The statistical distribution of aerosol optical depth

A.C. Povey*, R.G. Grainger

*National Centre for Earth Observation, University of Oxford, UK; *adam.povey@physics.ox.ac.uk*

Motivation

Knowledge of the statistical distribution informs how data should be summarised and aggregated. Since [1], aerosol optical depth (AOD) has been considered to follow a log-normal distribution. This was recently supported by a theoretical demonstration that "any first order kinetics process with a stochastic rate… will induce log-normal dependence" [2]. As reviewed in [3], AOD is better aggregated with a geometric rather than an arithmetic mean.

The utility of the log-normal distribution has only been evaluated relative to the normal distribution [4, 5, 6], but there are other distributions that can describe a continuous, positive variable.

This poster examines the distribution of AOD observed by AERONET Level 1.5 and a selection of satellite algorithms: MAIAC, Dark Target and Deep Blue on MODIS Terra and Aqua alongside ADV, Swansea University and ORAC on (A)ATSR.

Detailed evaluation of satellites and models against sun photometers

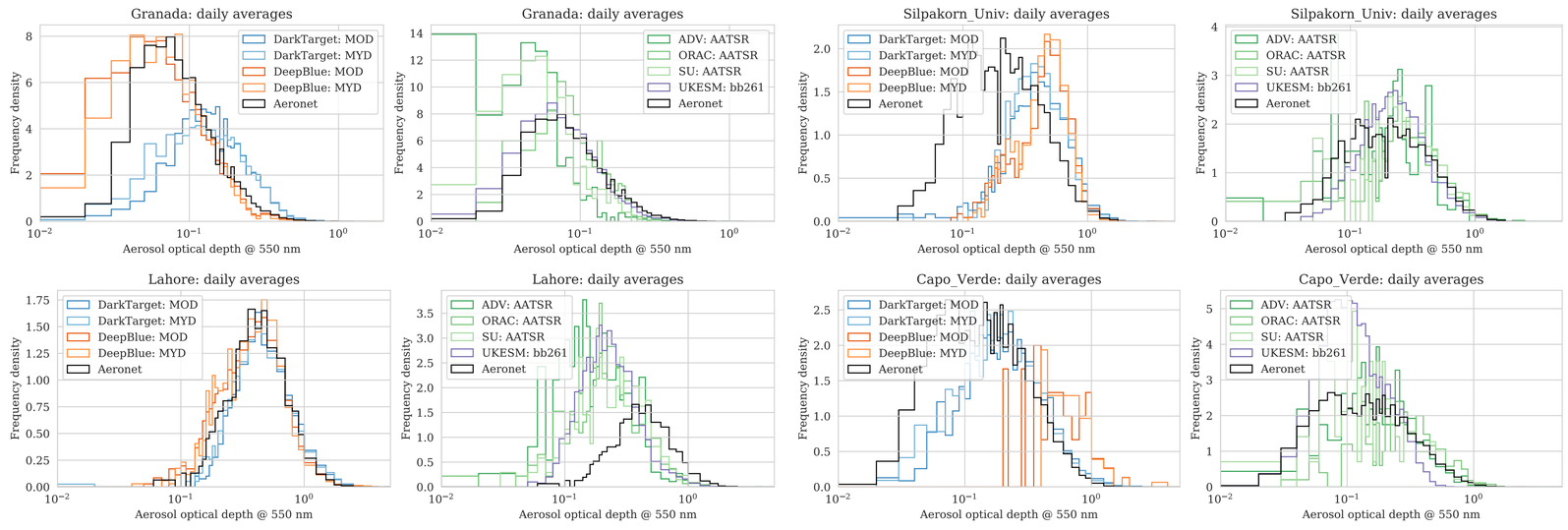

Figure 3: Distribution of daily geometric mean AOD observed over four AERONET [7] sun photometer installations: Granada, Spain; Silkaporn University, Thailand; Capo Verde; and Lahore, Pakistan (*clockwise from top left*). Observations from AERONET (black) are compared to the MODIS Dark Target (blue) and Deep Blue (orange) products, three AATSR retrievals (green), and the UK Earth System Model (purple). **Monomodal environments (left) are well fit by a log-normal distribution.** More complicated environments (right) are better fit by a generalised gamma distribution, but appear to be bimodal. **No one method performs universally well.**

Distribution varies between sensors

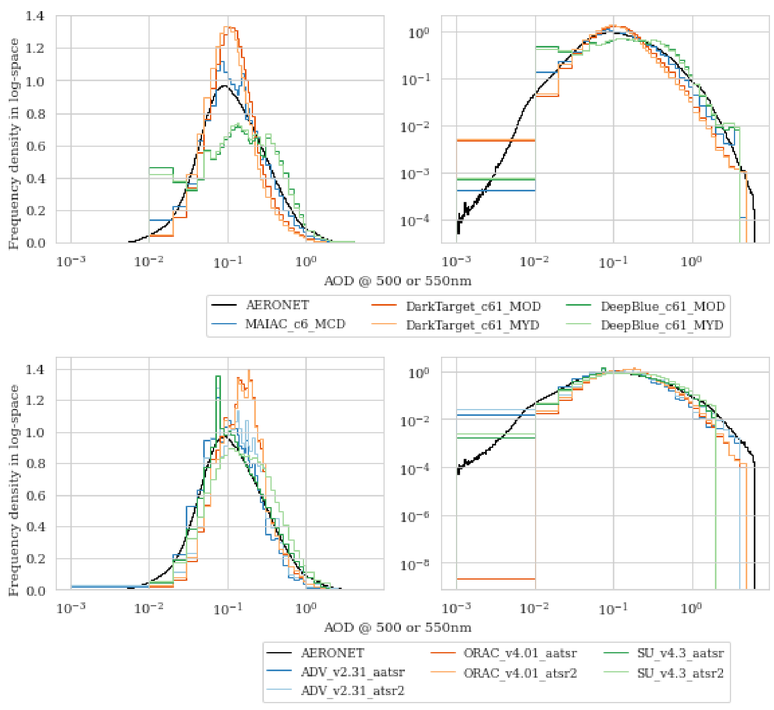

Figure 1: The frequency density of AOD observed by the MODIS (top) and ATSR (bottom) sensors (colours) superimposed on that from AERONET (black). MAIAC is closest to AERONET, with Dark Target doing well in clean conditions and Swansea in polluted.

Distribution is close to log-normal

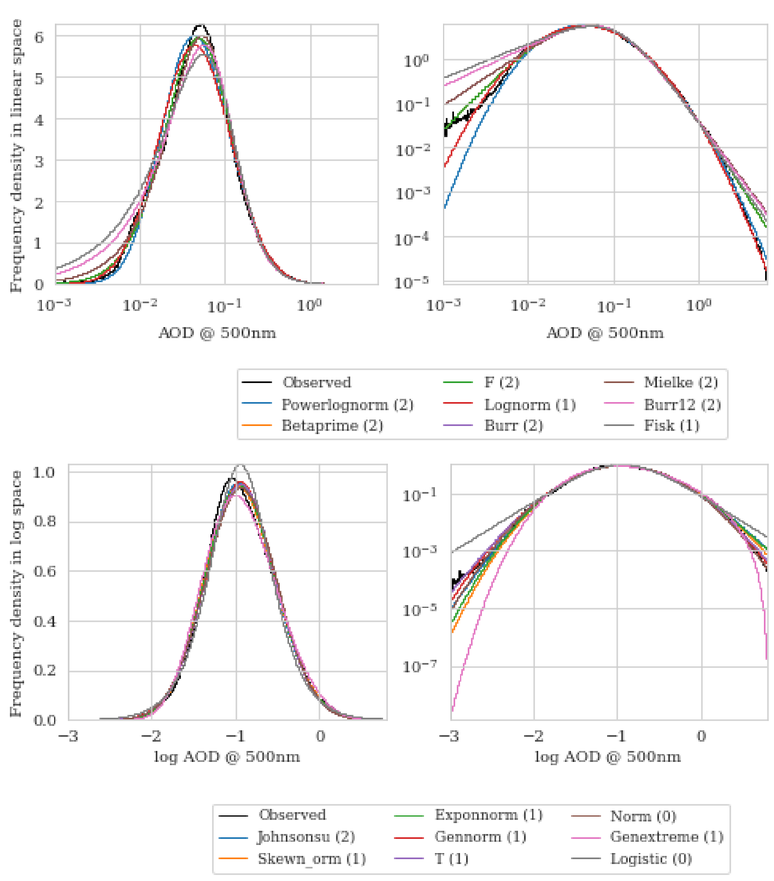

Figure 2: Fits of various statistical functions to the distribution of AOD observed by AERONET in linear (top) and logarithmic (bottom) space. No function accurately captures the mode but log-normals are best at the limbs. Note the AERONET excess for AOD<0.01.

Monthly variation

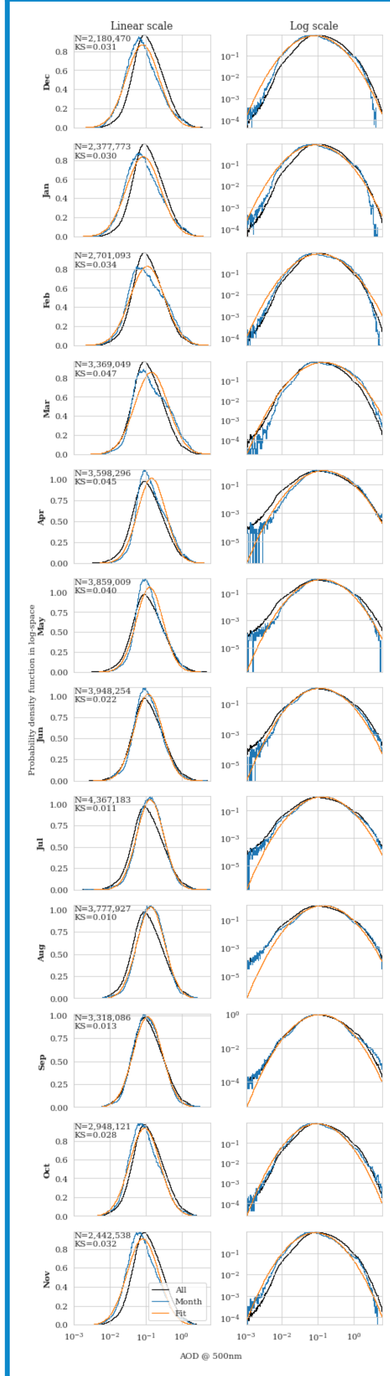

Figure 4: Distribution from AERONET by month of the year, shifting the southern hemisphere 6 months.

Hourly variation

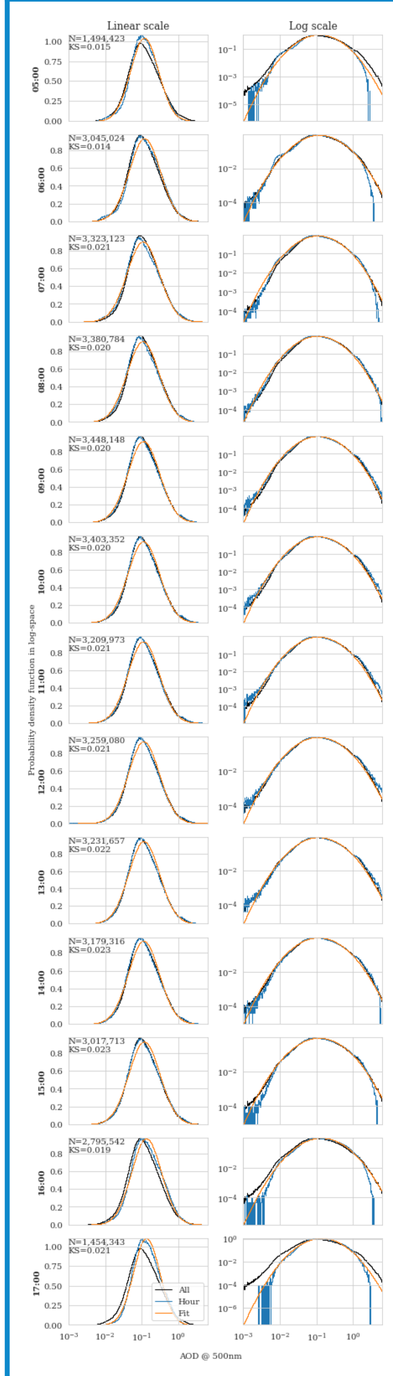

Figure 5: Distribution from AERONET by local solar hour, excluding those with $<10^6$ data points.

Geometric means over time

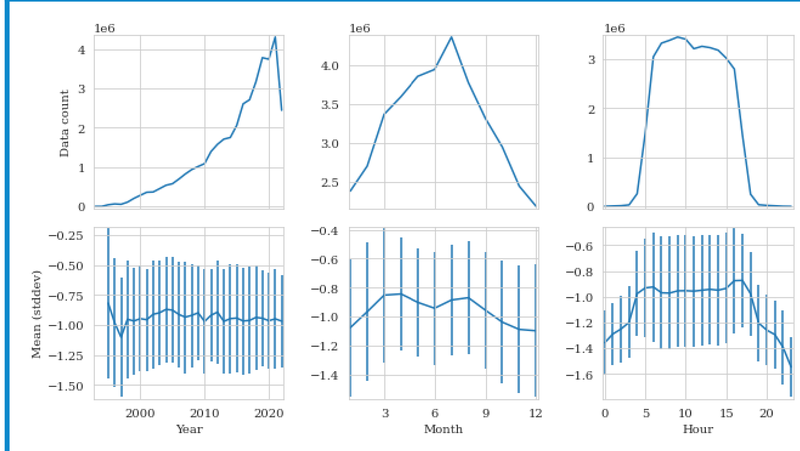

Figure 6: Top: Number of AERONET observations per year, month or hour (left to right); *Bottom*: Mean and standard deviation of AOD at 500 nm. There is a slight decrease in mean through the record, though the sampling changes substantially. AOD is larger in summer and in early afternoon, but there are also more observations at those times.

The distribution of AOD is shown in the plots at the centre of the poster. These are smooth but rarely entirely log-normal. There is an excess of very small AODs which appears concentrated in summer.

Bifurcation in spectral variation

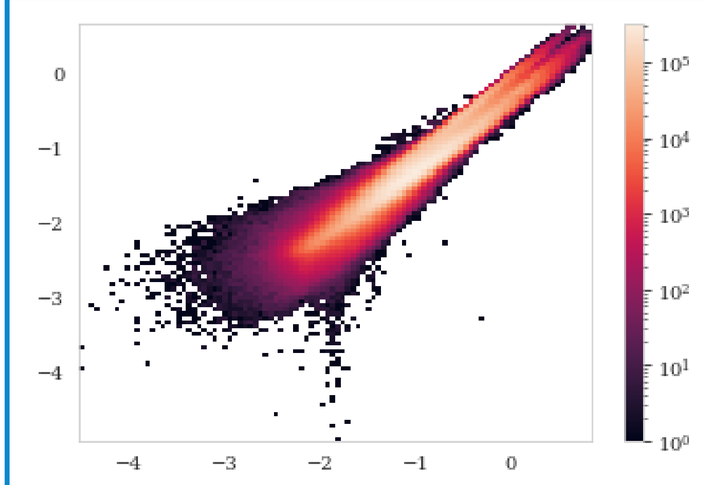

Figure 7: Joint histogram of $\log_{10}$ AOD at 870 nm against 500 nm from all AERONET observations.

Take-away messages

- The mean of AOD over a month is a poor representation of the underlying observations.
  - Daily means are better because conditions tend to evolve slower than that.
- AOD is log-normally distributed but is frequently multimodal.
  - Use geometric, not arithmetic, means.
  - A power log-normal distribution can be useful if a single mode is needed to represent a complicated environment.
- Describing the distribution of AOD observed allows a more nuanced comparison of datasets and models.
  - Highlights differences in sampling and filtering methods.

References

[1] Flowers, E. C. et al. (1969). doi:10.1175/1520-0450(1969)008<0955:atotus>2.0.co;2
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