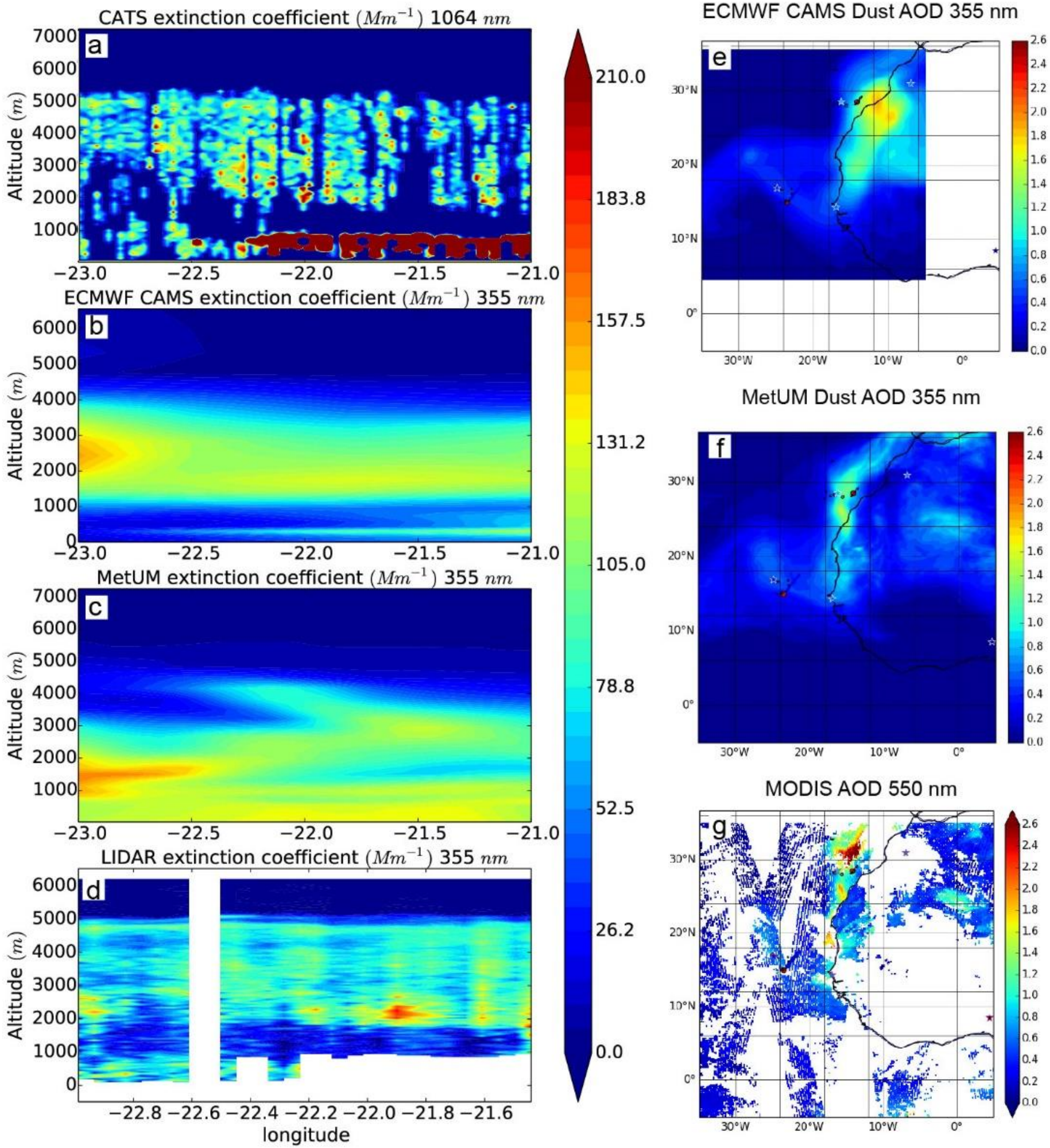
Aerosol extinction coefficient

- Comparable magnitude but differences in VD
- observed dust at 2-5km
- 0-4 km in MetUM
- 1-4 km in CAMS



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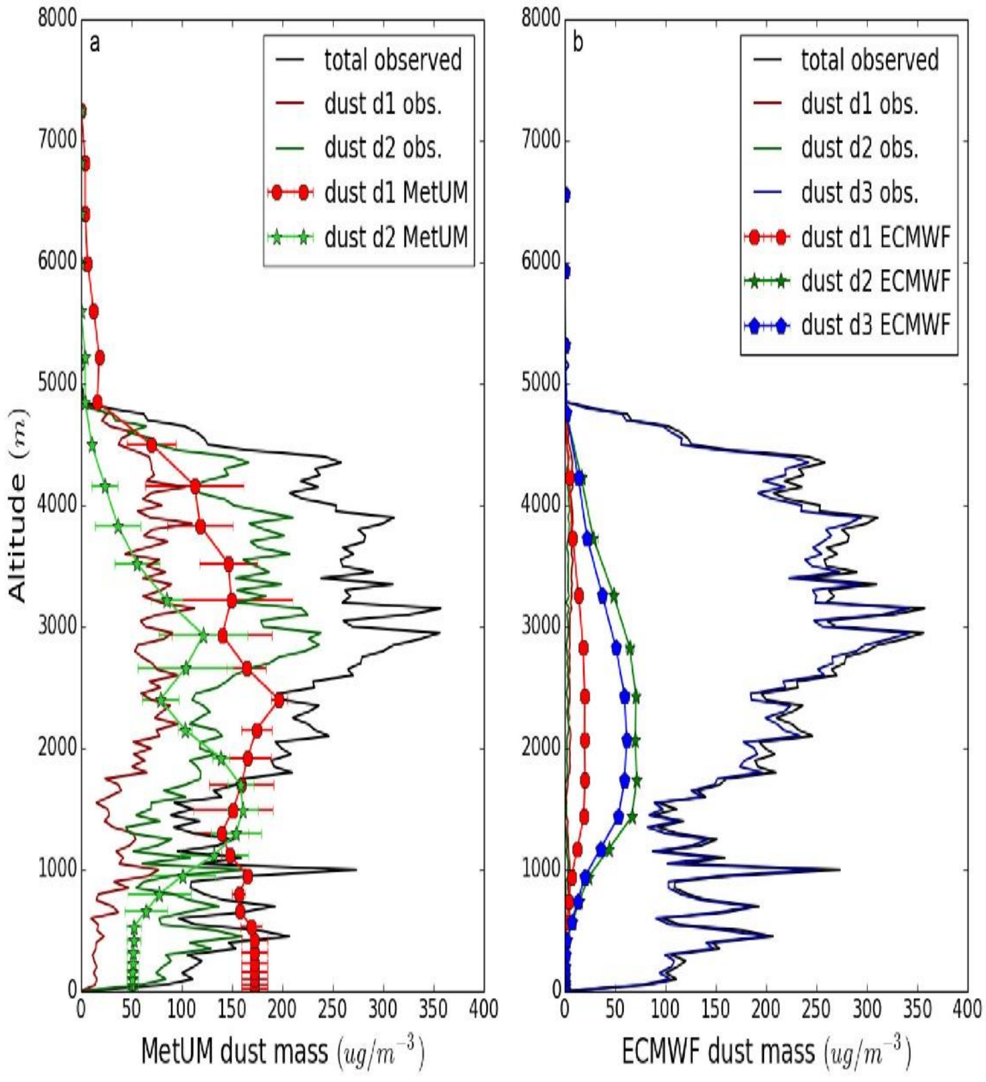

Dust concentrations in size bins

- MetUM not too dissimilar to obs, but with an overestimate of the weight of fine particles (d1)
- CAMS largely underestimates the weight of coarse particles (d3) and overestimates the fine ones (d1, d2)

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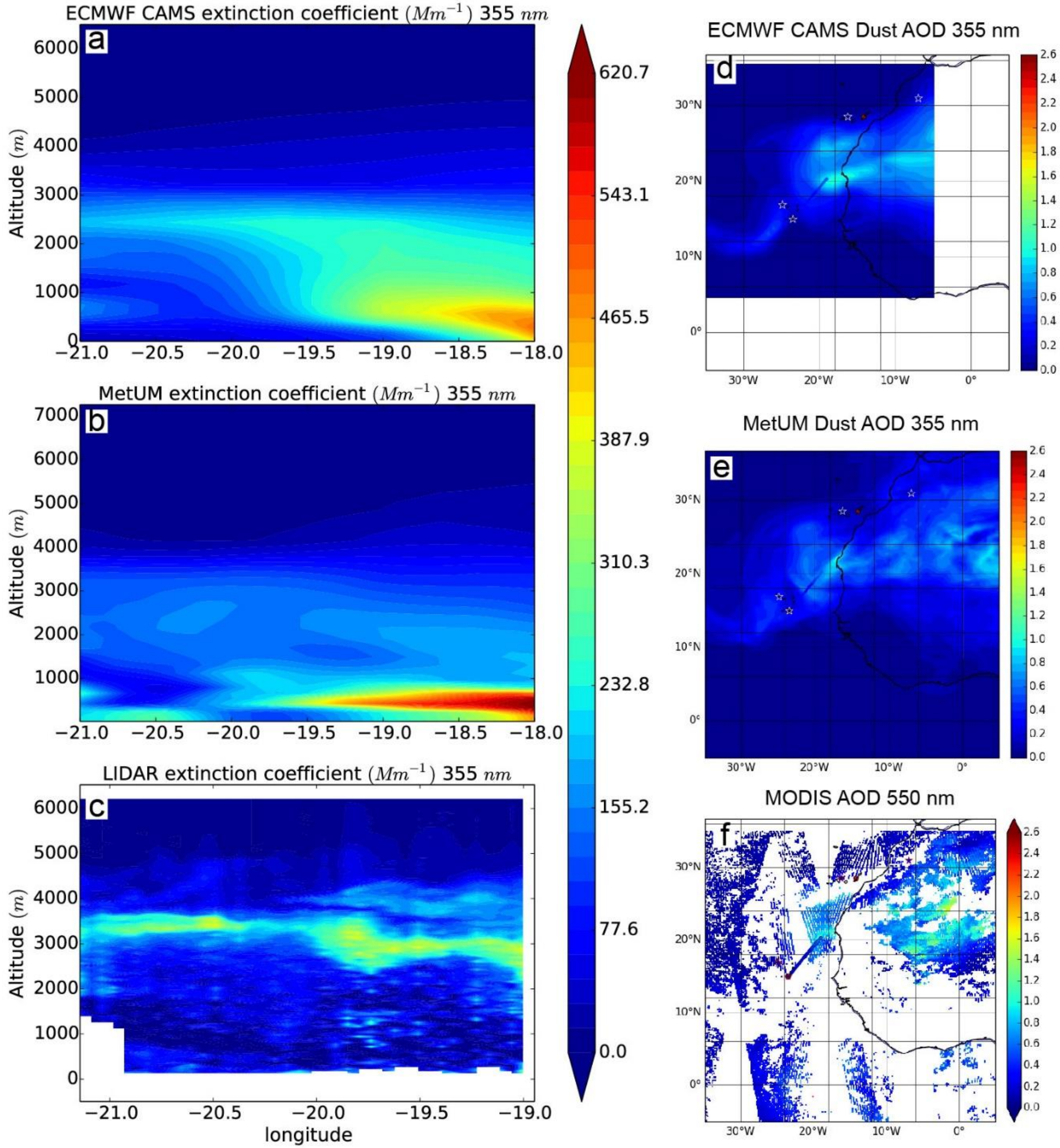
Aerosol extinction coefficient

- Observed dust at 2-4 km
- Predicted dust closer to surface
- CAMS better than MetUM for this case



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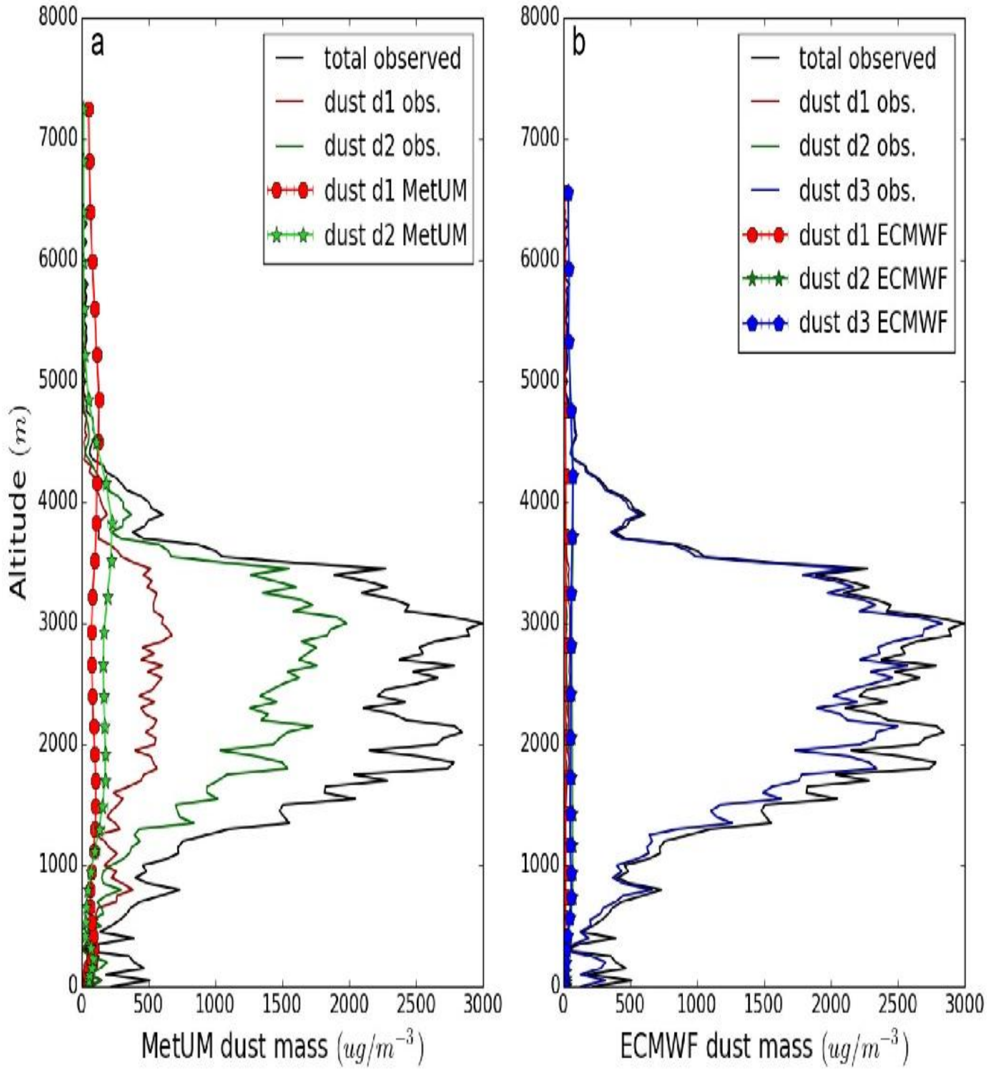

Dust concentrations in size bins

- Both models predict a dominance of coarse particles over fine
- The models however underestimate concentrations in each size bin

AER-D campaign findings (4) Model comparisons

On one hand:

- Both models tend to have the dust too low in the atmosphere compared with the observations (this effect seems more marked in the MetUM).
- Both models underestimate dust concentration and underestimate particle size.
- The models predict extinction and AOD of reasonable magnitude.

On the other hand:

- Modelled optical properties are computed from size-resolved dust concentrations.
- Modelled AOD is computed from the vertically-resolved extinction coefficient.

This paradox may be explained if we understand that models are constrained by operational observations of AOD through data assimilation, verification and tuning.

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AER-D campaign findings (4) Model comparisons

- Modelled optical properties are pulled towards observations, even when the microphysical properties from which they are computed are out of scale
- Finer particles make a greater contribution to aerosol extinction per unit mass, and the mismatch between the concentration and optical properties can be compensated through the modelled size-distribution
- Thus, AOD, vertical distribution, and particle size-distribution are deeply interlinked, and models will compensate errors in one variable with errors in another, in order to deliver results comparable to observations.
- These errors, however, will affect processes in the models such as e.g. (a) transport, (b) deposition, (c) dust gradient downstream from sources, and (d) the intensity of sources and sinks.
- This study highlights the need to refine the models, but also the potential ***usefulness of augmenting the set of global dust observations used operationally, to include vertical distribution (e.g. from spaceborne lidar or hyperspectral IR) and size-distribution (e.g. from disposable dust-sondes)***.

References

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