Response to Referee #1:

We appreciate the very helpful feedback from the referee. The referee's comments are listed in *italics*, followed by our response in blue. New/modified text in the manuscript is in **bold**.

1. The only glaring hole in this manuscript is a discussion on the computational time needed to complete this new oversampling technique. It is discussed at some length in Section 4.2, but it is brief and unclear. Based on my understanding, the satellite data needs to be discretized to 0.05 km resolution? I would imagine this would be very computationally demanding. Can you provide more information on this? Can you provide some comparisons? For example in Figure 8, how long does it take for various oversampling techniques? Perhaps this should be discussed in Section 5.1.

No, the satellite data does not have to be discretized to a 0.05-km grid. The appropriate level of discretization is instrument-dependent and presented in Fig. 7. For example, the OMI oversampling grid should be discretized to a resolution finer than ~16 km, so that the physics-based oversampling can outperform the tessellation by giving smaller errors in comparison with the 0.05 km resolution case. Here the 0.05 km resolution is used as the "exact observation" where discretization error is negligible, i.e., a standard to be compared with. We do not intend to perform all oversampling at 0.05 km resolution. To clarify this point, the following sentence is added at line 27, page 12 of the original manuscript:

"**One should note that this discretization at 0.05 km is used to get the 'true' map of OMI observation where the discretization error is negligible. It is unnecessary to oversample at this fine grid in general.**"

Computational time of physical oversampling is generally not a concern. It takes 9×10^{-4} s to run the point oversampling, and 1×10^{-3} s to run the physical oversampling per OMI pixel for 1 km grid, which are both implemented in Matlab. Our tessellation code was written in FORTRAN, and it takes 5×10^{-4} s per pixel for 1 km grid. Physical oversampling for elliptical pixels (IASI and CrIS) to the same grid is faster by about a factor of 4 because their pixels are smaller and no projective transformation of pixel vertices is necessary. We would like to avoid reporting exact run times in the manuscript as they will depend on the machines, programming language (FOTRAN is generally faster than Matlab/Python), and level of optimization. The bottom line is that the physical oversampling is not slower than conventional oversampling approaches. We included the following sentence at the end of Section 5.1:

"**The physical oversampling also does not require more computational resources than point oversampling and tessellation, making it suitable for a wide range of spatial scales and target grids.**"

2. Along the same lines, under the assumption that this technique is computationally intensive, it should be made clear in the abstract (and perhaps even title) that this technique is most useful for localized studies of air pollution and not for larger regions or global studies.

As indicated above, the physical oversampling does not require more computational resources than point oversampling and tessellation. We are currently applying the physical oversampling in several continental-scale studies (North America, East Asia). For example, with one CPU core, it takes 15 minutes to oversample one year of CrIS data over the contiguous US (CONUS), which includes 5×10^6 pixels, at 2 km resolution. It takes 24 minutes to oversample to 1 km (same resolution shown in Fig. 10 of the manuscript) for the entire CONUS domain. As such, this technique is not limited to localized studies.

Page 2 Line 26: "help to beat down" is not appropriate. Suggest re-word

"Beat down" is revised to "**average out**".

Page 2 Line 26: This sentence is a run-on. Suggest splitting into two sentences.

This sentence (references are not shown) is revised to "**These 'Level 3' products help to average out the observational noise that can be significant for individual Level 2 retrieval and make satellite data more accessible for scientific studies and the general public. These products may also lead to additional discoveries, such as emission and lifetime estimates, source identification, trend analyses, assessment of environmental exposure for public health, and satellite data validation.**"

Page 3 Line 23: OMI nadir spatial resolution is typically referred to as 13 x 24 km2.

13×24 km^2 is the nadir pixel size for the "tiled" OMI pixel product that assumes no overlap between adjacent pixels. However, this is not the accurate physical representation of OMI pixels because they do overlap. We clarify the numbers by adding an explanation as

"**These OMI pixel polygons are close to rectangles, ranging from 14×26 km^2 (or 13×24 km^2 if assuming non-overlapping pixels) at nadir to 28×160 km^2 at the swath edges.**"

Page 3 Line 24: The sentence, "An alternative. . ." is unclear. Suggest re-word.

This sentence is revised to "**Alternatively, OMI pixels can be represented as tiled polygons with no overlap between adjacent pixels. These tiled pixels produce a seamless swath image, but are less accurate, especially in the along-track direction.**"

Page 6 Figure 2: This figure is a bit confusing. The second sentence in the figure caption is not necessary. Also, it would be good to provide the numbers of correct oversampled pixels (presumably 97 if I did the math correctly) and to provide all three numbers (correct, false positive, and false negative) as percentages directly on the plot and in the text.

The figure and caption are revised as suggested.

Page 7 Line 1: The word "tessellation" should be in this section title

Revised as suggested.

Page 10 Figure 4: What is the grid size of these plots? 0.05 km?

These are generic 2D super Gaussian functions not following any real pixel size. The resolution is 5% of the FWHM of the vertical direction. For OMI nadir pixel this would corresponds to a resolution of 0.7 km. This information is added to the figure caption.

Page 12 Lines 5 -11: This section is unclear. Please re-word.

This section is revised to:

"**It is computationally demanding to numerically integrate the spatial response of all satellite pixels over each grid cell. To simplify it, one may discretize the spatial response function to the target oversampling grid and use the spatial response value at the grid center to approximate the integration. As such, the spatial response function only needs to be evaluated once per pixel per grid cell. To improve this simple discretization scheme, we calculate a weighted average of the spatial response values at the grid center and grid corners (as proposed for MODIS by Yang and Wolfe, 2001). Because the grid corners are shared by neighboring grid cells, this approach only doubles the spatial response calculation but significantly reduces the error induced by discretization ("discretization error" hereafter). Appendix B gives a detailed comparison of different discretization schemes.**"

Page 13 Figure 6: It is unclear what Figures 6a and 6b are representing. What is "ground truth"? What is an "ideal OMI observation"? It's not clear what these terms mean in the context of this manuscript. The figure caption and subsequent text referring to this figure should be clarified.

The text has been clarified in the response to the first comment. Moreover, the following sentences are included in the caption of Fig. 6:

"**The pattern in (a) is the ground truth of the concentration distribution. The pattern in (b) represents the ideal observation by OMI because no errors are introduced during the oversampling process.**"

Page 18 Line 1: Are "all" southerly/northerly winds included? Or is there a threshold (e.g., only wind speeds > 1 m/s/)? Please be explicit.

Yes, all southerly/northerly winds were included. This sentence is clarified as

"**Figure 10 shows the physical oversampling of NH_3 total column under southerly wind (meridional wind component > 0, a and c) and northerly wind (meridional wind component < 0, b and d) and high PBL temperature (> 15 °C, a and b) and low PBL temperature (< 15 °C, c and d). Here the PBL temperature is the average air temperature from surface to the top of the PBL, weighted by pressure.**"

Page 18 Line 1: What is "PBL temperature"? Is it the average of the temperature from the surface to the top of the PBL? Or the temperature at the top of the PBL?

It is the average of temperature from the surface to the top of PBL, weighted by pressure. It is clarified in the text.

Page 18 Line 5: Mention NARR spatial resolution is 32 km.

Done.

Page 18 Line 13: Remove the words "conceptually simple".

"conceptually simple" is replaced by "physics-based".