Quantifying the impact of industrial emissions on clouds

The ORAC Team

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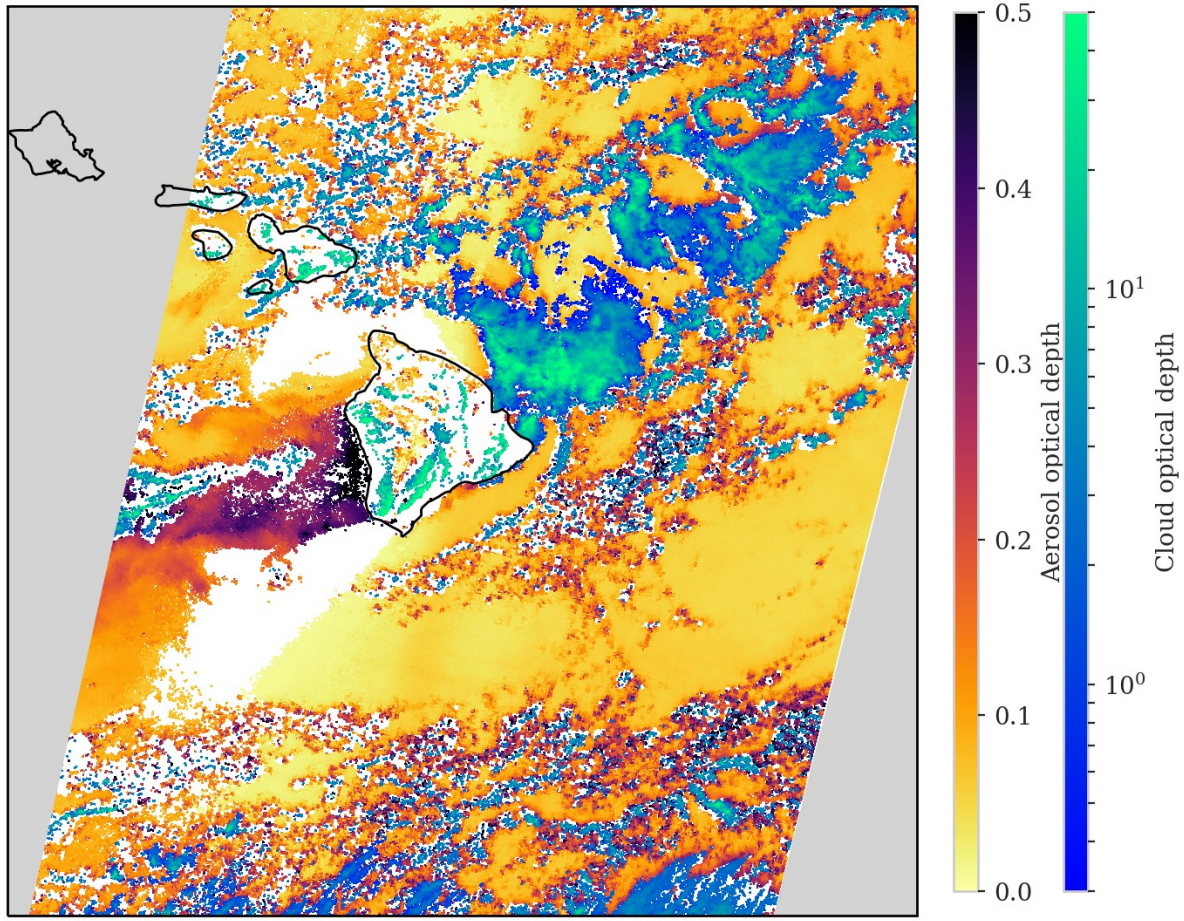
Talk outline

- Introduction to ORAC data
- Demonstration of the method around Mt. Kilauea, Hawaii
- Application to anthropogenic sites



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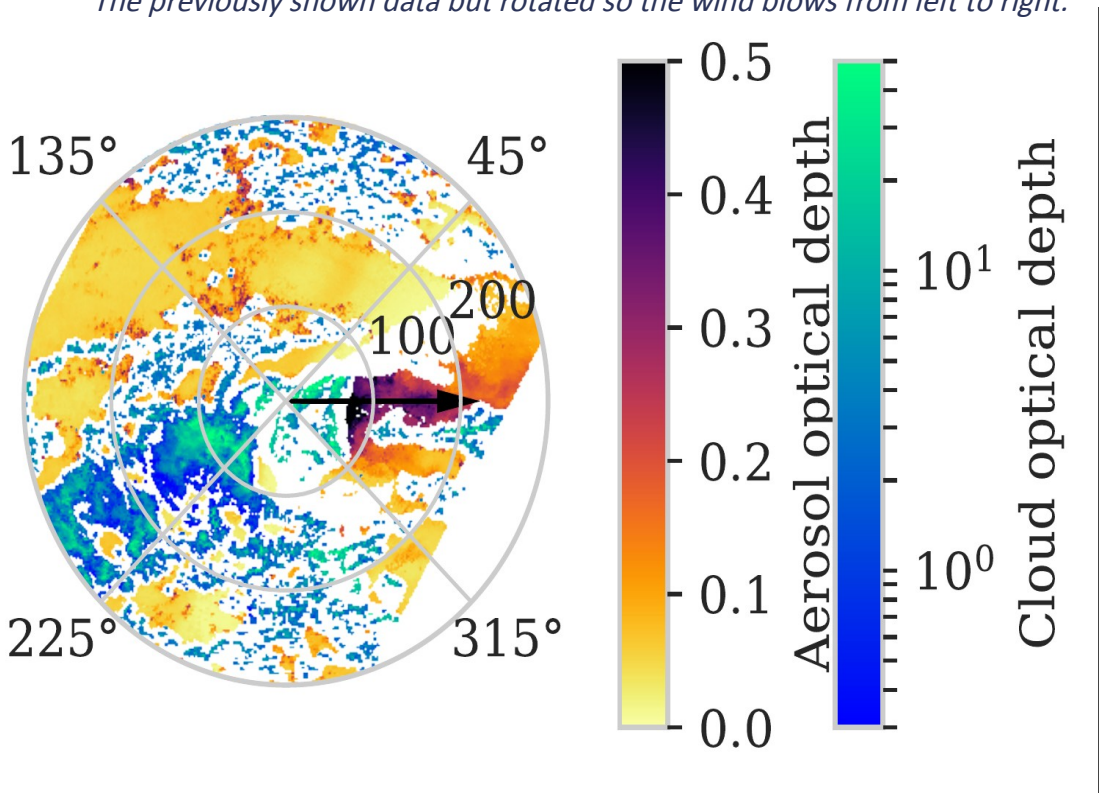
Aerosol and cloud data

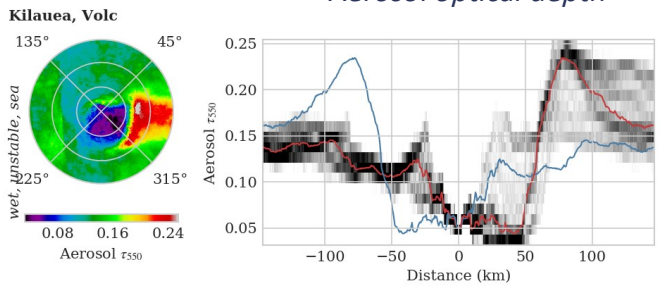
- The Optimal Retrieval of Aerosol and Cloud, ORAC, is a retrieval of aerosol, cloud and surface reflectance from single and multi-view visible and IR satellite imagery.
- This study concentrated on aerosol sources that dominate the local area. Data is aligned with the wind direction.
  - Upwind air should be relatively clean and downwind will be perturbed by emissions.
  - Aerosol data within 10km of a cloud excluded to minimise contamination.
  - Averages all data from the AATSR mission (2002-2012).

The previously shown data but rotated so the wind blows from left to right.

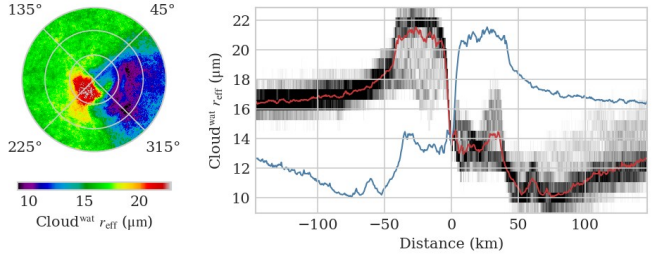


Cloud variations around Mt. Kilauea

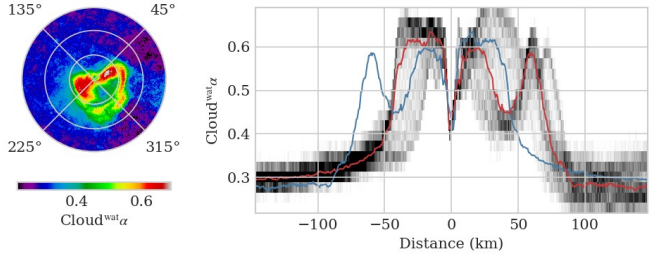
Aerosol optical depth



Cloud effective radius



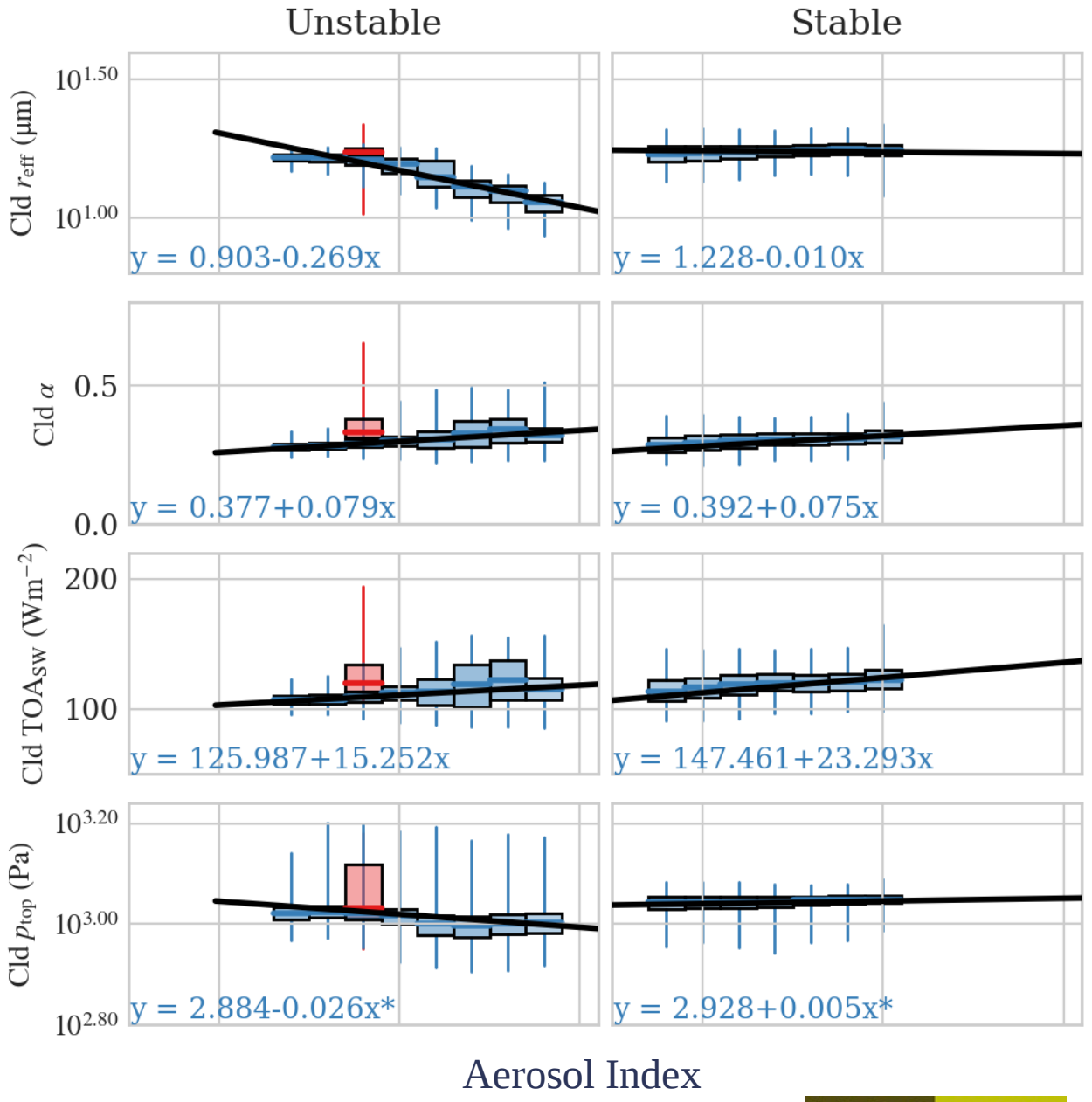
Cloud albedo (at 550 nm)



- Each plot pair summarises a different variable around Kilauea.
  - The rectangual plots show the distribution of each variable as a function of distance from the volcano.
    - Median is in red. The reflection of the median is shown in blue to compare upwind to downwind.
  - The polar plot shows the averaged field, with upwind to the left and downwind to the right.
    - The volcanic aerosol plume is very clear in the AOD map. Cloud effective radius decreases in the same region.
  - Low values in the centre of the plot correspond to lower quality retrievals over land.
  - Cloud albedo is enhanced in the centre of the plume but is generally decreased on the lee of the summit due to a decrease in the atmospheric stability.

Cloud variations around Mt. Kilauea

- To map the variation of cloud with aerosol index rather than distance, treat each point in the previous plot as independent and tabulate them into histograms.
- Separate histograms made for conditions that are:
  - Stable or unstable, where lower tropospheric stability < 17 K.
  - Dry or humidy, where free tropospheric humidity < 40%.
  - Land or sea, with the former in red. (There's not much land at Kilauea.)



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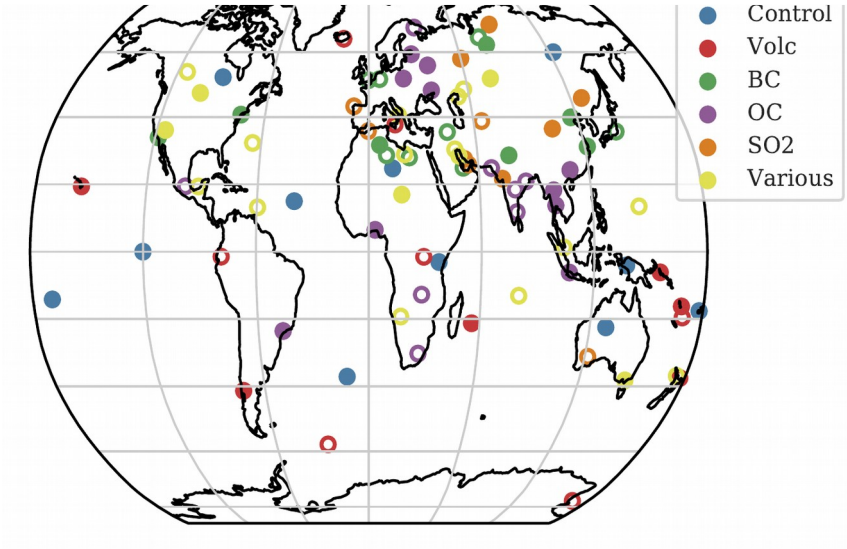
Exploring a range of aerosol sources

- In total, 88 sites were evaluated.
  - Including volcanoes, areas of frequent flaring, populous cities, regions of anomalously high emissions in the CMIP6 database, and some controls (remote or mountanous areas).
- For each site, the average field is tabulated into a histogram of cloud albedo vs. aerosol index.
  - Note: Aerosol effective radius, and consequently Angstrom exponent, are poorly constrained over land so AI is not very reliable there.
  - The following plots only show wet, unstable conditions. Other conditions show lower sensitivities.

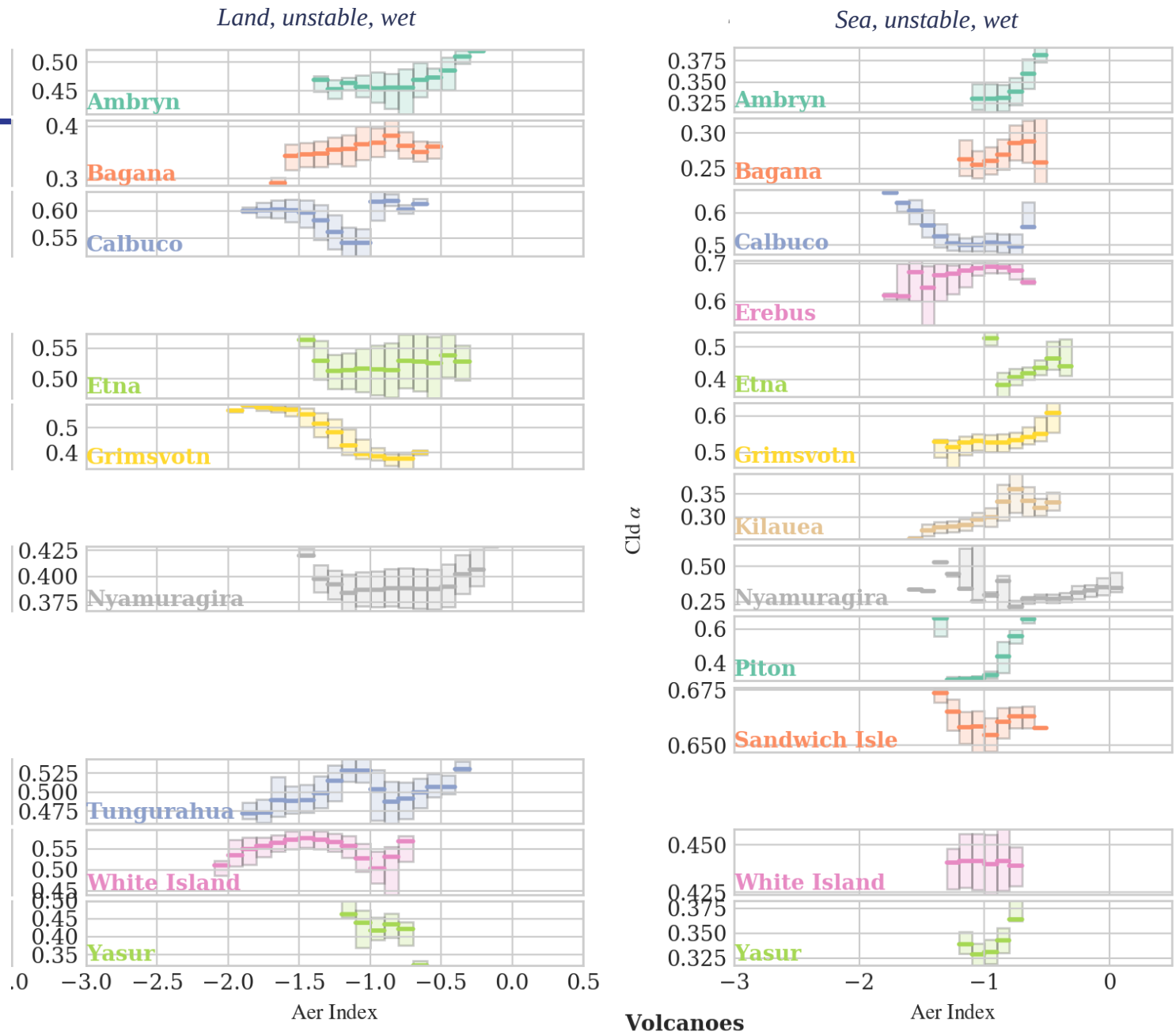
Location of the sites used and the dominant emitted aerosol type.



- As expected, not every site “worked” (the empty circles).
  - Meaning that not every site showed a clear difference in AOD between the upwind and downwind directions.

Variation of cloud albedo with aerosol index

- A number of volcanoes are shown over land (left) and sea (right) with
  - X) Log aerosol index; Y) Cloud albedo
  - Thick line) Median; Box) Quartiles
  - Similar plots are given against AOD, which is more reliable over land.
- For the majority of volcanoes, cloud albedo increases by about 0.1 for a unit change in AI.
  - Locations where albedo decreases appear to have very limited sampling (i.e. wind rarely blows from Calbuco over the sea).
- Over land, there is less consistent behavior, with much smaller gradients.
  - Likely due to lower quality aerosol retrievals over land.



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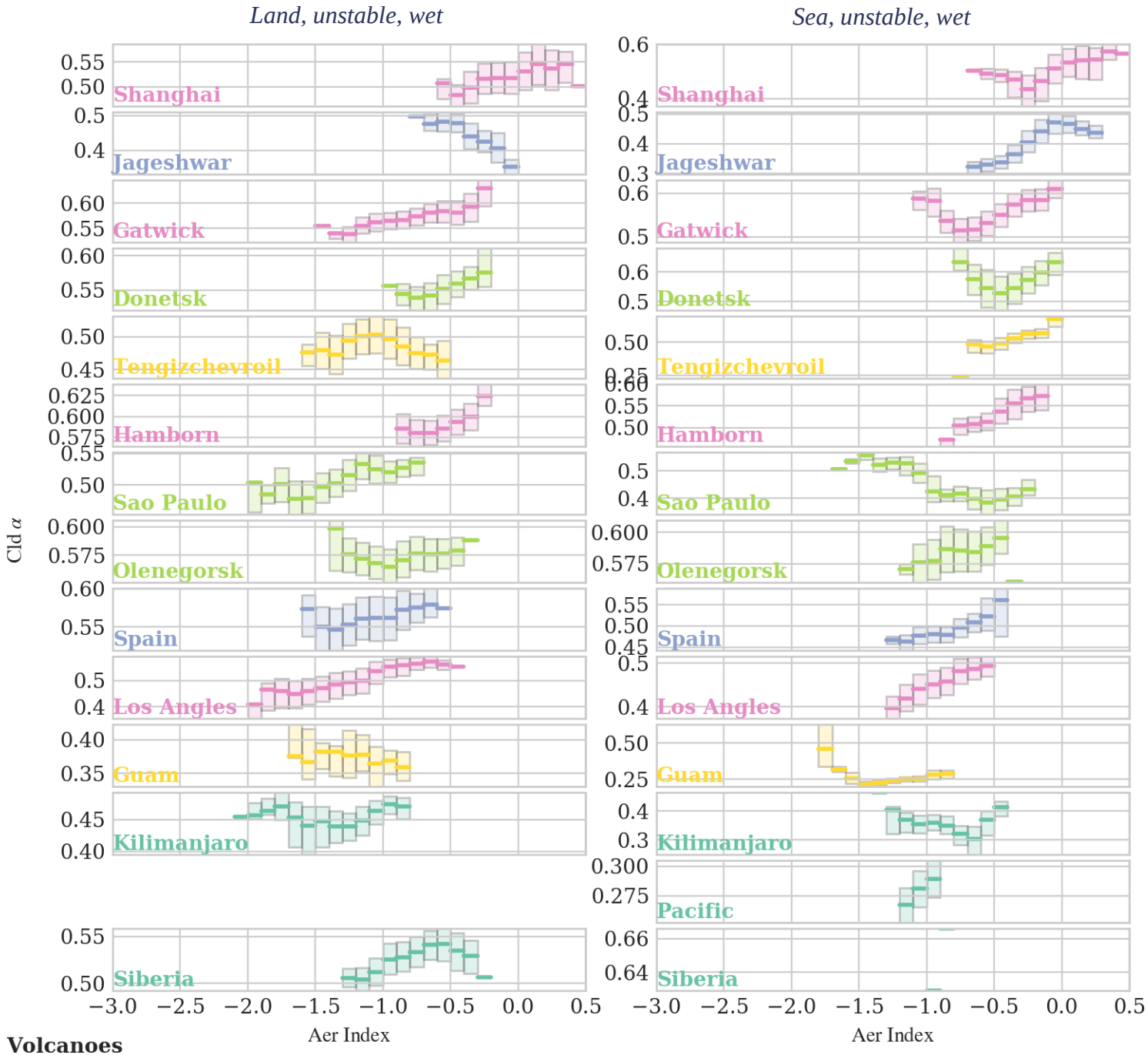
Variation of cloud albedo with aerosol index

- A variety of other sites, including anthropogenic sources, were also evaluated. A selection is shown here.
  - Pink = Black carbon
  - Blue = SO2
  - Green = Organic carbon
  - Yellow = Various
  - Teal = Natural control site
- Absolute values are inconsistent but the slope is generally consistent between land and sea.



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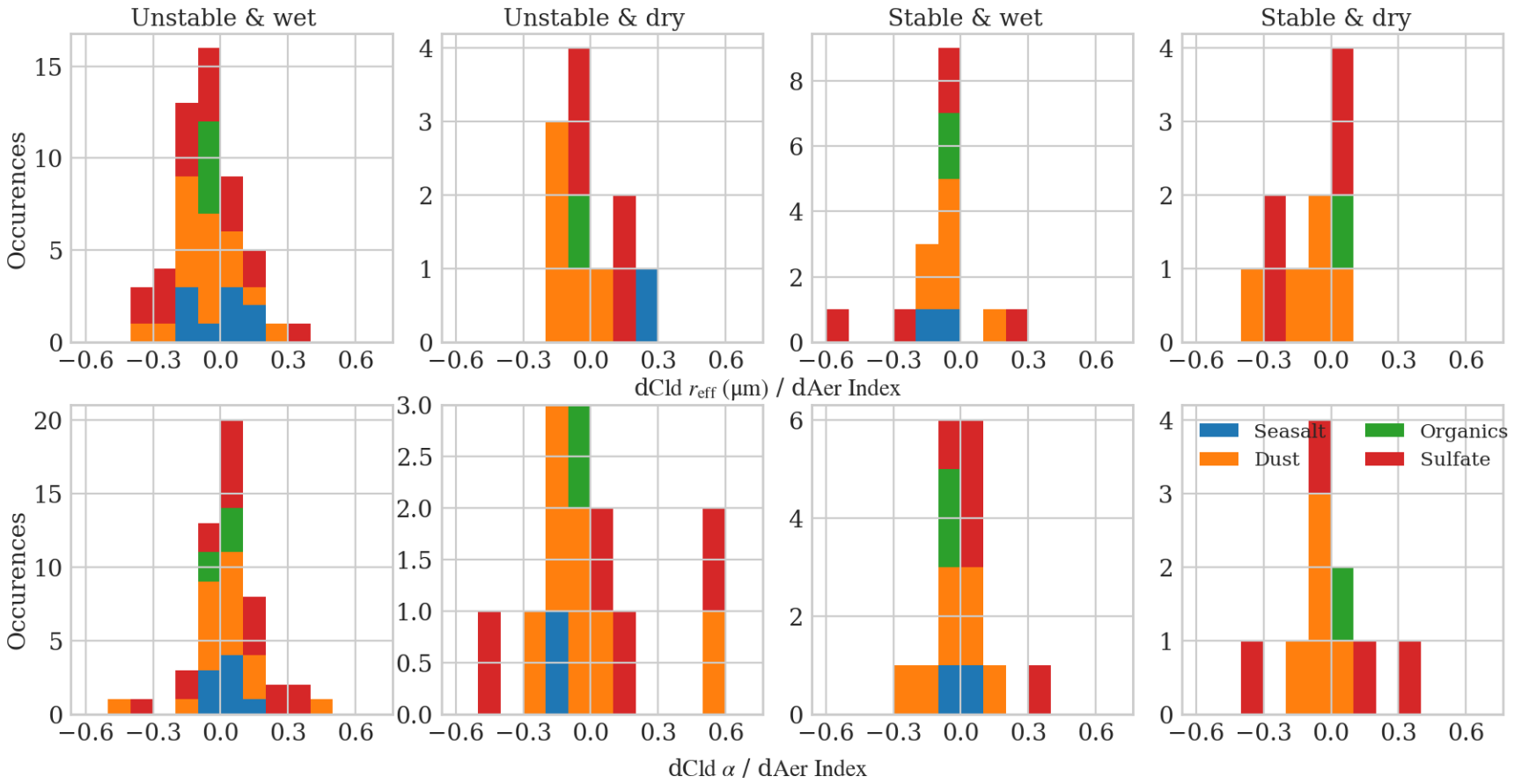
Change in cloud albedo with aerosol index



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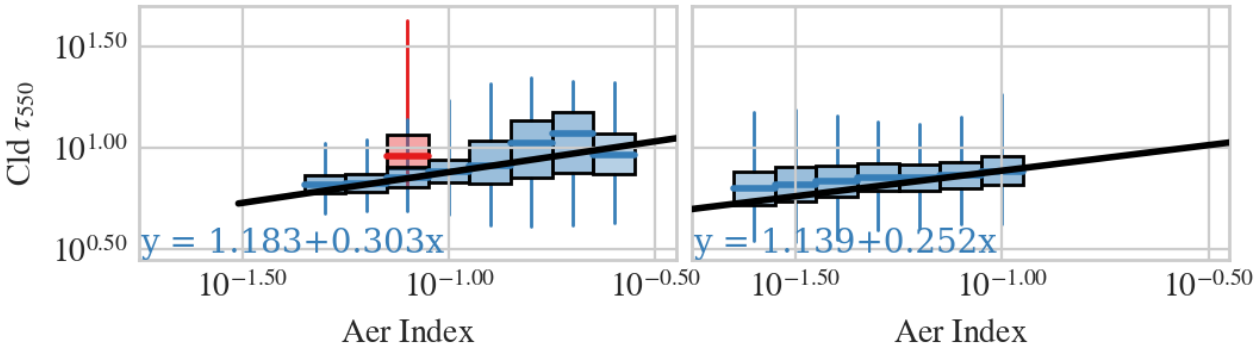
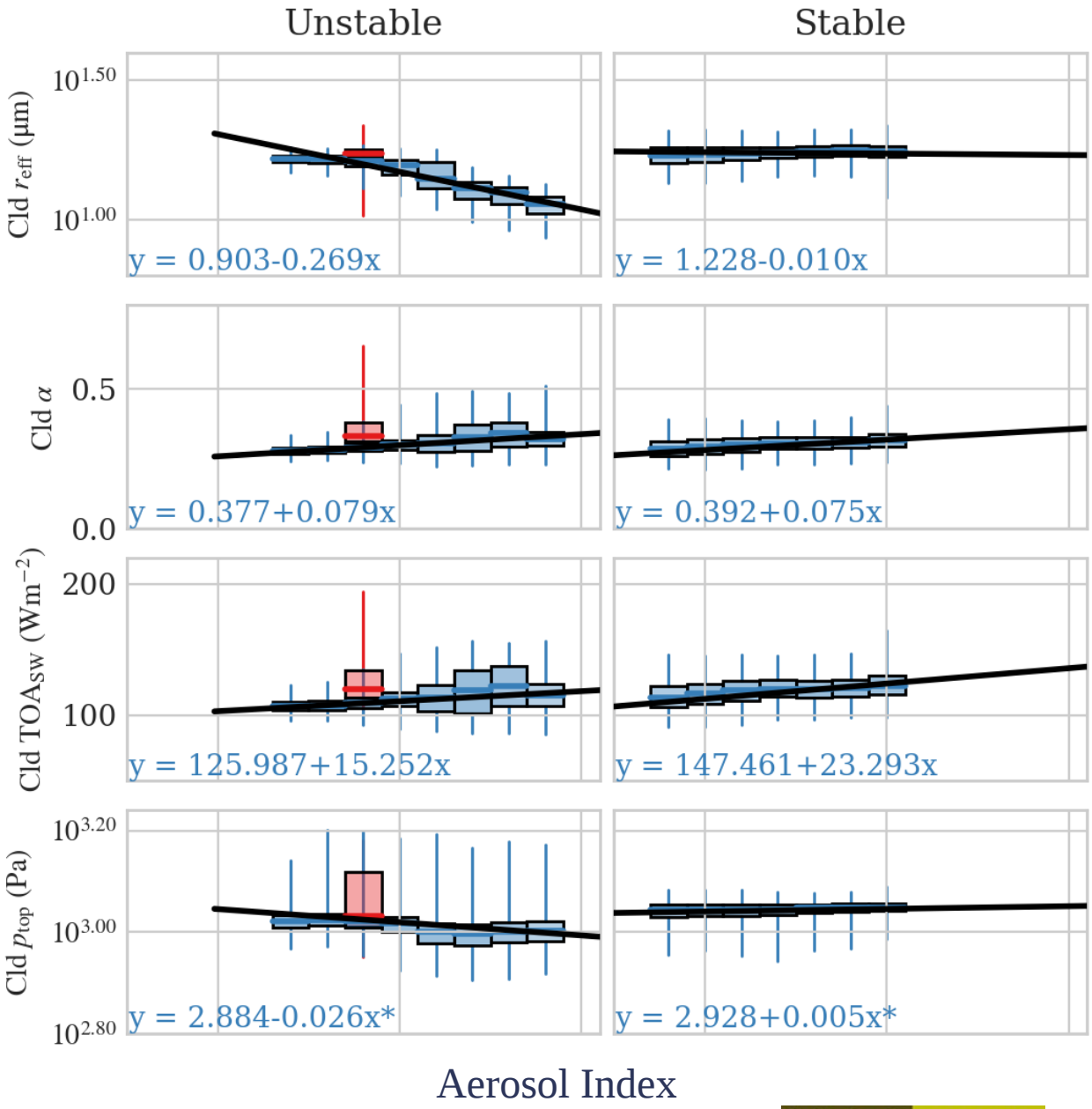
So why isn't this published?

- The variation of cloud optical depth is basically the same between stable/unstable and wet/dry conditions.
  - Implies our classification is insufficient.
  - Appears to be because, in ECMWF, different areas have different mean conditions, such that some areas may never achieve a particular category.





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Conclusions

- Volcanoes and other dominant aerosol sources provide a natural laboratory to study the interactions of cloud and aerosol.
  - This technique isn't expected to work everywhere so an objective means of selecting sites is being explored.
- Mostly, cloud effective radius decreases and cloud albedo increases as aerosol index increases.
  - This is, of course, a function of sampling and environment.
  - We need to work out if there’s a good reason why the functional form is consistent at some sites and not at others.
- The analysis will, eventually, be repeated with more bins for humidity and stability.
  - Various bugs will be addressed and he site selection will be reconsidered, in light of the current results.