A new perspective on satellite data

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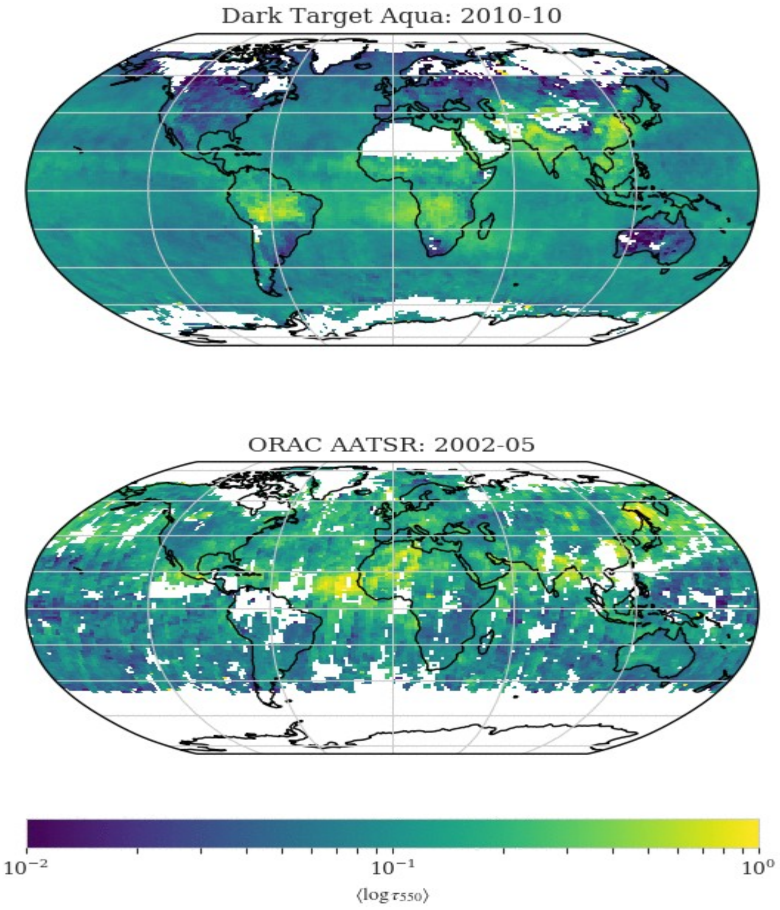
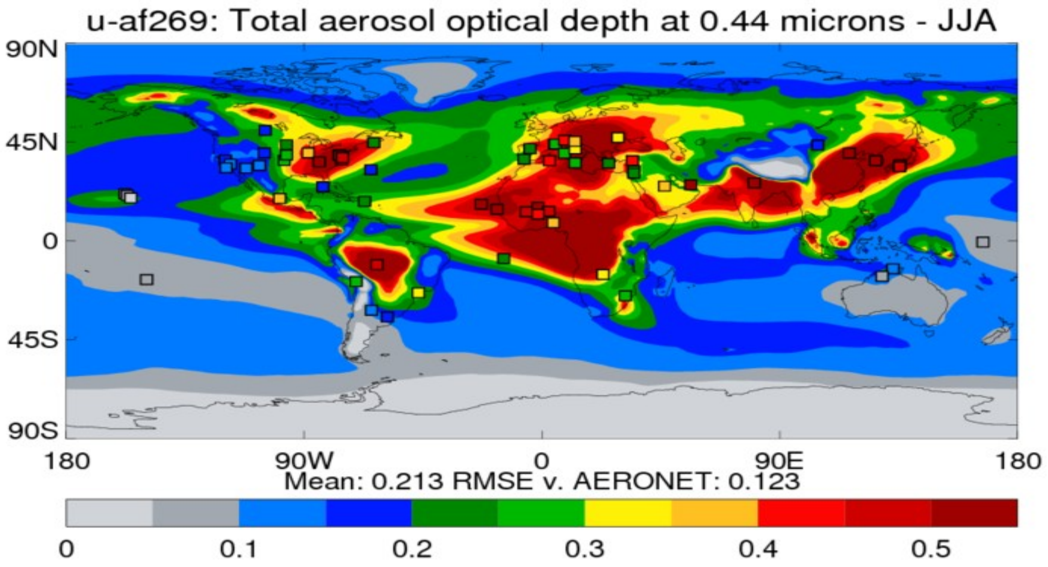
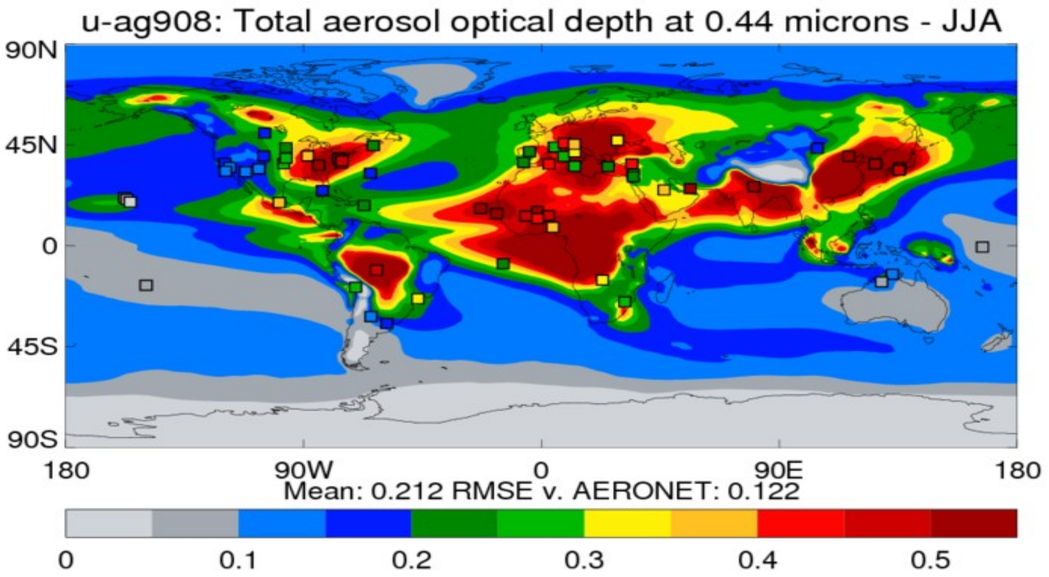


Talk outline

- The difficulty in comparing models to satellite observations
- Describing the distribution of observations
- More detailed perspectives for model and data comparisons

Comparing models to observations: a common approach





- Above is a traditional assessment of a model field by AutoAssess with two early versions of the UKESM.
  - Compares seasonal average aerosol optical depth from the model (background) to that observed by AERONET (squares).
  - Annual surface dust and sulphate concentrations are also compared to climatologies (not shown).
  - It's also common to compare models to monthly mean AOD from MODIS.
- A straightforward analysis that doesn't necessarily tell us how accurate the model is because...

Comparing models to observations: limitations

- An all-time average of a model grid cell is intrinsically different to the average of successful observations at a specific point or time.
  - Schutgens recommends that observations are averaged over 6 hrs for 210 km cells and 4 hrs for 110 km cells to minimise representation error. Only model cells collocated with observations would then be considered.
- This is illustrated below with zonal averages of AOD. Black dots are zonal averages of in situ observations, the red line is the same from a model, and the red dots are the model output after subsampling to have the same spatiotemporal distribution as the observations.
- But what if you only have monthly means?

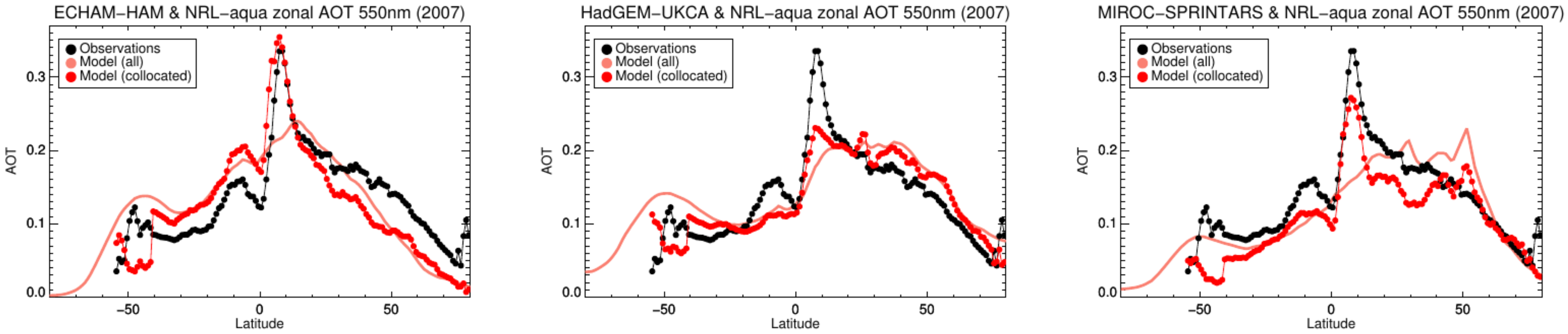
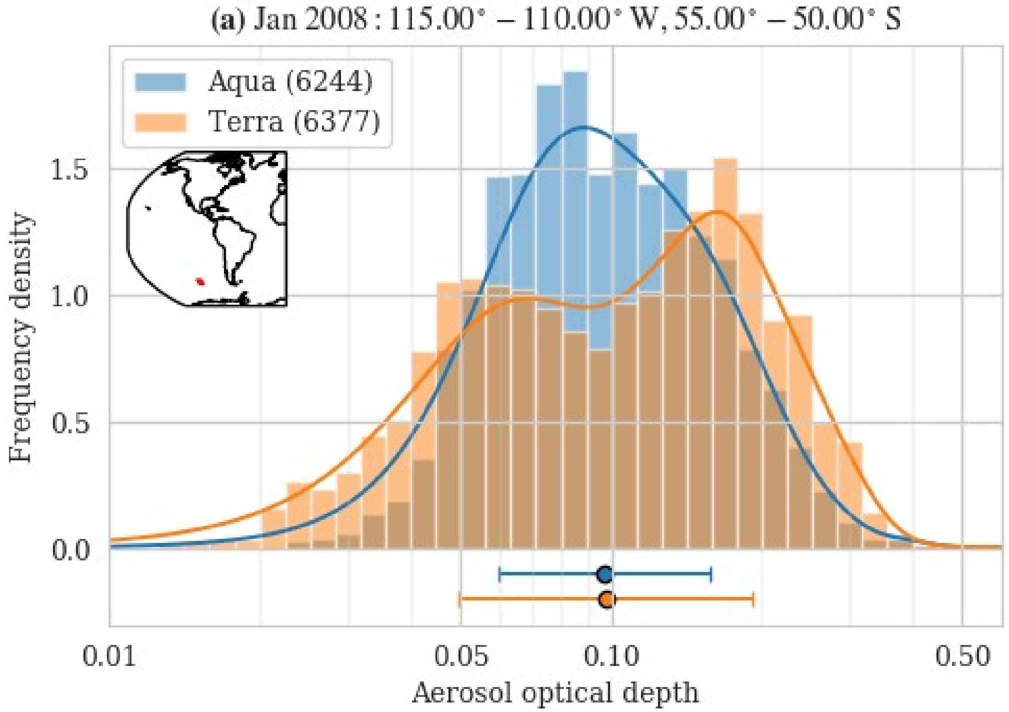


Fig. 1, Schutgens et al., doi:10.5194/acp-16-1065-2016

Considering the distribution of observed aerosol optical depth

- The importance of spatiotemporal variation in model assessment and data analysis implies (to me, at least) that simple means are a poor way of communicating satellite data to users.
  - They're easy to use but also easy to misuse.
- Given the significant differences in the distribution of AOD observed by different instruments, one option is to tabulate a histogram, showing the distribution of observations.
  - Clearly represents different regimes.
  - However, this substantially increases the file size and not many people know what to do with histograms (e.g. MISR have been providing them for almost a decade and no one noticed).

Fig. 1, Povey and Grainger (2019) doi:10.1109/LGRS.2018.2881762



Representing the distribution of observed aerosol optical depth

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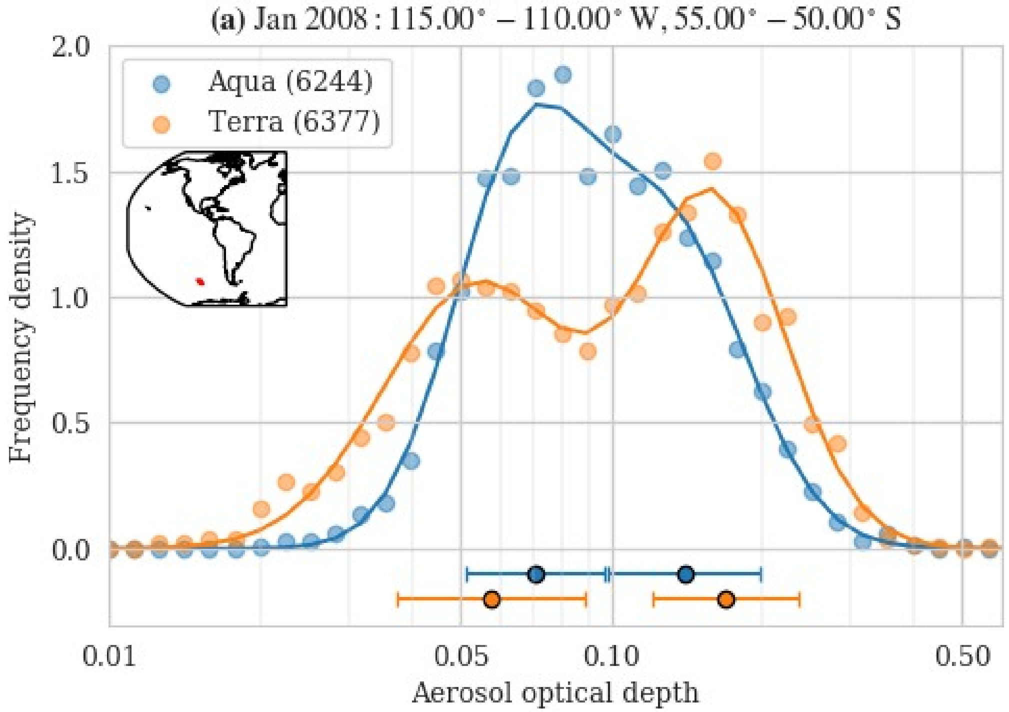
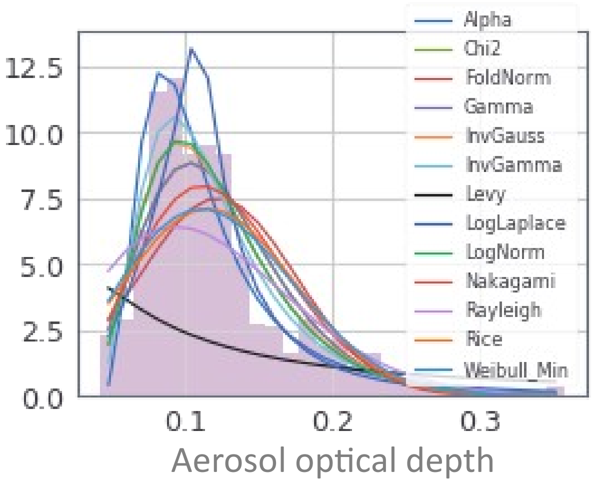
  - However, this substantially increases the file size and not many people know what to do with histograms (e.g. MISR have been providing them for almost a decade and no one noticed).
- Instead, fit a multimodal distribution to the histogram and report the parameters of that.
  - Only a few more numbers and they're closer to what the user understood by the data (i.e. what was the most common AOD here).

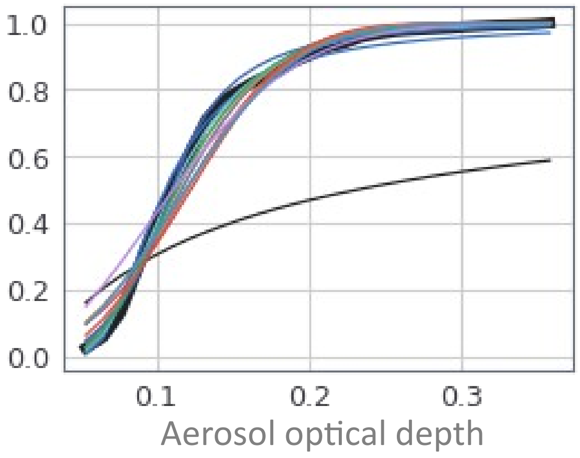
Fig. 2, Povey and Grainger (2019) doi:10.1109/LGRS.2018.2881762



What distribution to fit?

- AOD has been widely assumed to be log-normally distributed.
  - O'Neill et al. (2000, JGR) showed it was better than a normal distribution.
  - Sayer and Knobelspiesse just wrote a paper about how geometric means are more appropriate because of this: www.atmos-chem-phys-discuss.net/acp-2019-372
- I decided to check.
  - Take all the AOD observations in some region over some period and fit a variety of statistical distributions to it.
  - I tried the 44 positive-only distributions in scipy, evaluated both the raw data points and tabulated distributions of them, and looked at MODIS, AATSR, the UKESM, and AERONET.





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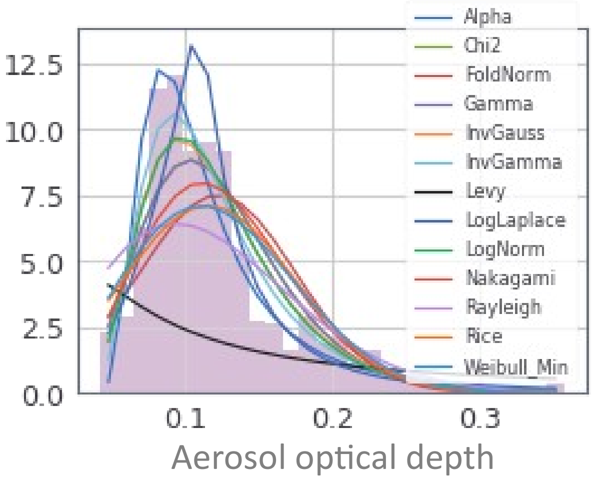
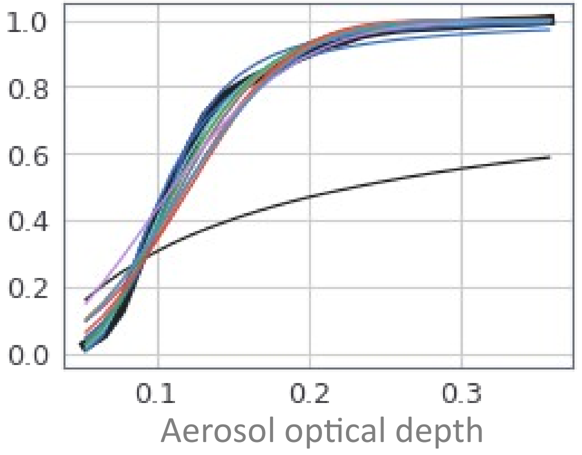
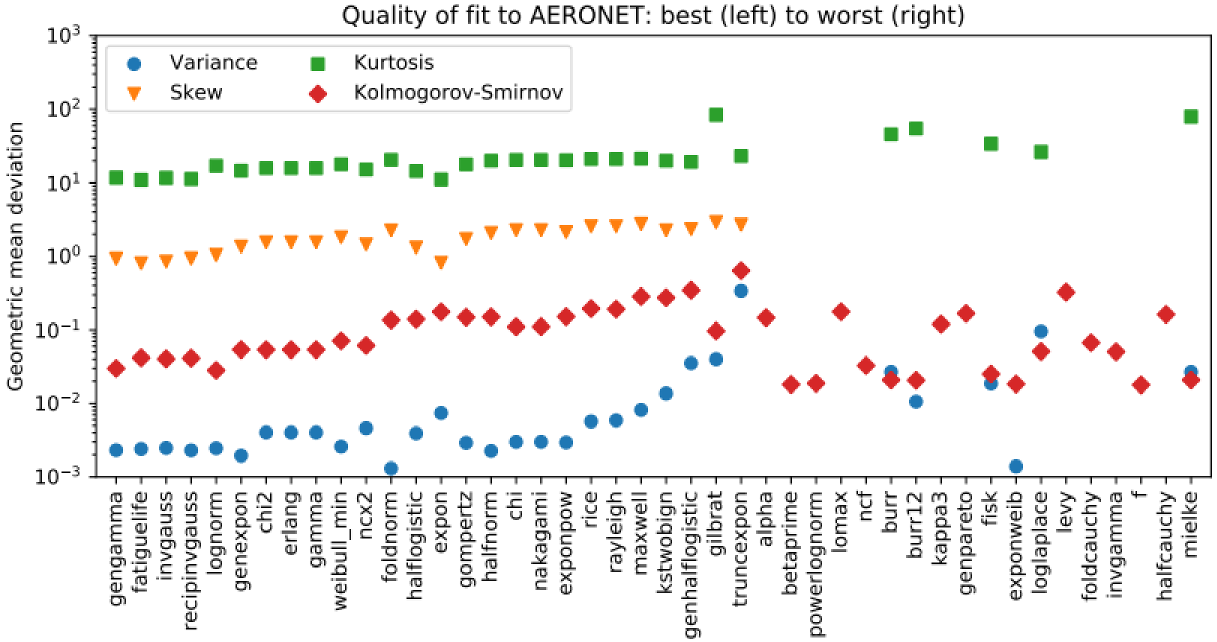
- On aggregate, the generalized gamma distribution was best. Log-normal was second to sixth (depending on parameters).
  - This was surprising.

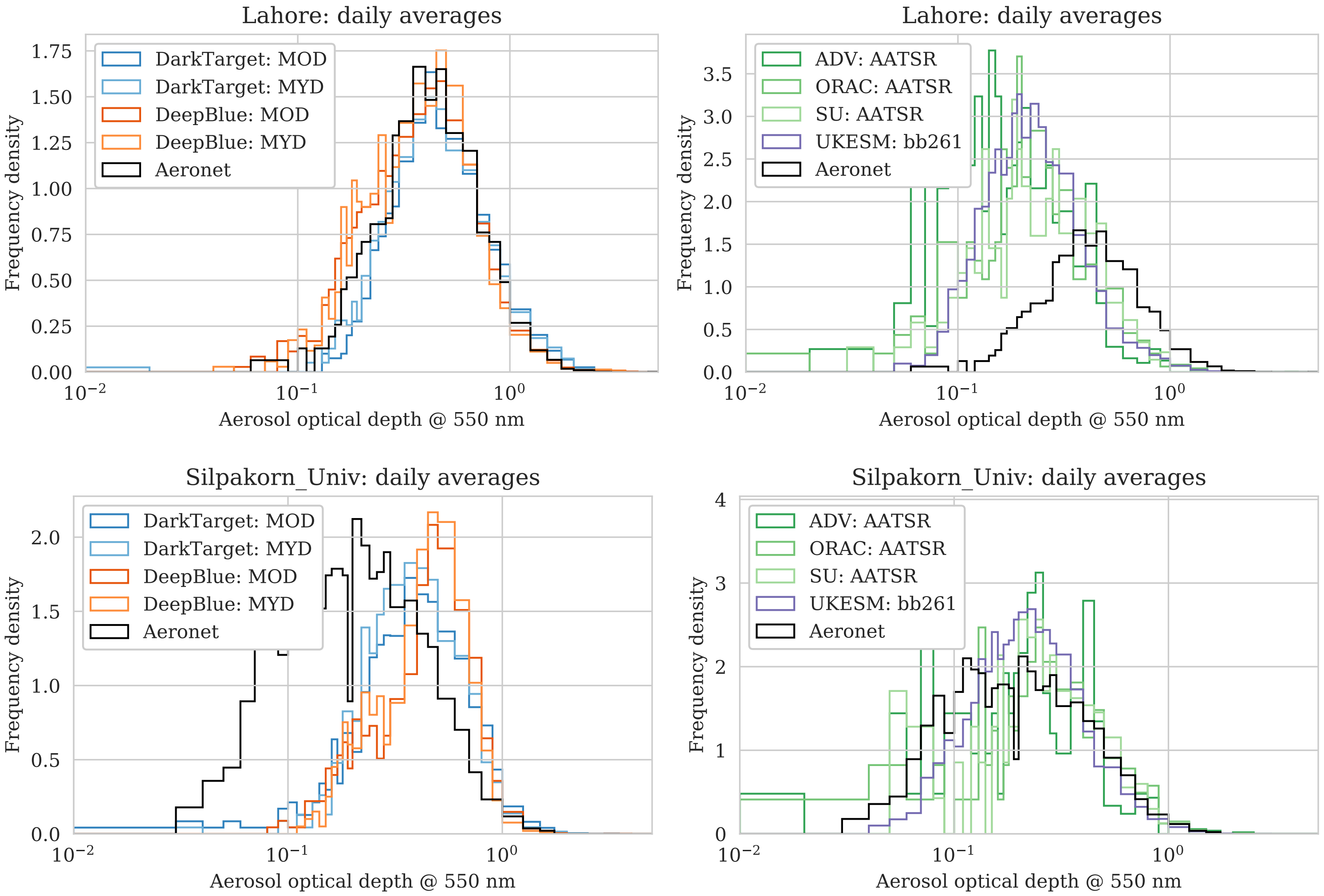






What distribution to fit?

- To understand what was going on, I isolated the AERONET sites where the generalized gamma and the log-normal distributions each did an exceptional job of fitting the data.
  - Shown opposite are the histograms of daily average AOD from AERONET (black), MODIS (left), AATSR, and the UKESM (right).
- The sites that were best described by a log-normal distribution had simple shapes. Those suited to a generalized gamma were more complicated and often bimodal.
  - Hence, the log-normal distribution is suitable, but one often needs more than one mode.



Comparing distributions between datasets

- Having selected a distribution, we can now fit it to our satellite datasets and see how they differ.
  - Up to three modes were attempted, requiring that all are distinct (by the Holzmann test) to accept the fit.
  - The Swansea data looks sparse as at least five bins had to contain observations to attempt a fit; their distributions are *very* narrow.
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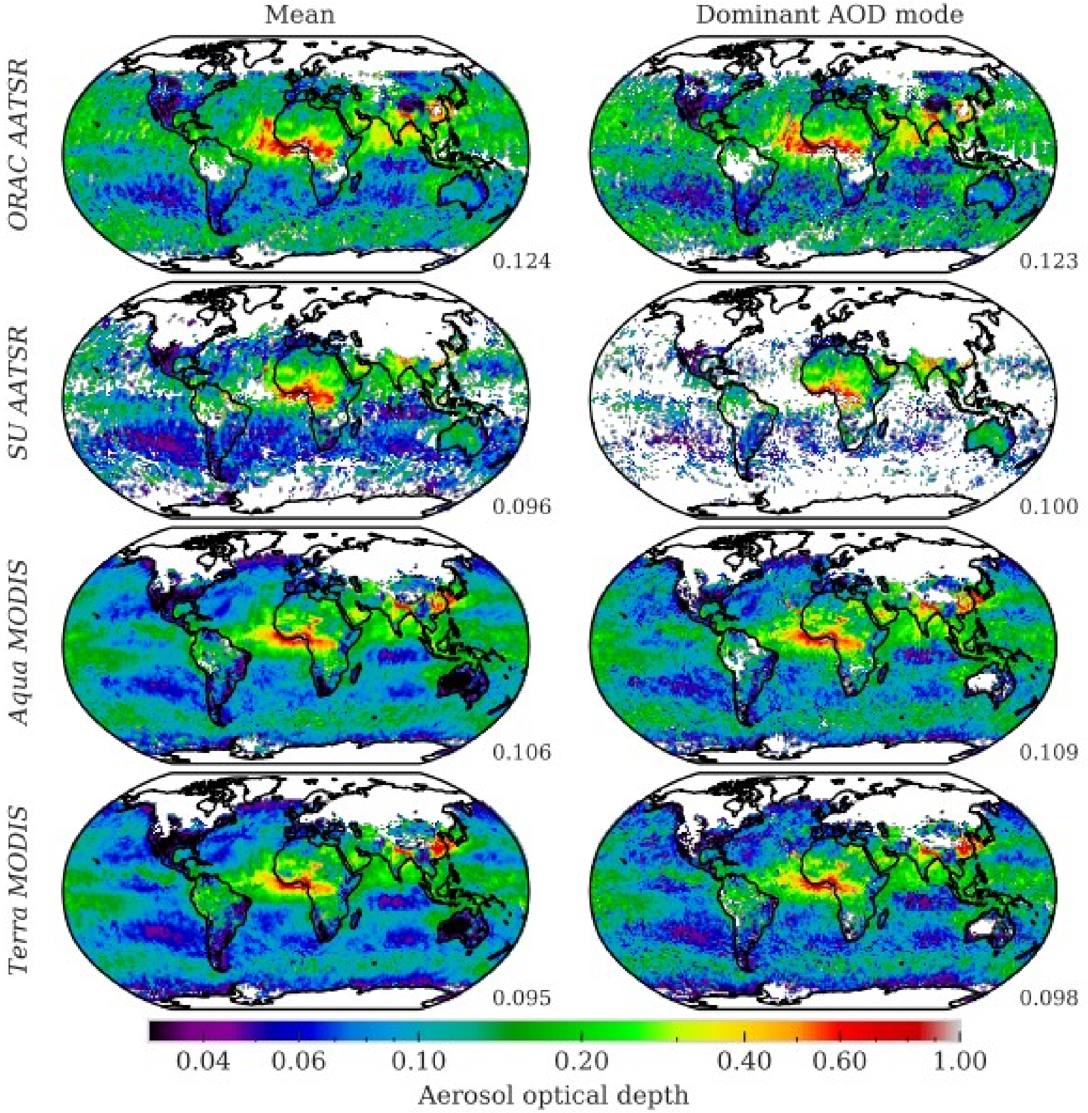
Fig. 3, Povey and Grainger (2019) doi:10.1109/LGRS.2018.2881762



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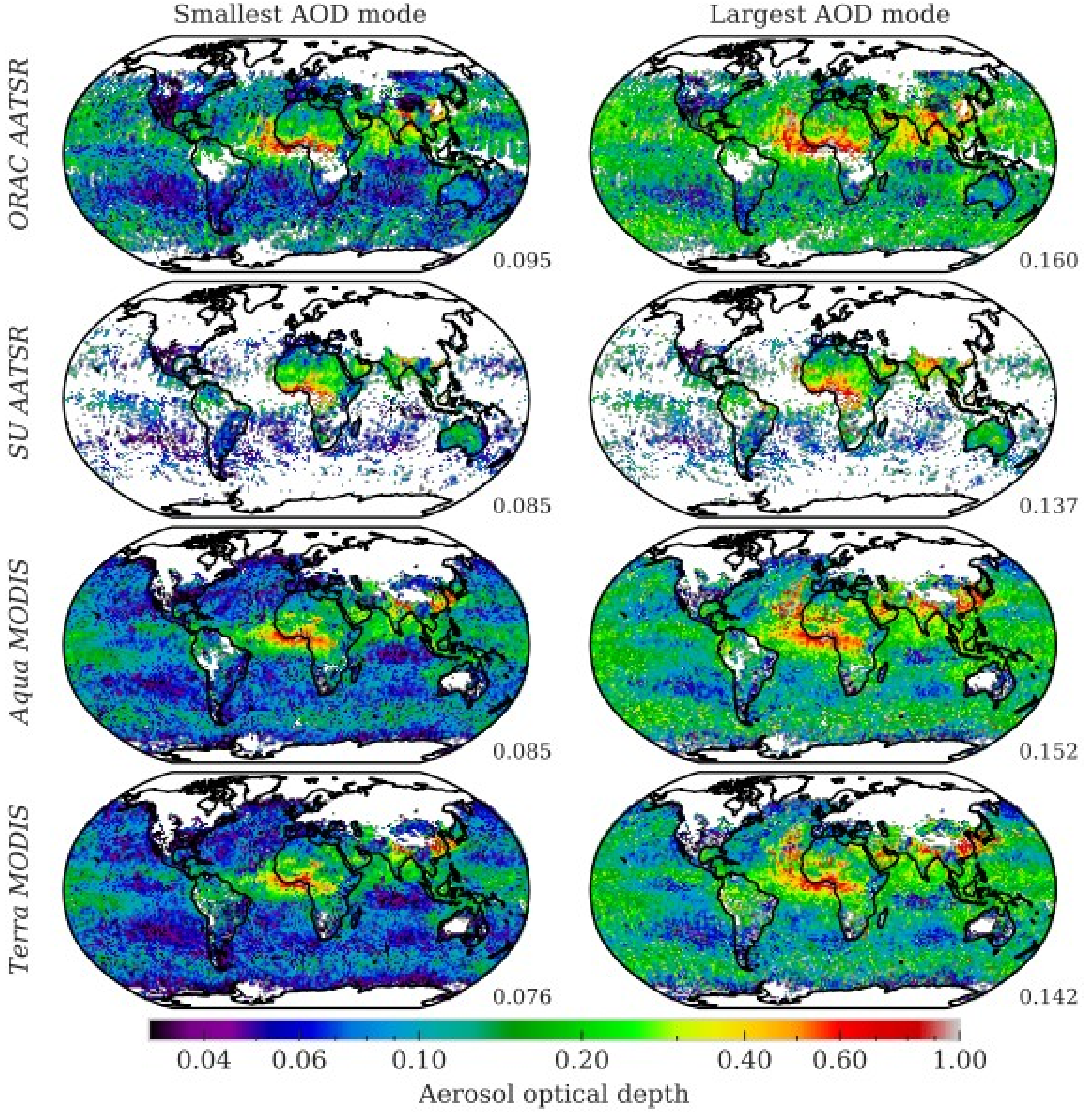
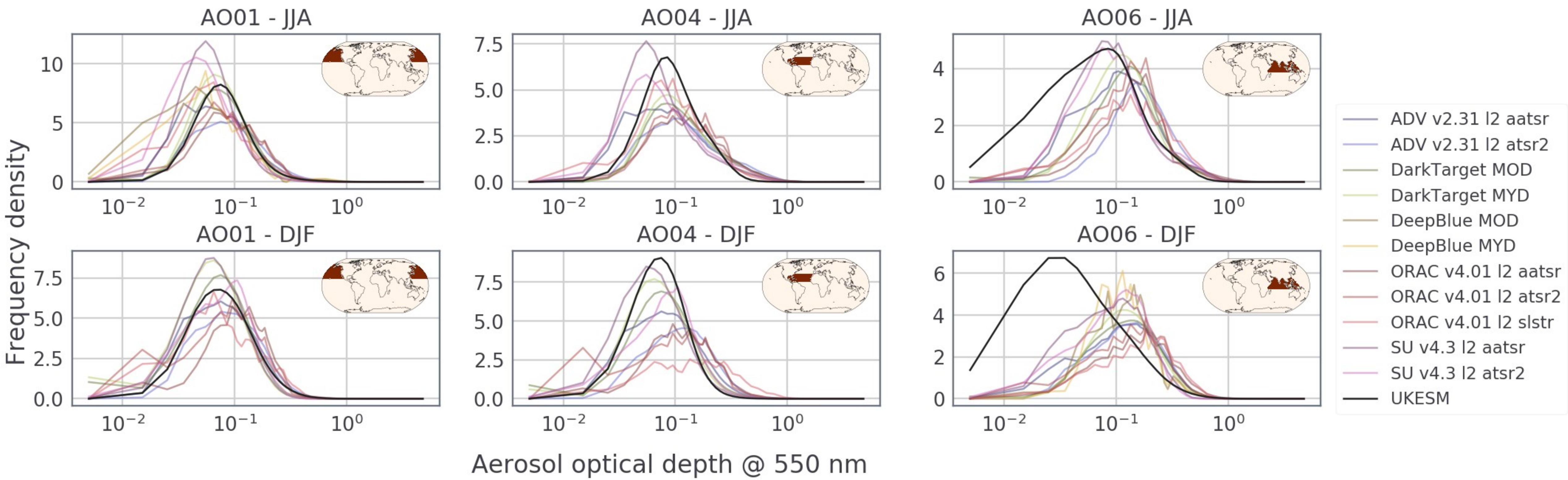
  - The Swansea data looks sparse as at least five bins had to contain observations to attempt a fit; their distributions are *very* narrow.
- The differences in mean value can be explained by sorting the modes fit.
  - For example, ORAC has many more pixels with high AOD. That AOD isn't that much higher, but it is more common (skewing the mean).

Fig. 5, Povey and Grainger (2019) doi:10.1109/LGRS.2018.2881762



Comparison of seasonal, regional distributions



- Distributions of aerosol optical depth over three ocean regions from 11 satellite data sets (combinations of 5 sensors and 5 algorithms in various pale colours) compared to the UKESM high-temporal resolution run (black).
- (Top) Summer; (Bottom) Winter.
- (Left) North Pacific; (Centre) Mid-Atlantic; (Right) North Indian.

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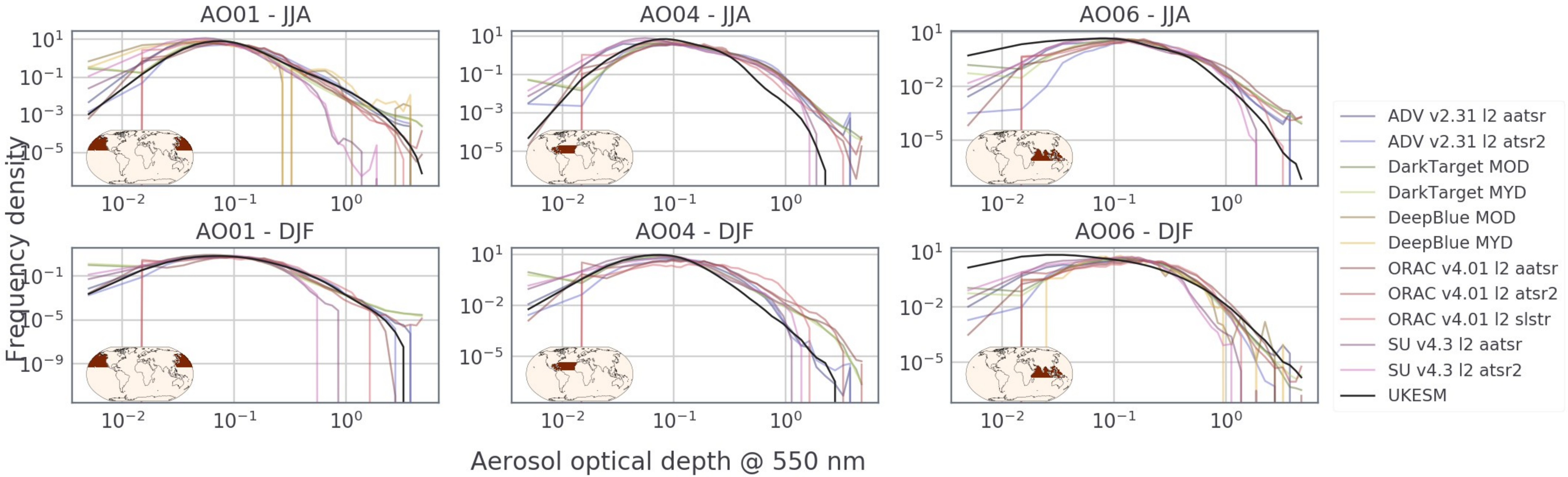

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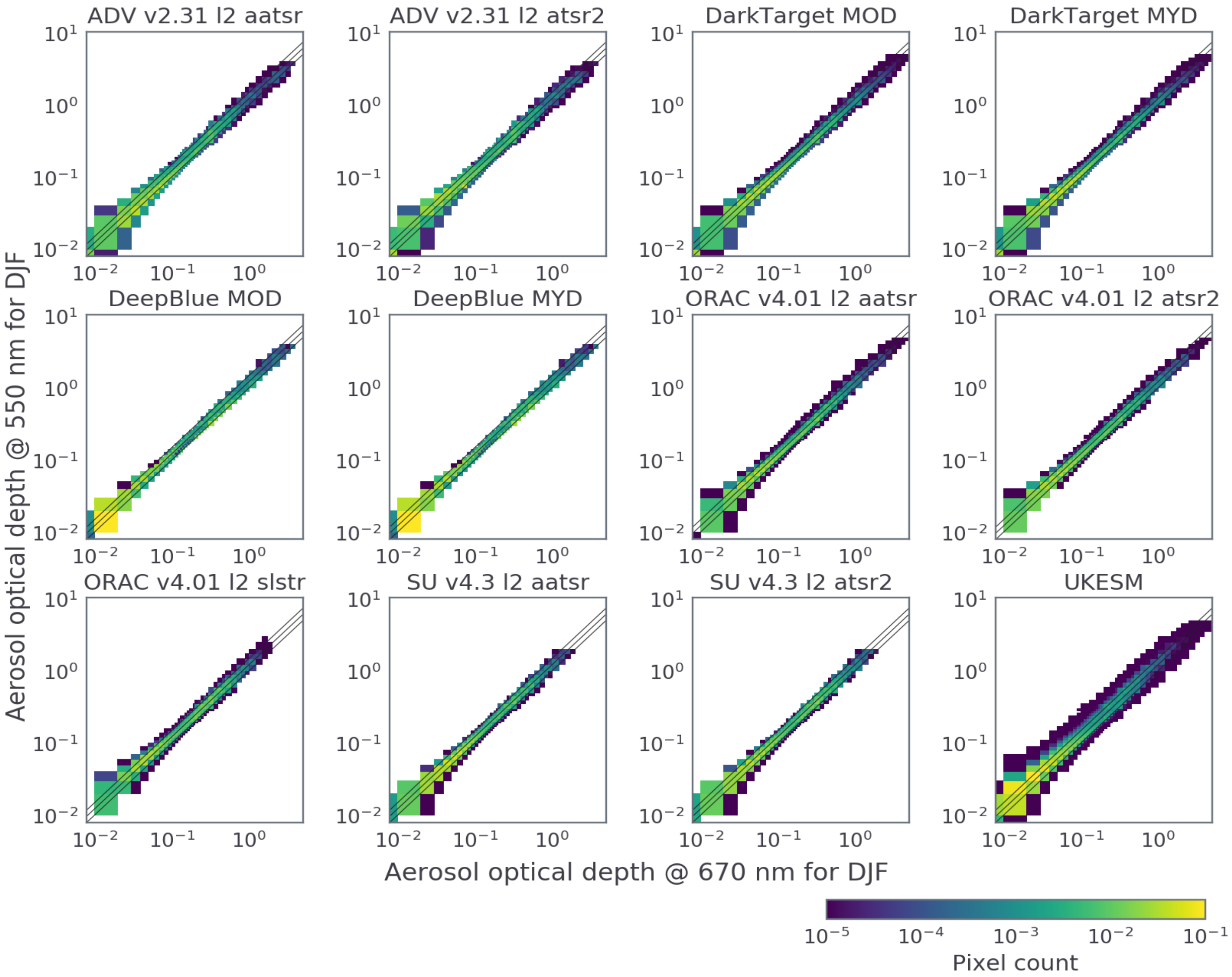
Potential issue with Angstrom exponent

- AOD was tabulated for both 550 and 670 nm. The 2D histograms opposite show their co-variation for each satellite dataset and the UKESM (bottom right).
  - Lines of constant Angstrom exponent are overplotted (0, 1, and 2).
- Though the satellites disagree on the distribution of AOD, they all exhibit a fairly narrow co-variation.
  - Similar results across all seasons and regions.
  - It should be noted that these values generally aren't retrieved independently.
- The UKESM presents a noticeably wider distribution, especially for negative exponents



Summary

- A variety of satellite datasets are available to evaluate the representation of aerosol in models.
  - They often don't agree with each other.
  - Remember that a model grid cell is fundamentally different to a satellite pixel. Subsampling the model to resemble an observation is important when comparing to real data. Read doi:10.5194/acp-17-9761-2017
- AOD is log-normally distributed.
  - However, it's often not *mono-modially* distributed.
  - If you need to represent AOD with a mono-modal distribution, the generalised gamma typically does a better job of representing the moments of the distribution.
- Considering the distribution of AOD, rather than just mean values, can improve the agreement between datasets and can provide a more robust metric with which to evaluate models.
  - I'm working on producing a modeller-friendly ensemble of aerosol Level 3 data.