Community Comment text from Sayedain and O'Neill in blue.

Author (Ashpole and Wiacek) replies in black.

This paper was, in our opinion, inadequately researched and showed a discouraging level of ill-justified conclusions.

Drs. Sayedain and O'Neill took time to present some detailed comments on our work, which we appreciate. However, our goals, approaches and conclusions were not summarized in their Community Comment and there is evidence that they were not fully understood.

Most notably, the authors demonstrated a lack of awareness of the expected magnitude of Arctic DODs (and Arctic AODs in general) at the regional level coupled with an attendant lack of citations to the existing Arctic DOD literature (there is admittedly not a lot of existing literature but it is easily found*).

While we used the phrase 'persistently high dust loadings' once (L214), it should and will be changed to 'more frequent signatures of extreme dust loadings' because we do not claim anywhere in our paper that Arctic Dust Optical Depths (DOD's) are **on average** > 0.5. This is only our threshold for an **extreme event** in the analysis, as supported by well known *in situ* measurements of DOD exceeding such values on occasion, including in Sayedain and O'Neill's own work, which we are familiar with (more on this below).

The Frequency of Occurrence (**FoO**) values shown in Figs. 1-3 are very low in absolute terms (<100 events over 20 years) but indeed higher in relative terms (between 0 % and 50 % of observations over 20 years, depending on location). However, we also show the total number of observations as quite low, and the seasonal dependence such that the vast majority of our extreme event data comes from satellite observations made in JJA (least snow and ice in satellite retrievals, peak time of Arctic dust mobilization).

Despite higher-than-expected fractions of extreme events in some Arctic places, our main result is not a map of average or extreme DOD values but rather a map of the **frequency of occurrence** of such **extreme** events. The logic as to why this would be useful in dust emission modeling work is based on "where there's smoke, there's fire", except repeated for dust: "where there are recurring extreme dust events over 20 years, there is potentially an active dust source there".

Our interest in **active dust source areas** is also the reason why we produced a high-resolution (0.1°) MODIS DOD product, and why we are concerned with analyses over land (the source of dust emissions). Lastly, our approach is not new – we apply previously published work on locating dust **sources** in this way in warm deserts to the Canadian Arctic Archipelago (**CAA**).

It is also surprising that their analysis is predominantly top-down with virtually no investigations at the event level.

This is an interesting point – individual studies can proceed by either approach, but eventually both approaches must meet and compare notes. We chose a top-down analysis in our study to explore potential dust **source areas** in a large geographic region (CCA) through a 20-year analysis of infrequent extreme events. We view it as entirely complementary to the 'event-level' approach of Sayedain and O'Neill, and others who have done related work in their group. Instead of carrying out event-level analyses that attempt to, e.g., validate satellite data or improve retrieval algorithms, we start from a place of accepting the big picture of what the satellite data are showing us, while understanding that there may be biases and limitations in such data. Our top-down approach yielded a map of likely dust emission hotspots (not average AOD or DOD, as the Comment claims) that agrees well in general with **bottom-up** estimates of dust 'Source Intensity' (SI) maps (as we show in Fig. 6). This comparison is the main 'validation' of our result.

Rather than studying 'events' to validate the MODIS DOD product (not our goal), we identified two 'new' dust source areas (unpublished in the literature, to our knowledge, and not found in the bottom-up SI map of Fig. 6) and we examined if they are consistent with being dust sources. Indeed, they have correct surface features for dust emission (see visible imagery we presented in Figures A1 and A2) with high average wind speeds for horizontal dust flux mobilization. We also discussed these areas with field Geologists who have visited the Québec/Labrador site during field studies and who confirm dust sources in this region. Nevertheless, we cautiously recommended in our work that additional observational studies are needed (including at the 'event-level', which is exceedingly difficult to do in remote areas, as is well known).

Finally we would underscore the fact that the authors did not use the DT MODIS option of AODs associated with dark pixels over water : this product is on much firmer ground than the DB AOD product and the DT product over land (much less dependent on the surface reflectance).

Again, we are looking for dust **sources**, which are on **land** and not over the ocean. It would be inappropriate for us to use Dark Target (DT) MODIS data, which is not optimized to perform well over brighter land surfaces. We are also not expecting or tracking dust plumes far from their source regions, including over dark water surfaces, as we are fully aware that there are no Arctic-equivalents of Saharan dust plumes – only that, very occasionally, near sources, DOD can reach levels comparable to some Saharan plume levels.

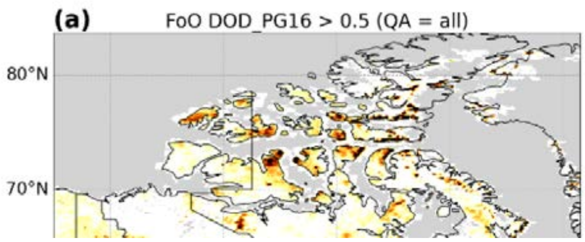
We agree that where in Section 3.6 of our paper we compare MODIS AOD to AEROET AOD in geographic boxes that include both land and ocean, neither dataset (DB nor DT) is ideal.

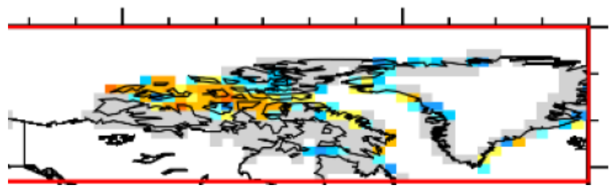
* including the recent publication by O'Neill et al., "Remote sensing setectability of airborne Arctic dust", (2025). That the authors apparently decided not to rebut its strikingly opposing message of very low Arctic DODs compared with their very high DOD results indicates a lack of due diligence on their part. Note also the Kawai et al. DOD simulations (that are cited in O'Neill et al): those simulations yielded CM AOD results which were even smaller than the CM AOD climatologies cited in the latter paper (DODs being, in general <~ CM AODs).

We are aware of O'Neill et al. (2025) and we read its Discussion paper in detail before our submission to ACP. We did not cite the work because it focuses on problems with using the Brightness Temperature Differences (BTD) at 11 and 12 μm to detect Arctic dust, which is quite different from the MODID DOD dataset. Furthermore, that paper largely focuses on detecting average values of coarse mode dust, while we concern ourselves with extreme values, and the study states that it is "difficult if not impossible to detect using passive satellite-based techniques at any wavelength", which we do not disagree with. However, we also knew that one of the concluding statements of this study is: *"While it is difficult to account for all examples of strongly negative $BTD_{11\text{-}12}$, it is very unlikely that airborne dust plays a major RS role in any case* ***other than***

***plumes of strong DOD (> ~ 0.5)**.”* Our work is precisely a tally of such extreme dust events in one satellite dataset. We are happy to cite O’Neill et al. (2025) as it supports the validity of our search for occasional extreme events in RS data.

As to the simulations of Kawai et al., who include Arctic dust emission in their model, again, our FoO maps for extreme events are not comparable to any climatology of average CM AOD or CM DOD (neither based on models nor based on measurements). However, it is nice to see in the Supplementary Materials of Kawai et al. that our FoO maps (left below) match the spatial patterns in their simulated annual mean dust emission fluxes (right below, red is logarithmically more emission than blue).





We have inserted comments throughout this pdf to explain our point of view and are open to exchanges with the authors if they wish clarification on any of those comments. Our major high-level comments are the comment on lines 76 and 214 and the comment associated with the sentence that starts on line 295.

We are of course open to collaborative and collegial exchanges and modifications that will frame our results in the most objective light, while recognizing that our goals were not satellite dataset validation nor event-level studies of individual optically thick dust plumes far from their sources. We will directly address the main points made on lines 76, 214 and 295, and a few other points, leaving the specifics of all modifications for later in the peer-review process.

[end of high-level comments]

LINE 76 (MODIS DB vs DT): Given that there are significant areas of open water in the late-spring to early-fall in the CAA and that open water dark target (DT) AODs are clearly a more universally accepted product than deep blue (DB) AODs, why was the analysis limited to dust events over land?!

The analysis was limited to dust events over land because dust sources exist on land and that is the focus of our study. Given the low dust emissions in the Arctic, it only makes sense to look for thick plumes (AOD > 0.5) right over land sources, as per the available *in situ* observations of such events. Plumes transported farther from sources will be diluted and also de-coupled from their source areas.

(b.t.w: the quality flag (QA) of the pixels used for DOD pixels should have been stated).

The effect of the quality flag is shown in Fig. 2 and discussed in detail below that (on pg. 10).

We have tested the Level 2 (L2) DB algorithm in the Arctic and have found examples of significant positive biases of the latter over the former at the boundaries between the two products.

Good to know. Curious if this was in individual L2 granules or an L3 product. Either way, our FoO maps primarily show potential dust source regions away from coasts.

Conversely, we have also found examples of obvious dust events over land that the DB algorithm did not catch* (while the MAIAC algorithm at least produced AOD estimates over land). We have also seen that the DB AOD product can be very sporadic (low sampling numbers) relative to the DT algorithm. See, for e.g. the Aug. 18, 2011 event (URL below **) and scroll through, day by day, the whole summer of 2011 while turning the DT and DB AOD algorithms on and off.

This is in agreement with our low numbers of MODIS DOD (DB) observations over 20 years (Fig. 1, bottom row) and shows that our work on sources (over land) could perhaps be improved in a future study using the MAIAC product.

We also noted examples of suspicious similarities between dark reflectance patches and both high DT and DB AODs (to the point where the suspicious DT and DB AODs would "hover" over the same place from day to day [see ** below, for e.g.] while DK AODs over water would evolve in a fashion that was coherent with the natural appearance of plumes in the RGB images).

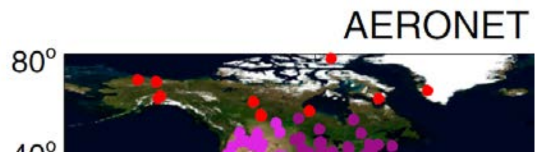
That is interesting. Perhaps local dust (of a coarser size) is indeed 'hovering' over the source area by actually being repeatedly injected into the atmosphere near the time of the satellite overpass and then settling out at night, while the transported dust fraction (of a finer size) is more mobile.

Finally, the authors should have been aware of Sayer et al.'s (2019) paper on the validation of the DB AOD algorithm: a paper which included OPAL and PEARL in the set of DB AOD validation sites (those site statistics were part of their "BOR" category) over a nominal validation period of 2000 to 2017. The marginal correlation coefficients (<= 0.42 for Terra and <= 0.56 for Aqua) and the small number of validation points (we can provide those statistics upon request or the authors can contact Sayer directly) are not the type of scattergram results that one would employ to claim satellite-derived DOD statistics that are decidedly outside the norm.

Sayer et al.. Validation, stability, and consistency of MODIS Collection 6.1 and VIIRS Version 1 ....

Thank you for this newer reference on the DB product from MODIS and VIIRS. We find that it reports the correlation coefficients between AERONET and MODIS Terra and Aqua in the BOR region as 0.75 and 0.76, respectively (Table 1), with respective numbers of coincident validation data points as 10,225 and 9,158. We see that the BOR region is **1)** very sparsely validated by AERONET (Fig. 2, red points, figure snippet reproduced below, with just one point in the Canadian Arctic), which is not news to anyone, **2)** that the fraction of days with L3 coverage is low (< 0.25) in the Canadian Arctic (Fig. 15), also not news, and **3)** that inter-sensor correlation is high for AOD (Fig. 16) but mixed for AE (Fig. 17), with AE correlation 'ok' between Aqua and Terra, but poor between either of these and VIIRS (we come back to this last point below).

Irrespective of the above, which does not send a strong signal not to use MODIS DB data in the Canadian Arctic Archipelago, we make no claims about 'satellite-derived DOD statistics' – only their frequency of occurrence as a spatial map, based on 20 years of 'hits' of extreme values.



To summarize all these critical DB AOD / DOD comments, the authors were, given the significant physical / optical complexities of the Arctic environment, found wanting in not performing a much more detailed analysis of the DB AOD product that was the basis of their dust analysis (and they notably did not report any event-based DOD analysis: the very large-DOD statistics that they reported should have motivated them to at least find a few concrete examples of such strong regional DOD values)

We already addressed the essence of this comment in our responses above.

*see, for e.g.: Link

** this was one of our events of interest Link

LINE 214: It is a significant oversight that the authors do not cite Sayedain et al., (2023) in addition to the Huck et al. paper. Sayedain et al. provided in-situ lidar as well as AERONET-derived estimates of coarse mode (CM) AODs and OPS (Optical Particle Sizer) measurements of CM particle-volume concentration near the source of strong sub-Arctic dust plumes (the Kluane Lake, Yukon site of Huck et al). They developed a means of classifying dust plumes using correlations between the lidar CM AODs and the CM OPS concentrations and the attendant correlation between the lidar CM AODs and AERONET CM AODs to respectively (i) define the presence of a dust plume on any given day and (ii) to define whether that dust plume could be remotely sensed (their class "D_{RS}"). Referring to their Figure 2 ensemble of (red-coloured) class "D_{RS}" points one can show that ~ 11% of those DODs were > 0.5." (the relatively broad (averaging) footprint of MODIS will have its own influence on the reduction of DODs within a near-source plume). These near-source DODs will systematically decrease (along with the % > 0.5) as the dust plumes are dispersed downwind. In a nutshell: 'persistently high dust loading' is largely limited to the close vicinity of the drainage basins whose wind-erosion dynamics incite the plumes.

Sayedain, S. A., O'Neill, N. T., King, J., Hayes, P. L., Bellamy, D., Washington, R., Engelstaedter, S., Vicente-Luis, A., Bachelder, J., & Bernhard, M. (2023). Detection and analysis of Lhù'ààn Man' (Kluane Lake) dust plumes using passive and active ground-based remote sensing supported by physical surface measurements. Atmospheric Measurement Techniques, 16(17), 4115–4135. https://doi.org/10.5194/amt-16-4115-2023.

As we mentioned in the second paragraph of this reply, the phrase 'persistently high dust loading' snuck into this manuscript and needs to change to 'more frequent signatures of extreme dust loadings' because we do not make any claims of average dust loadings, only their frequencies. Drs. Sayedain and O'Neill comment that our Fig. 7 represents AOD values for the Arctic and point out the 'astonishing' occurrence of AOD ~2. Indeed, that would be quite astonishing, but fortunately Fig. 7 shows the **spatial average** (in a very large geographic region) of the **frequency of occurrence** of **extreme** values of AOD (i.e., AOD > 0.5), not the spatial average of AOD itself. (The figure also shows DOD values in the same sense.) We will re-label the y-axes of this figure for improved clarity, although it is discussed in the text.

We are aware of the work of Sayedain et al. (2023) but chose not to cite it because it does not change our goals, methods or conclusions and we had already cited Huck et al. (2003), who show extreme dust events near the same dust source in the Yukon Territory. We will nevertheless cite it because, as the authors note, there are so few field measurements of dust and their study also documents extreme dust events using both *in situ* and ground-based remote sensing measurements (extreme to the point that they cause false positive cloud events in AERONET algorithms).

As Sayedain and O'Neill point out in their comment above, they estimate 11% of plumes that can be remotely sensed had DOD > 0.5, which further supports our attempts to identify the spatial mapping of the frequency of such events in MODIS DOD data (at high spatial resolution) to identify dust source regions. Our relative frequencies of such extreme events are 0-50%, depending on location in a large and unmonitored (from the ground) geographic region, which is not grossly different from their finding of 11% at one spatial location downstream of a dust source.

Their study is primarily concerned with the classification of dust events as those that can be detected remotely (with active and passive ground-based remote sensing data) and those that cannot; they also postulate the presence of dust particles of radius 11-12 μm based on their data, and they explore the detectability (by remote sensing) of fine mode dust particles that would better indicate long-range dust transport in the Arctic. It is interesting to consider how such extremely large particles (reasonable right at a dust source) that occupy a near-surface layer of 1-2 km thickness (their Fig. 3) would show up in passive MODIS measurements (based on surface-reflected solar radiation) as compared to passive AERONET measurements (no surface reflection).

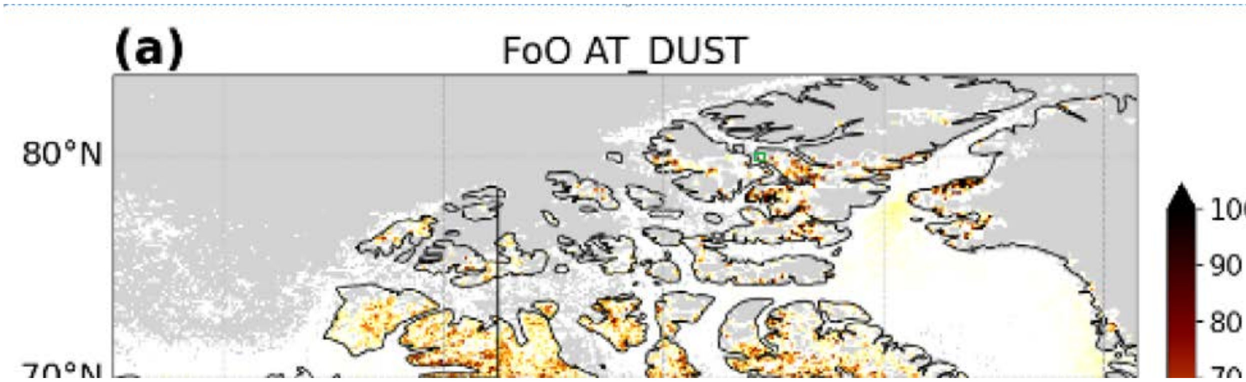
LINE 295 VIIRS: Dust "accounting for 80% of all aerosol type retrievals in some hotspots" over a 3-year period (and notably over substantial regions according to Fig. 4a) is simply unrealistic. Fine mode Arctic haze and fine mode smoke AODs will, in general, dominate DODs that are not measured very near to strong local dust sources.

In light of the poor correlations between VIIRS and MODIS Terra or Aqua reported by Sayer et al., 2019, we will re-check our results based on VIIRS products of Aerosol Type == 'Dust'. Regarding (*) below, AOD > 0.3 is not 'our' threshold, but rather this is the VIIRS threshold for producing an Aerosol Type == 'Dust' product, which we used in our analysis.

W.r.t. to our own DOD experience at KLRS (see the comment above in line 214 concerning the <~ 11% FoO at the near-source site of KLRS). We also have significant experience at Eureka and other sites in or near the Canadian Arctic Archipelago where (publication being prepared) the near source DODs are generally <~ KLRS DODs).

The VIIRS analysis of the authors shows FoO values ranging from ~ 10 to 50 over 3 years (2020-2022) in the Eureka region (their Figure 4a). An investigation of all AERONET L1.5 (cloud-screened) data at the OPAL AERONET (Eureka) site from 2020 to 2022 resulted in a grand total of 7 CM (coarse mode) L1.5 AODs >0.3*. The authors should have carried out this type of concrete detailed validation**. In general they failed to produce satellite-based DOD validation at any kind of event level.

Regarding (**), the documented presence of 7 CM events at Eureka (on the same day) is on the same order of magnitude as the lower bound of ~10-50 events in various nearby places in our Figure 4a (over the same time periods), which we reproduce below, with a tiny **green square** at the location of Eureka (80 N, for those not familiar with its location who may have a hard time spotting the green square). Also, as we illustrate with our Fig. 10 for **Resolute Bay** (with much more data available for comparison to MODIS than at Eureka, which we show in Fig. 8), the location of a point station even in close proximity to a dust source may not guarantee detection of dust at that station, unless the station is positioned precisely downwind of the dust source. **Given that Eureka is one of the only observing stations in the Canadian Arctic Archipelago and that retrieval numbers dwindle so high north, one can hardly speak of any meaningful satellite-based DOD validation in this region –** not that this was our goal in section 3.2, called 'Inferences about dust over Canada from VIIRS'. That section was written to document extra correlative data that shows dust in the Arctic, as was Section 3.3 for CALIOP products of Aerosol Type == 'Dust'.



* the VIIRS retrieval threshold for AOD employed by the authors

** for the record, those 7 CM AODs occurred on one single day (16:24 to 16:45 UTC on 23/03/2020). The MODIS image of that day (Worldview URL below) shows a completely snow-covered surface in the Eureka region. In effect there was no validation data available for the period of 2020 to 2022 that would sustain any claims of DOD retrieval validation in the high Canadian Arctic

At the "point" (single site) to regional (6 AERONET sites) scale of the CM AOD climatology of AboEl-Fetouh et al. (2020) (AeF) the largest (geometric mean x geometric standard deviation) summertime CM AOD (an upper limit for DODs) was 0.003 x $2.13_{\pm 1}$ for the month of June at Resolute Bay and OPAL, Nunavut. This number is smaller by two orders of magnitude than the 0.5 threshold of

Figures 3 and 4: the attendant FoO computations using a lognormal distribution* driven by AeF's stats yielded, not surprisingly, FoO percentages that are all much below 1%)

* results which can be supplied upon request

Worldview URL

Again, we presented qualitative Aerosol Type == 'Dust' VIIRS products while the authors are referring to climatologies of CM AOD (> DOD), also from the handful of ground-based (point observation) stations operating in the remote Arctic environment.

Other comment: Our experience has been that CALIOP dust classification and attenuated extinction coefficient capabilities are at the margins of significance with respect to the weak optical signals of dust in the Arctic. Kawaii et al. (2023) tried to develop a CALIOP-derived local dust optical-depth climatology for the Arctic and found that CALIOP predictions of DOD were significantly greater than predicted by their simulations (see their supplementary material). There is no published literature on the successful validation of CALIOP retrievals of weak and low altitude Arctic dust plumes.

Our CALIOP data of Aerosol Type == 'Dust' is based on JJA observations (2006 – 2020), when dust-cirrus confusion will be least (below, right). We do not draw any critical conclusions from this figure except to note that signatures of the **increased count** of boundary layer-like dustiness (< 1 km altitude) are apparent during dust emission season in the large geographic region we call the "Canadian Arctic Dust Belt", and also in the vicinity of Greenland. Nevertheless, we don't dispute that even the heavily-averaged (in space and time) CALIOP figure of dust classification counts may be pushing the limits of detection and we are happy to learn more about this.

As to Kawai's simulations (below, left), there are a number of reasons why their simulations could be lower than the potentially true (but unvalidated) CALIOP reality, i.e., model representation of dust source areas; model resolution (1.9° x 2.5° with 30 layers between 0-40 km) influencing both 3-D wind speeds *and* representations of snow and ice cover and soil moisture; moreover, the nonlinear dust flux parameterization itself can be updated. See, e.g., the work of Meng et al. (2021, GMD) who have implemented offline dust emissions in GEOS-Chem (with a source function spanning low latitudes) at the native resolution of the meteorological fields (0.25° × 0.3125°), which lead to better agreement in comparisons to (low-latitude) AERONET; or see the high resolution (0.25° x 0.25°) SI map that we compare to in Fig. 6 (Vukovic, 2021; 2022).

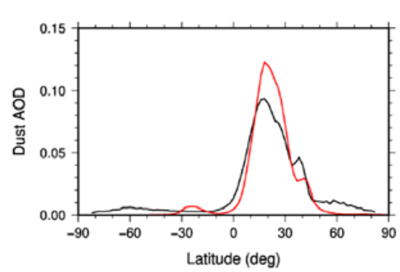


Figure S4. Annual-mean zonally averaged dust AOD observed by CALIPSO at 532 nm (black) and simulated by our model for 550 nm (red) for the years 2010–2019. The observed dust AOD was derived from the "dust" subtype in the CALIPSO retrievals and does not include the "polluted dust" subtype, which specifies a mixture of dust and smoke or urban pollution.