Determination of Aerosol Optical Depth (AOD), For Middleton sun-photometer SP02-1086, During the period 2020 through 2024.

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This document consists of four parts and applies to the Middleton SP02-1086 (2020-2024).

1) A short description of the calibration process.
2) Sample calibration plots.
3) Tables of Top Of Atmosphere values for years 2020 through 2024.
4) A comparison to available coincident Aerosol Robotic Network (AERONET) values during the years 2020 through 2024.

Determination of Middleton SP02 Aerosol Optical Depth (AOD).
January 2020 through May 2025.

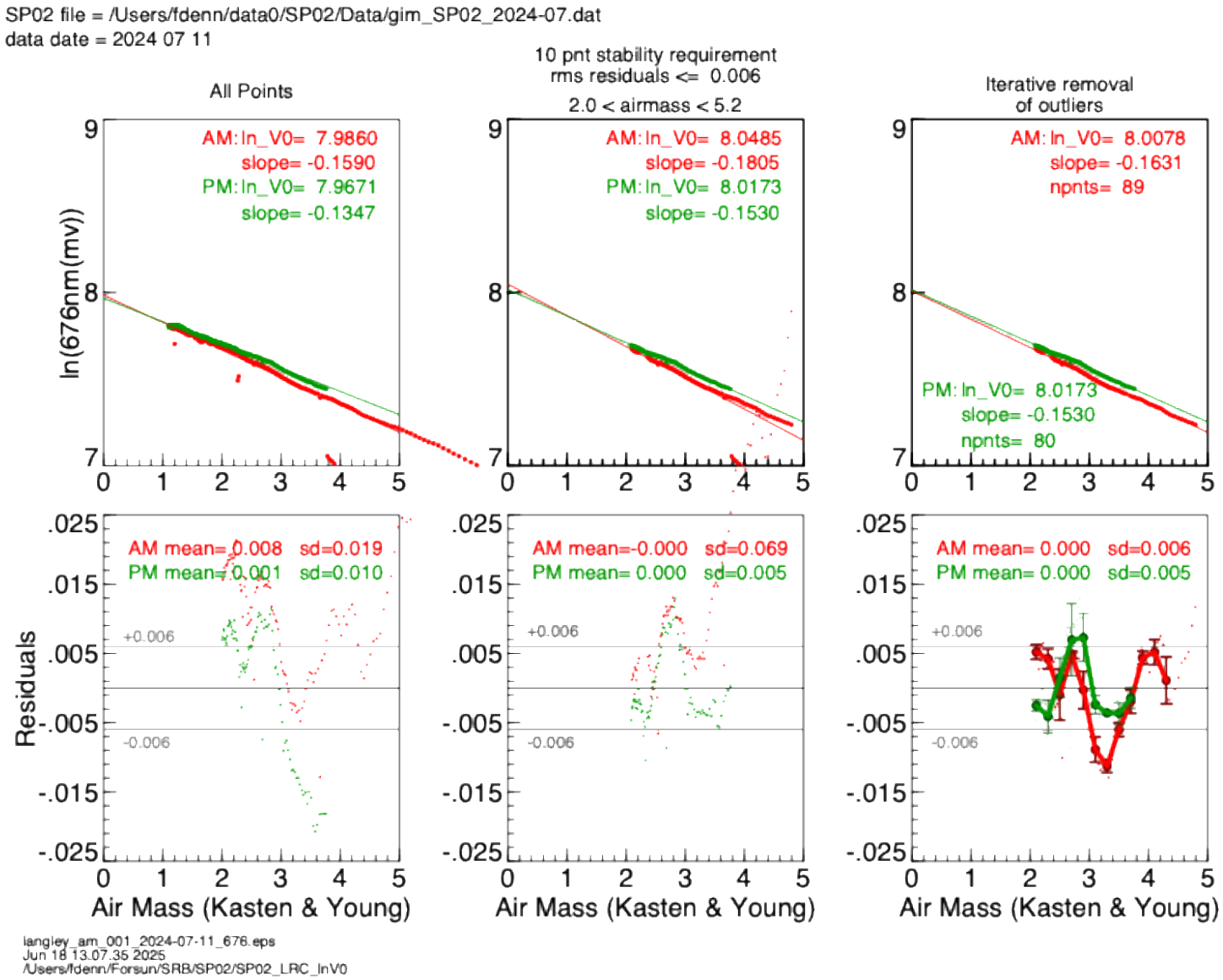
Aerosol optical depth is a measure of the extinction of a narrow band (approximately 10nm) irradiance from the sun. To make this measurement the extraterrestrial irradiance, Also known as Top Of Atmosphere (TOA) or V0 value must first be determined. The V0 determinization is known as Langley extrapolation. The Middleton SP02 measures at the following four wavelengths ~413nm, ~500nm, ~676nm and ~860nm.

A Langley extrapolation is preformed by plotting the natural log of the narrowband irradiance, usually the raw voltage from the instrument, on the vertical axis versus airmass on the horizontal axis. An airmass of 1 is defined as directly over head. The airmass used here is the approximation of Kasten and Young from 1989. Air mass is not a simple trigonometric function due to the curvature of the earth atmospheric system. Here air mass measurements are taken over a range of 2 to 5.2. An extrapolation is then made to zero air mass irradiance value (TOA).

Often TOA measurements are made high on a mountain under clear skies, this is not possible for us. Additionally, filters degrade over time. The degradation of filters over time necessitates periodic evaluation of the V0 values. We have preformed TOA extrapolations over a period of about 5 years. Filters have been applied to the TOA measurements to get the most stable and useable measurements. Data filter requirements are; A minimum airmass range of 1.5, A minimum of 50 points in the Langley fit, A running stability requirement, And residuals with respect the fit line of less than 0.006. An example of a Langley fit is shown in Figure 1.

Near the end of May 2025, the SP02 filters were changed therefor TOA data presented here do not apply past the end of May 2025. There was essentially no useable after November 2024 so the effective end date for this analysis in the end of 2024.

Figure 1. An example of a Langley fit and extrapolation to zero air mass. The top left most plot shows all the raw data. The top middle plot shows the data after stability requirements and residual requirements have been applied. The top right plot shows data after an iterative removal of residuals have been applied.



For each wavelength (413nm, 500nm, 676nm, and 860nm) a fit has been made to the five-year data set. Points outside two standard deviations of an initial fit have been removed, and a new fit line has been determined. An example for the 676nm case is shown in Figure 2.

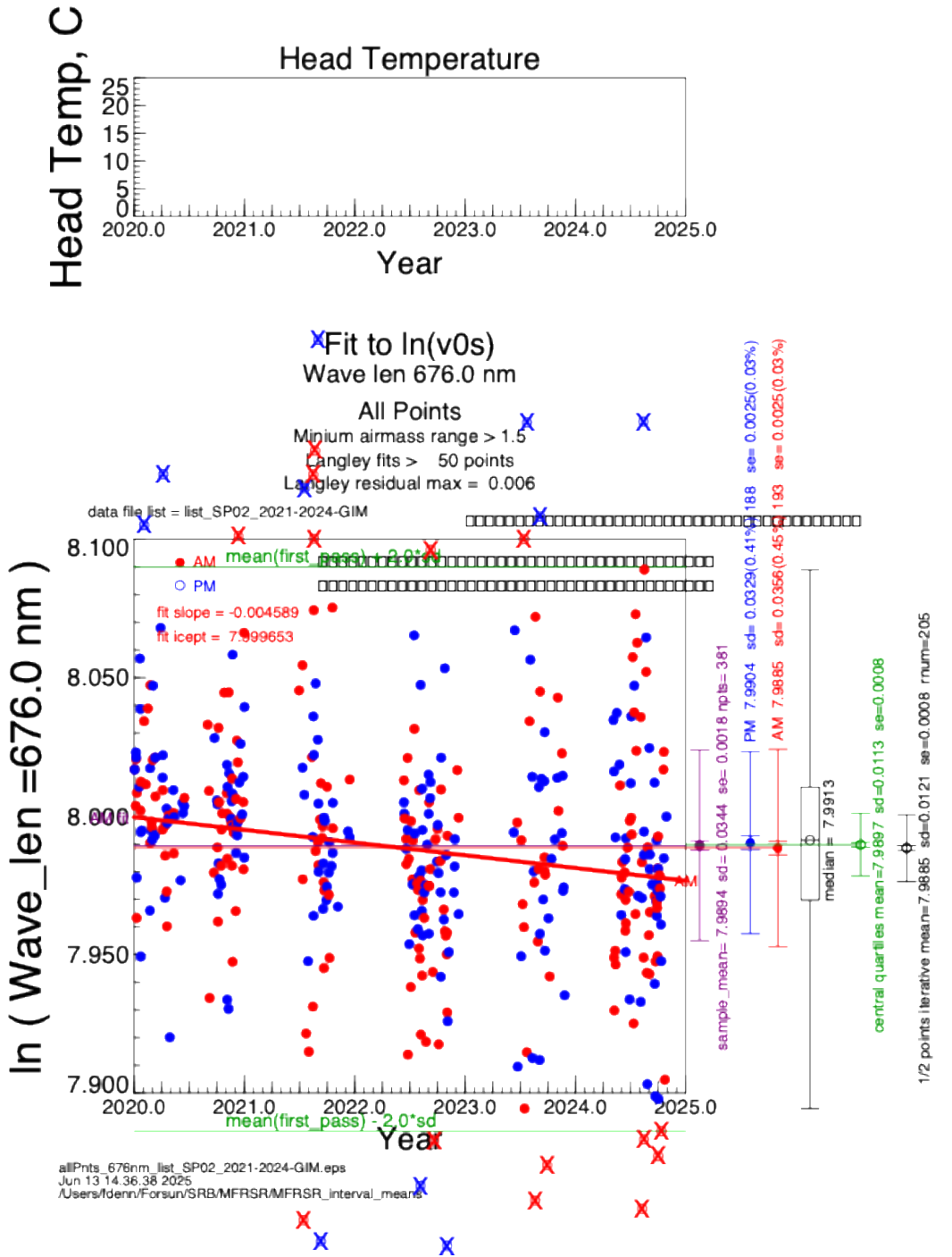


Figure 2. An example of a five-year fit to the TOA values for the 676nm case. Points outside two standard deviations (marked an X) of an initial fit have been removed and a new fit line has been determined.

Tables 1 through 5 show the monthly TOA values derived from the 5-year fit.
The first row is a description of the file.
The second row is column headings.
The next 12 rows are the monthly TOA values.

The first two columns are for the data year, and month.
The next 7 columns are for V0 values,
followed by 7 columns of standard deviation with respect to the fit,
followed by 7 columns indicating the number of data points in the fit.
The Table was developed for a seven-channel instrument therefor three columns 1,4, and 7 of each set of 7 data columns contain no data.

After the TOA data there is a blank line, followed by descriptive lines.

Table 1. TOA values for year 2020.

TOA_SP02_interval_means_fit_2020; Minium air mass range > 1.5, 50 points required for a Langley fit, Langley residual max 0.006

year	mn	0.000	413.000	500.000	0.000	676.000	860.000	0.000	(year, month, 7-means, 7-std_devs, 7-npoints_in_mean)											
2020	1	0.000	8.961	8.396	0.000	7.999	7.769	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	2	0.000	8.960	8.395	0.000	7.999	7.768	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	3	0.000	8.959	8.394	0.000	7.999	7.767	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	4	0.000	8.958	8.394	0.000	7.998	7.766	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	5	0.000	8.957	8.393	0.000	7.998	7.765	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	6	0.000	8.956	8.392	0.000	7.998	7.765	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	7	0.000	8.955	8.392	0.000	7.997	7.764	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	8	0.000	8.954	8.391	0.000	7.997	7.763	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	9	0.000	8.953	8.390	0.000	7.996	7.762	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	10	0.000	8.952	8.390	0.000	7.996	7.761	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	11	0.000	8.950	8.389	0.000	7.996	7.760	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2020	12	0.000	8.949	8.388	0.000	7.995	7.759	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0

fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive

Table 2. TOA values for year 2021.

TOA_SP02_interval_means_fit_2021 ; Minium air mass range > 1.5, 50 points required for a Langley fit, Langley residual max 0.006

year	mn	0.000	413.000	500.000	0.000	676.000	860.000	0.000	(year, month, 7-means, 7-std_devs, 7-npoints_in_mean)											
2021	1	0.000	8.948	8.388	0.000	7.995	7.758	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	2	0.000	8.947	8.387	0.000	7.994	7.757	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	3	0.000	8.946	8.386	0.000	7.994	7.756	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	4	0.000	8.945	8.386	0.000	7.994	7.755	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	5	0.000	8.944	8.385	0.000	7.993	7.754	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	6	0.000	8.943	8.384	0.000	7.993	7.754	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	7	0.000	8.942	8.384	0.000	7.993	7.753	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	8	0.000	8.941	8.383	0.000	7.992	7.752	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	9	0.000	8.940	8.382	0.000	7.992	7.751	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	10	0.000	8.939	8.381	0.000	7.991	7.750	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	11	0.000	8.937	8.381	0.000	7.991	7.749	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2021	12	0.000	8.936	8.380	0.000	7.991	7.748	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0

fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive

Table 3. TOA values for year 2022.

TOA_SP02_interval_means_fit_2022 ; Minium air mass range > 1.5, 50 points required for a Langley fit, Langley residual max 0.006

year	mn	0.000	413.000	500.000	0.000	676.000	860.000	0.000	(year, month, 7-means, 7-std_devs, 7-npoints_in_mean)											
2022	1	0.000	8.935	8.379	0.000	7.990	7.747	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	2	0.000	8.934	8.379	0.000	7.990	7.746	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	3	0.000	8.933	8.378	0.000	7.990	7.745	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	4	0.000	8.932	8.377	0.000	7.989	7.744	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	5	0.000	8.931	8.377	0.000	7.989	7.743	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	6	0.000	8.930	8.376	0.000	7.988	7.743	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	7	0.000	8.929	8.375	0.000	7.988	7.742	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	8	0.000	8.928	8.375	0.000	7.988	7.741	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	9	0.000	8.927	8.374	0.000	7.987	7.740	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	10	0.000	8.926	8.373	0.000	7.987	7.739	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	11	0.000	8.924	8.373	0.000	7.986	7.738	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2022	12	0.000	8.923	8.372	0.000	7.986	7.737	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0

fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive

Table 4. TOA values for year 2023.

TOA_SP02_interval_means_fit_2023; Minium air mass range > 1.5, 50 points required for a Langley fit, Langley residual max 0.006

year	mn	0.000	413.000	500.000	0.000	676.000	860.000	0.000	(year, month, 7-means, 7-std_devs, 7-npoints_in_mean)												
2023	1	0.000	8.922	8.371	0.000	7.986	7.736	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	2	0.000	8.921	8.371	0.000	7.985	7.735	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	3	0.000	8.920	8.370	0.000	7.985	7.734	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	4	0.000	8.919	8.369	0.000	7.985	7.733	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	5	0.000	8.918	8.369	0.000	7.984	7.732	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	6	0.000	8.917	8.368	0.000	7.984	7.731	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	7	0.000	8.916	8.367	0.000	7.983	7.731	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	8	0.000	8.915	8.367	0.000	7.983	7.730	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	9	0.000	8.914	8.366	0.000	7.983	7.729	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	10	0.000	8.913	8.365	0.000	7.982	7.728	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	11	0.000	8.911	8.365	0.000	7.982	7.727	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2023	12	0.000	8.910	8.364	0.000	7.981	7.726	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0

fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive

Table 5. TOA values for year 2024.

TOA_SP02_interval_means_fit_2024; Minium air mass range > 1.5, 50 points required for a Langley fit, Langley residual max 0.006

year	mn	0.000	413.000	500.000	0.000	676.000	860.000	0.000	(year, month, 7-means, 7-std_devs, 7-npoints_in_mean)													
2024	1	0.000	8.909	8.363	0.000	7.981	7.725	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	2	0.000	8.908	8.363	0.000	7.981	7.724	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	3	0.000	8.907	8.362	0.000	7.980	7.723	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	4	0.000	8.906	8.361	0.000	7.980	7.722	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	5	0.000	8.905	8.361	0.000	7.980	7.721	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	6	0.000	8.904	8.360	0.000	7.979	7.720	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	7	0.000	8.903	8.359	0.000	7.979	7.720	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	8	0.000	8.902	8.358	0.000	7.978	7.719	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	9	0.000	8.901	8.358	0.000	7.978	7.718	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	10	0.000	8.900	8.357	0.000	7.978	7.717	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	11	0.000	8.898	8.356	0.000	7.977	7.716	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0
2024	12	0.000	8.897	8.356	0.000	7.977	7.715	0.000	0.000	0.042	0.044	0.000	0.036	0.035	0.000	0	65	168	0	193	218	0

fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive
fit to am points over the interval 2020 though 2024 inclusive

A comparison to AERONET follows.

Comparisons are shown for each of the common wavelength channels for each year, for a total of 18 plots (Figures 3 through 20).

Figure 3. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2020, for the 500nm channel located at LRC.

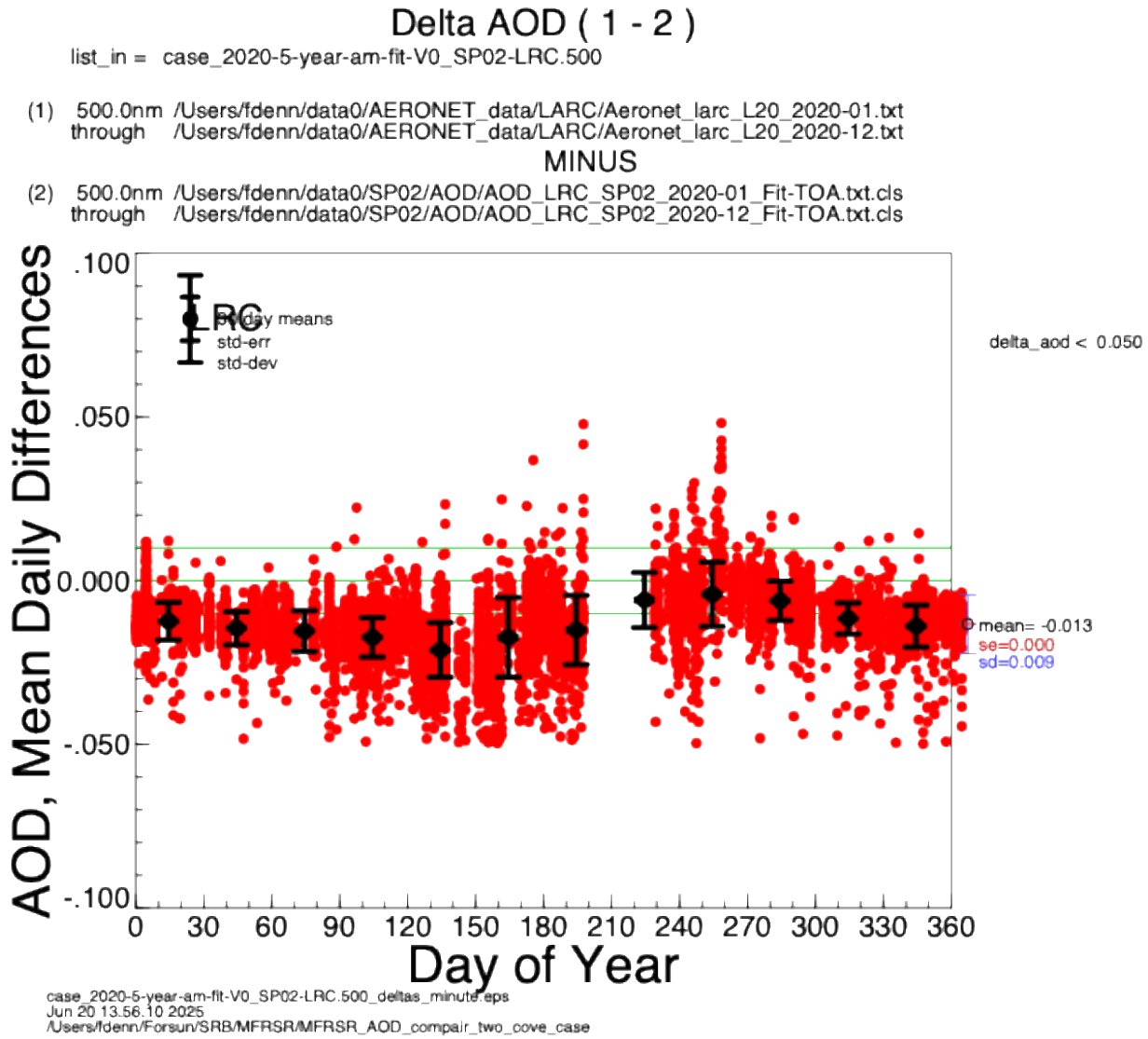


Figure 4. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2020, for the 676nm channel located at LRC.

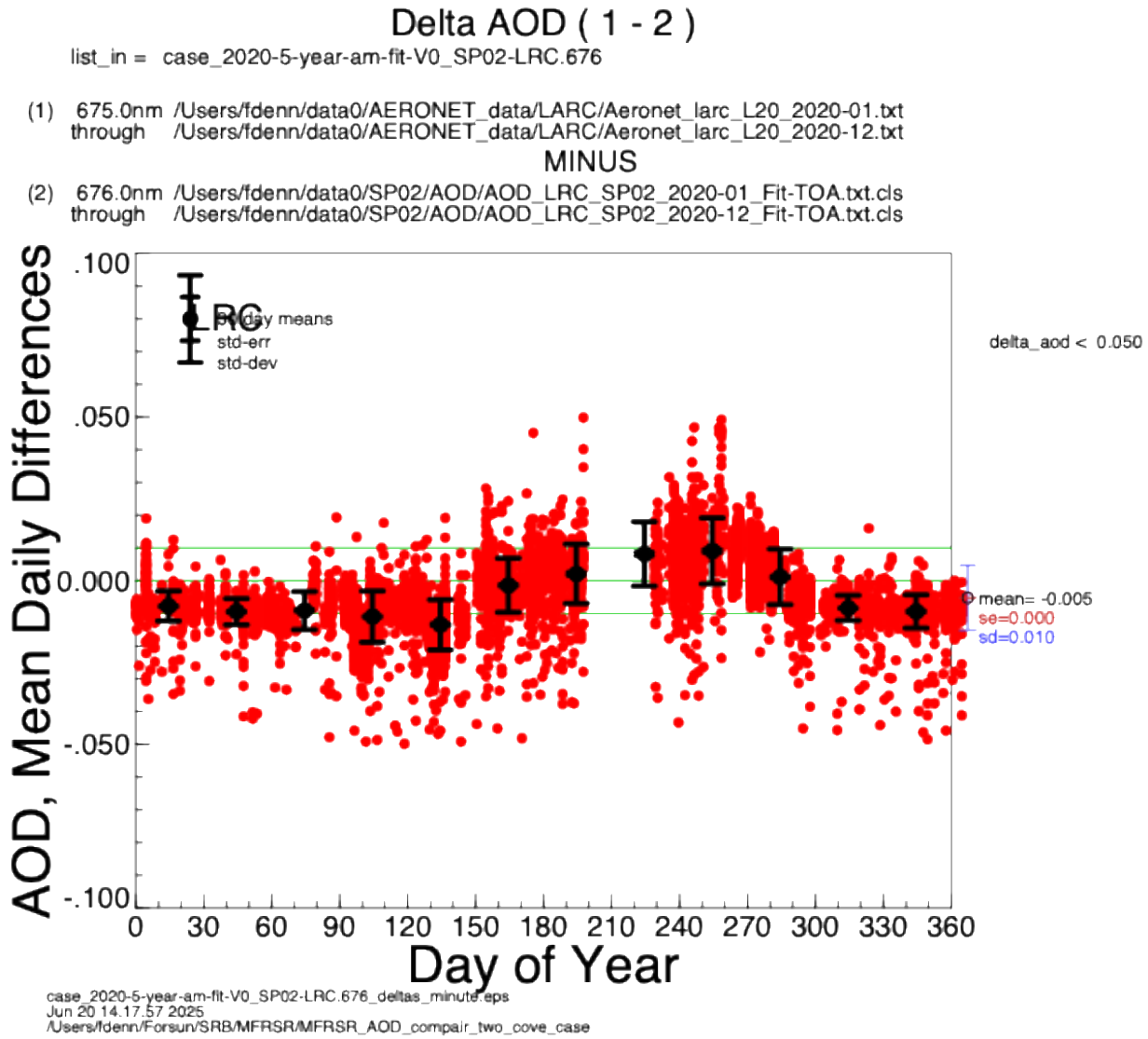


Figure 5. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2020, for the 870nm channel located at LRC.

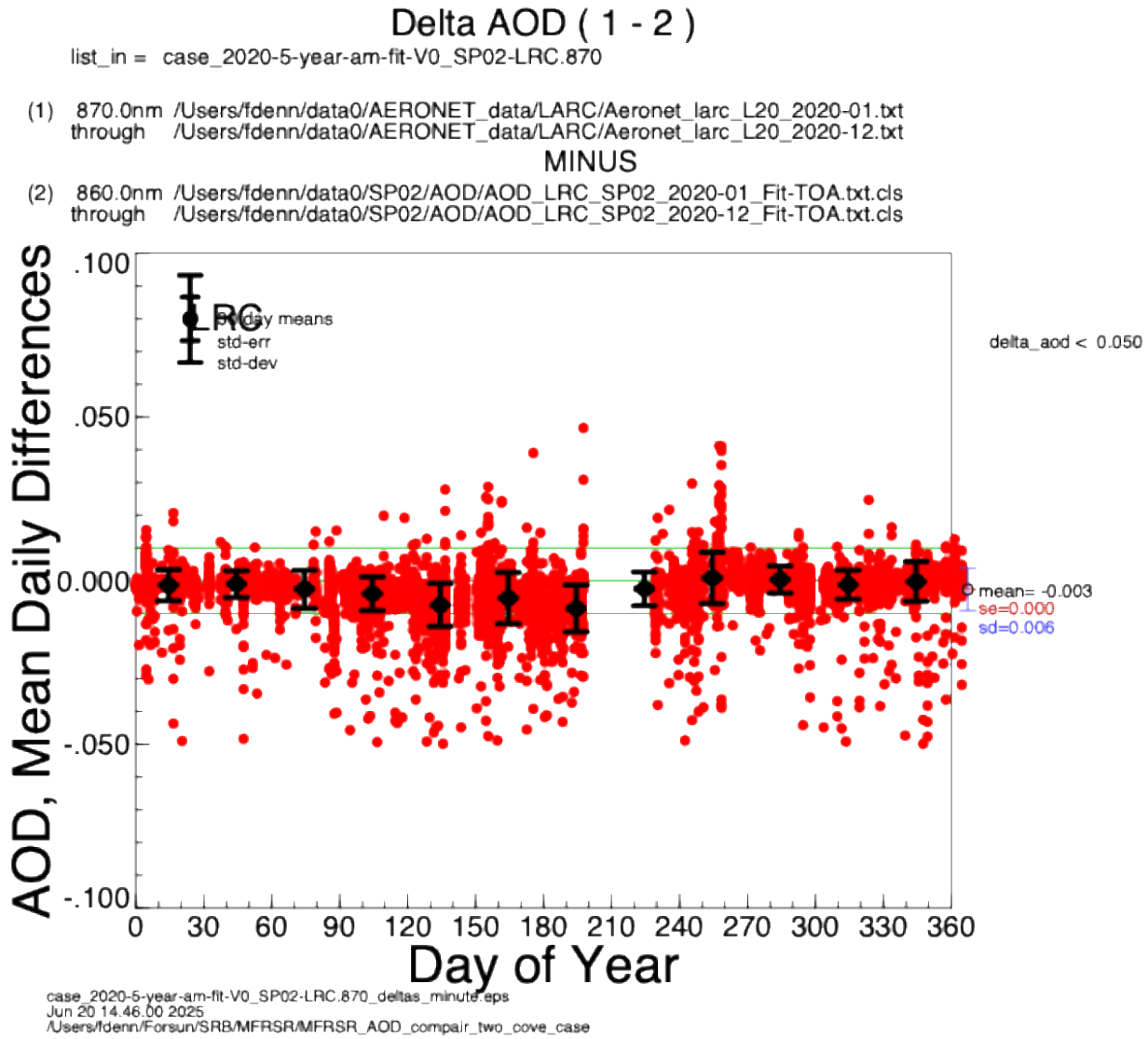


Figure 6. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2021, for the 500nm channel located at LRC.

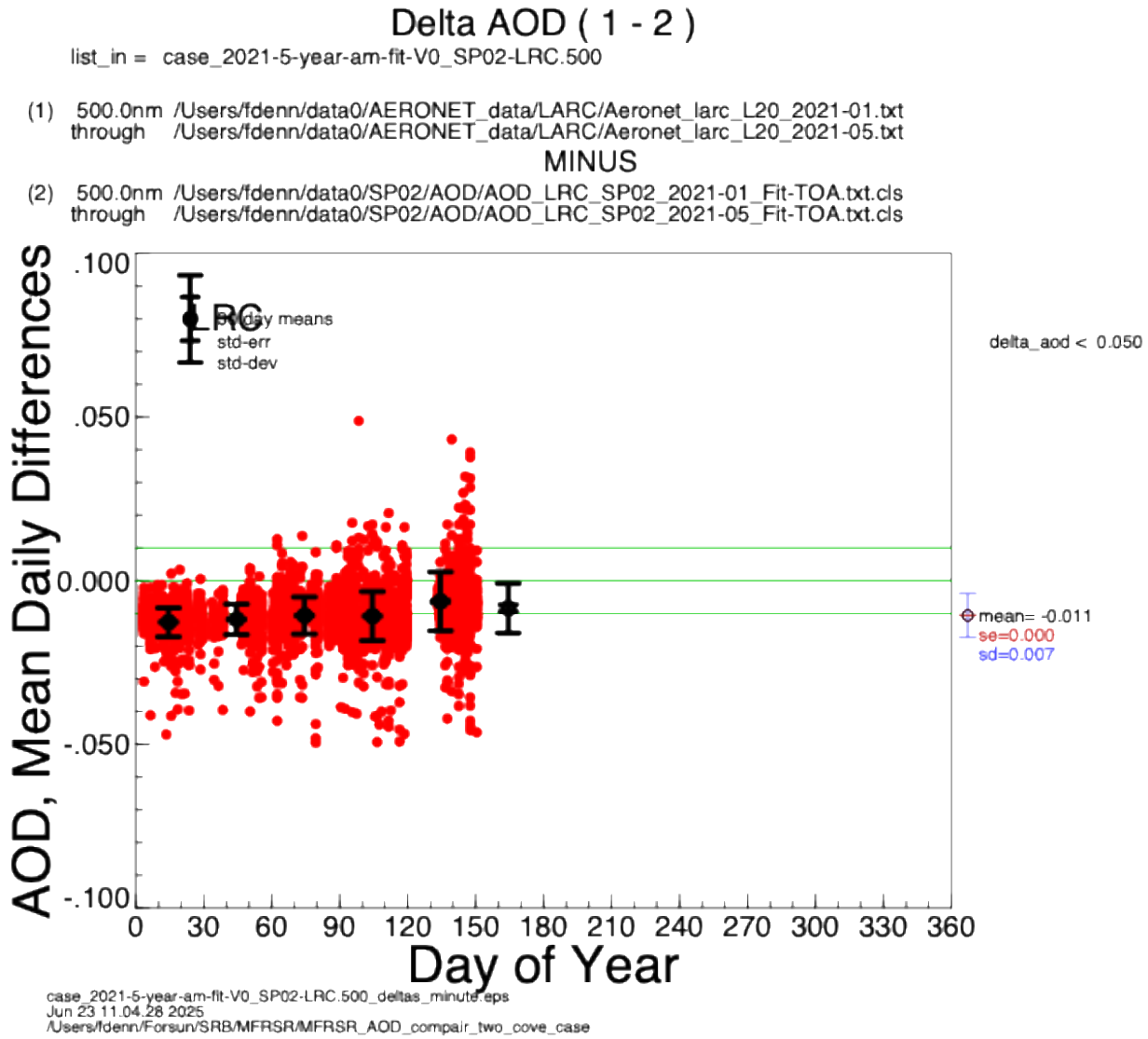


Figure 7. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2021, for the 676nm channel located at LRC.

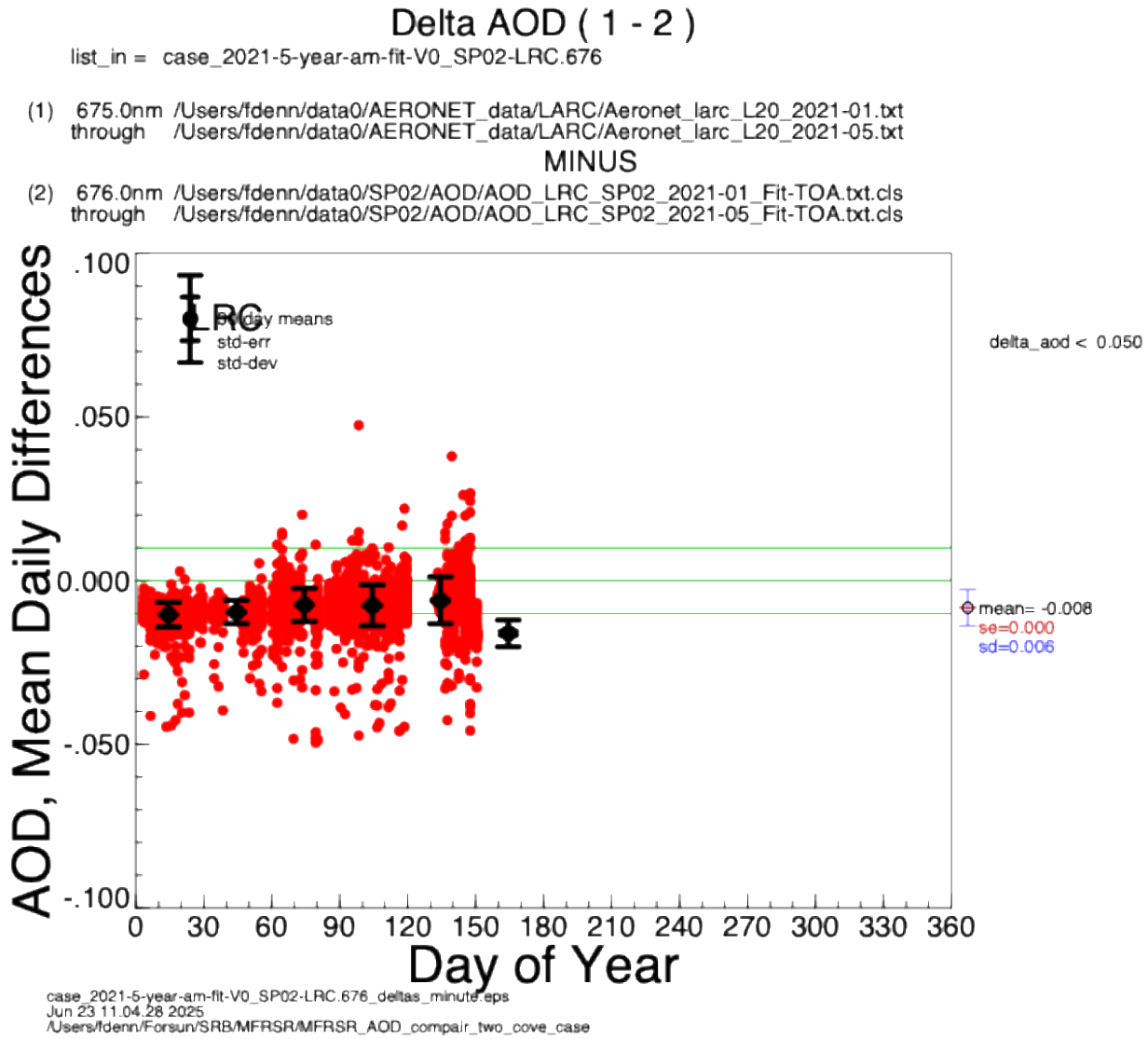


Figure 8. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2021, for the 870nm channel located at LRC.

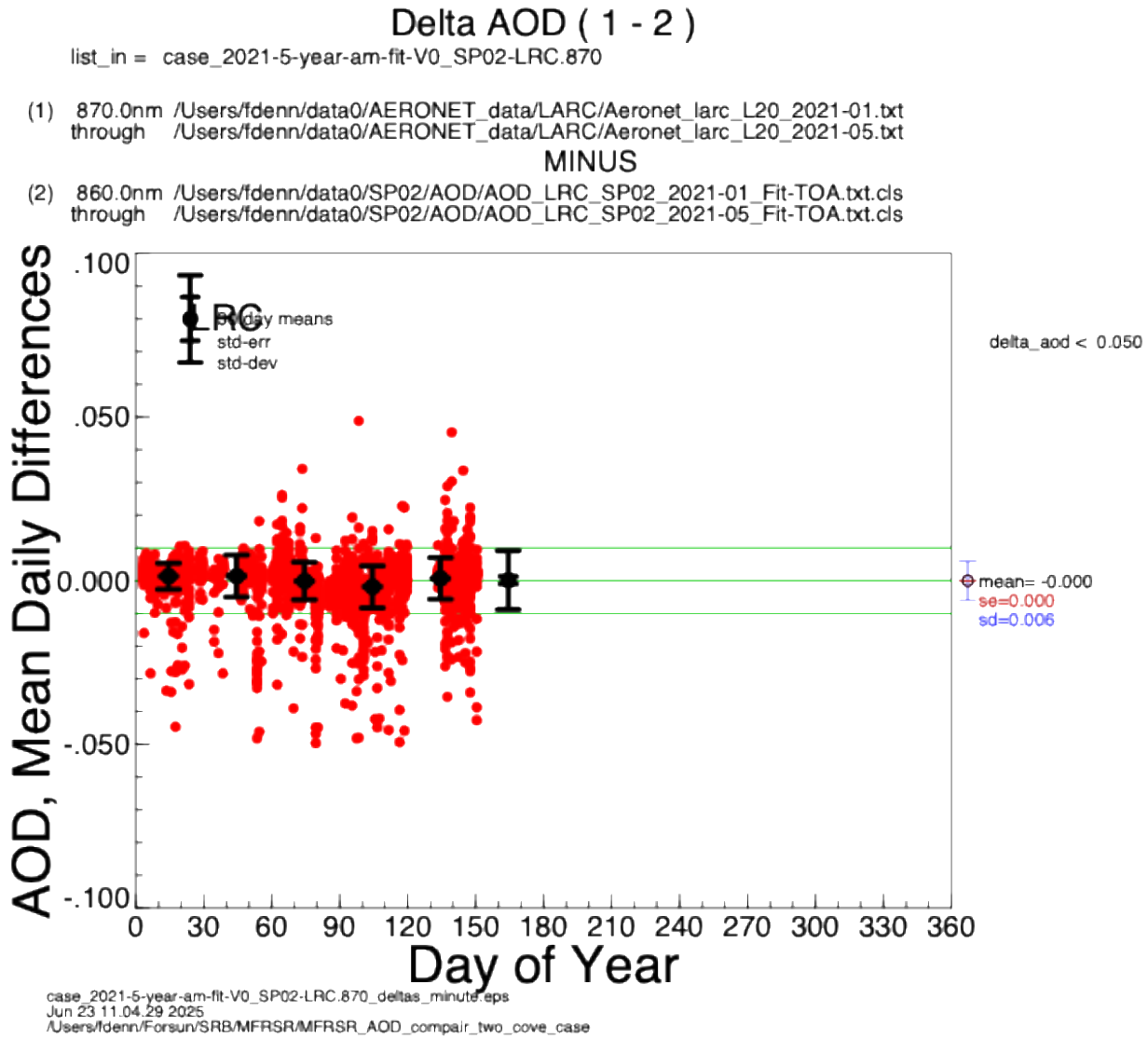


Figure 9. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2021, for the 500nm channel located at GIM.

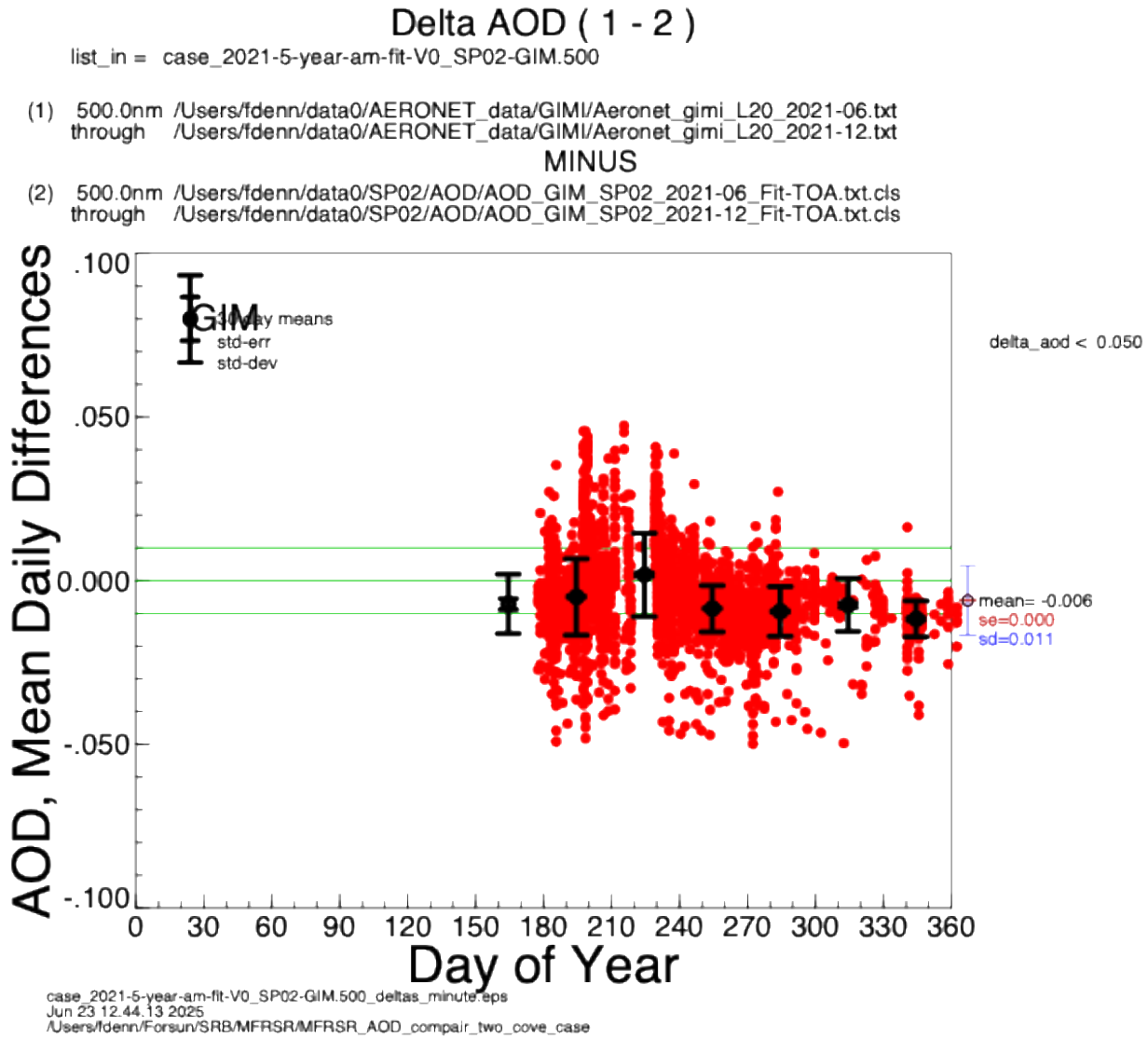


Figure 10. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2021, for the 676nm channel located at GIM.

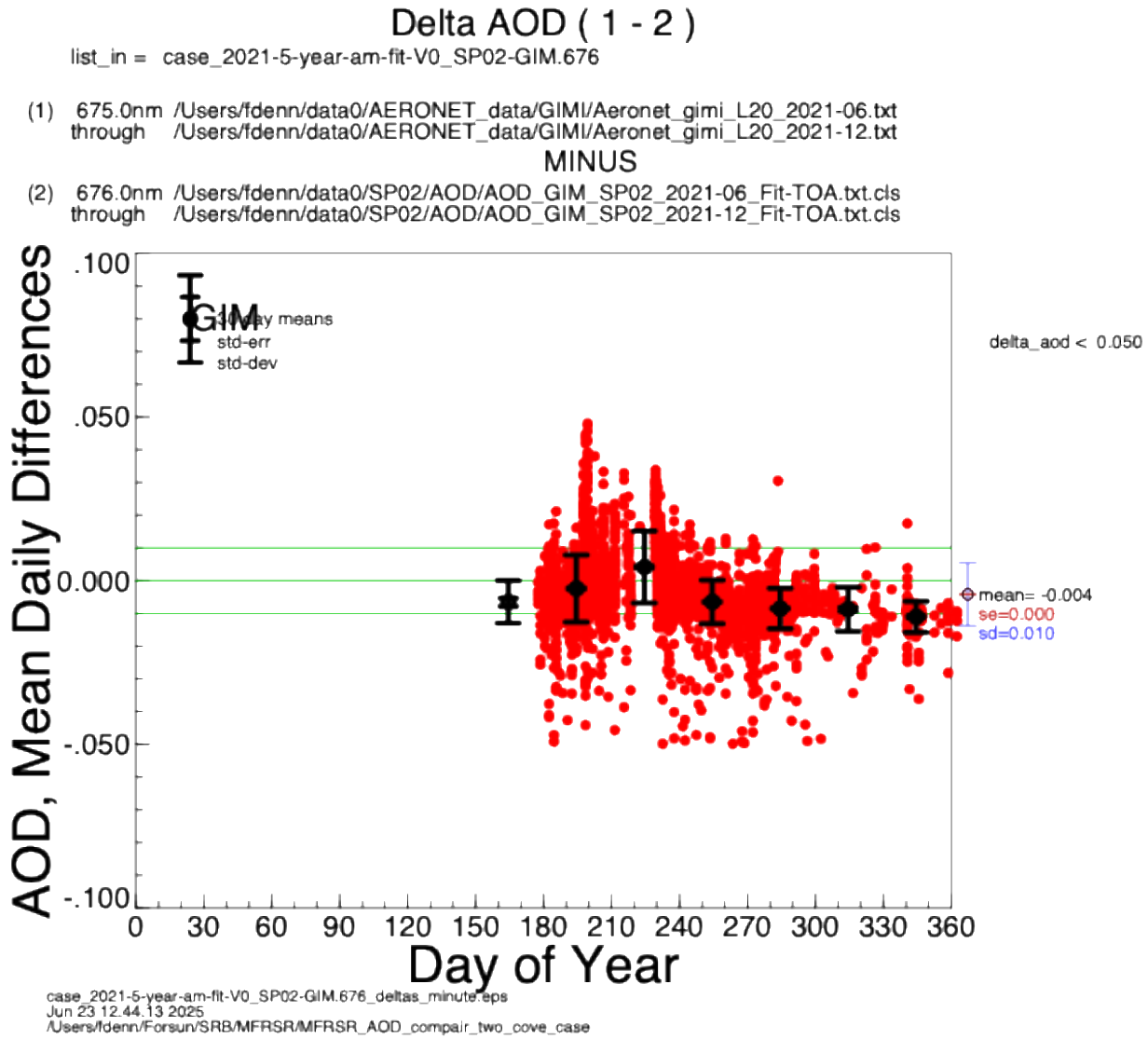


Figure 11. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2021, for the 870nm channel located at GIM.

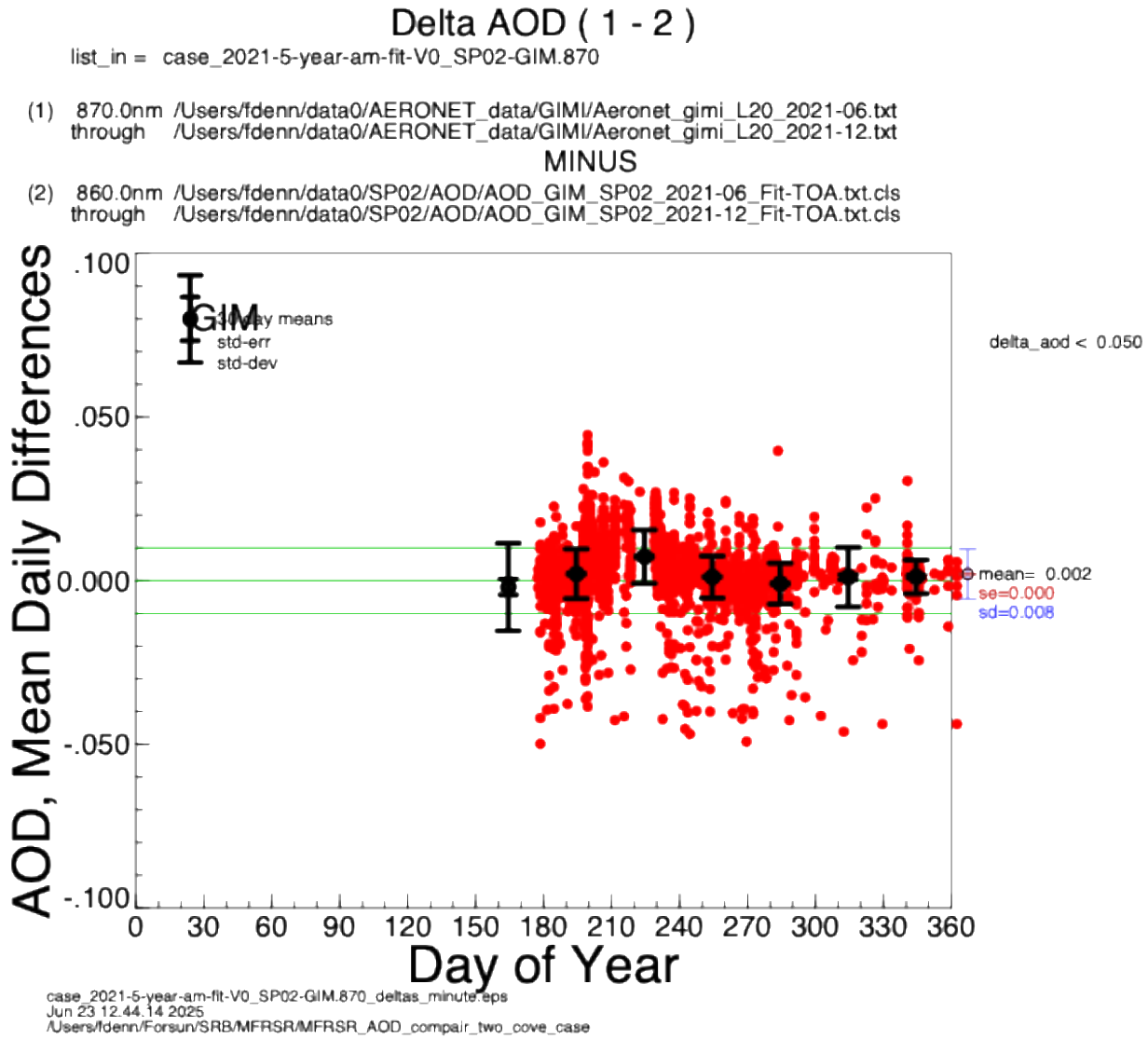


Figure 12. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2022, for the 500nm channel located at GIM.

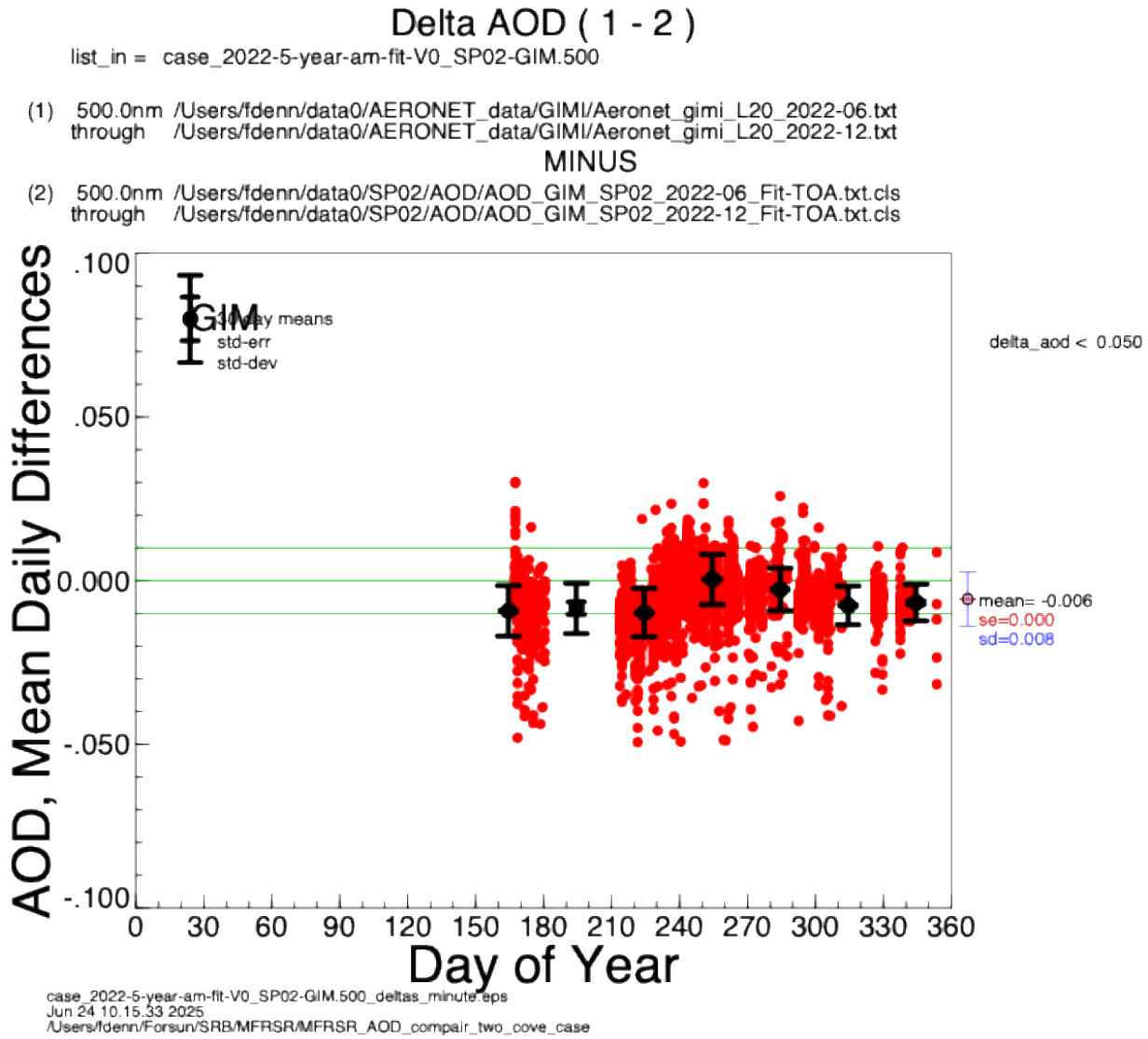


Figure 13. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2022, for the 676nm channel located at GIM.

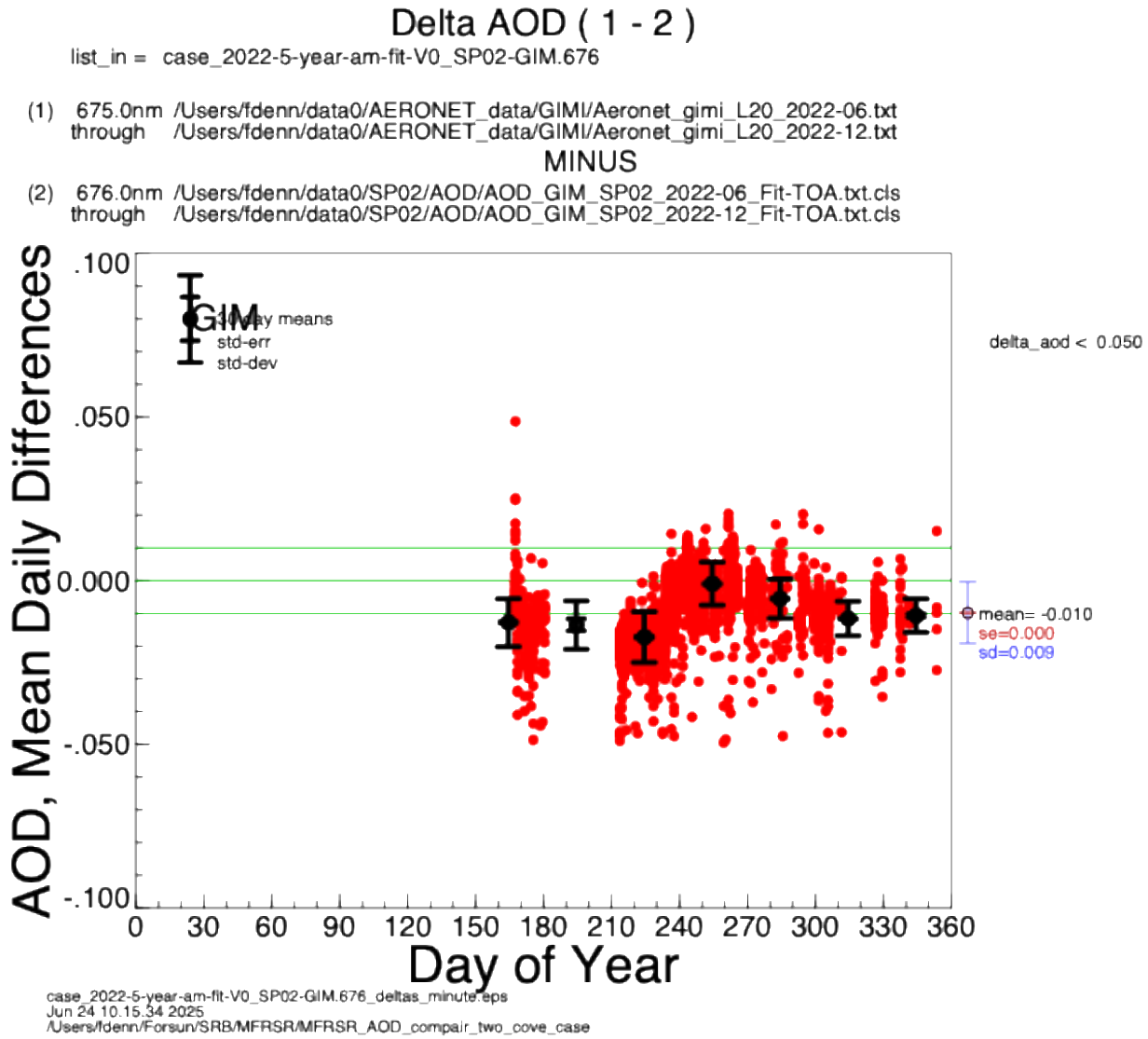


Figure 14. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2022, for the 870nm channel located at GIM.

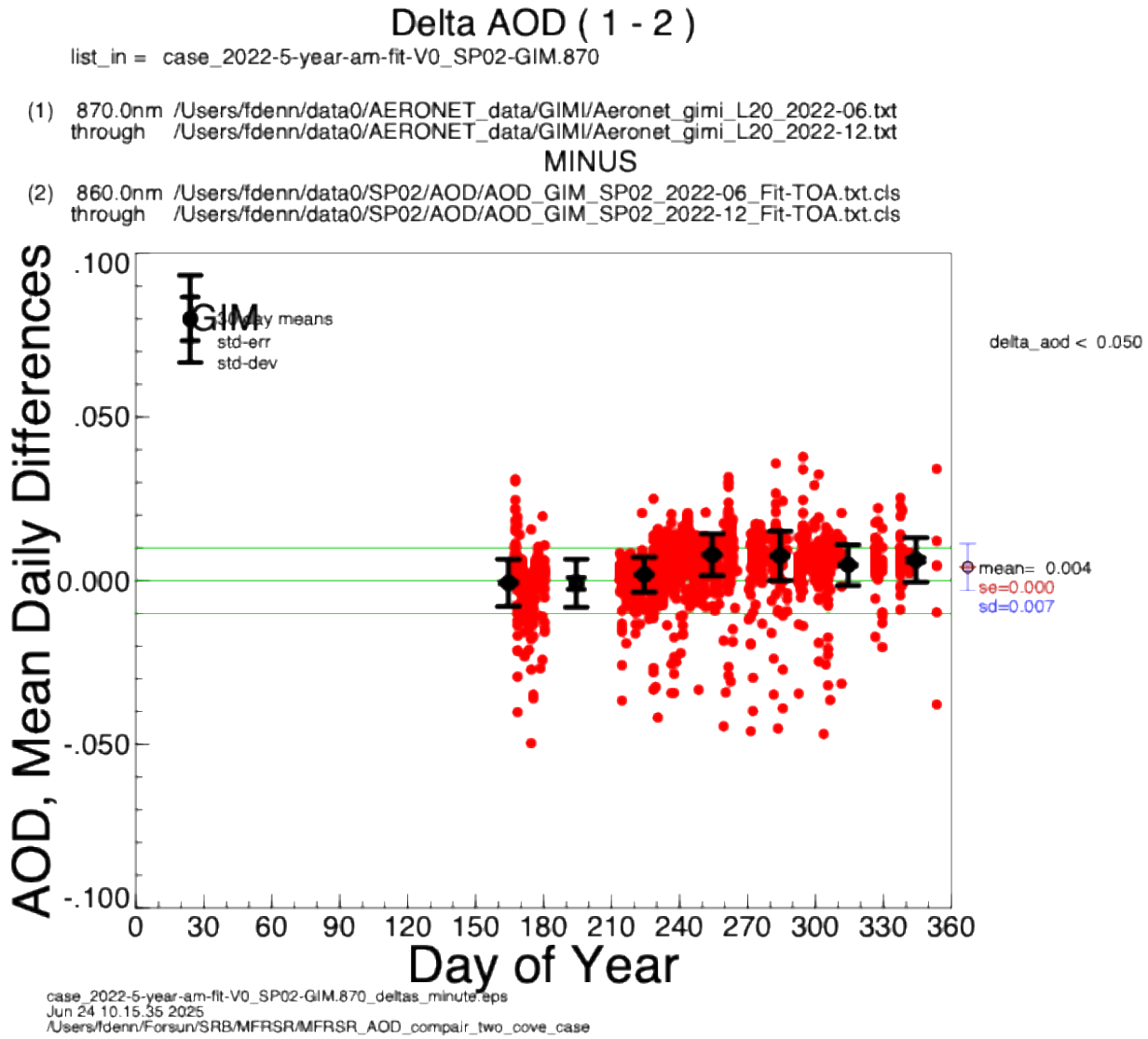


Figure 15. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2022, for the 500nm channel located at GIM.

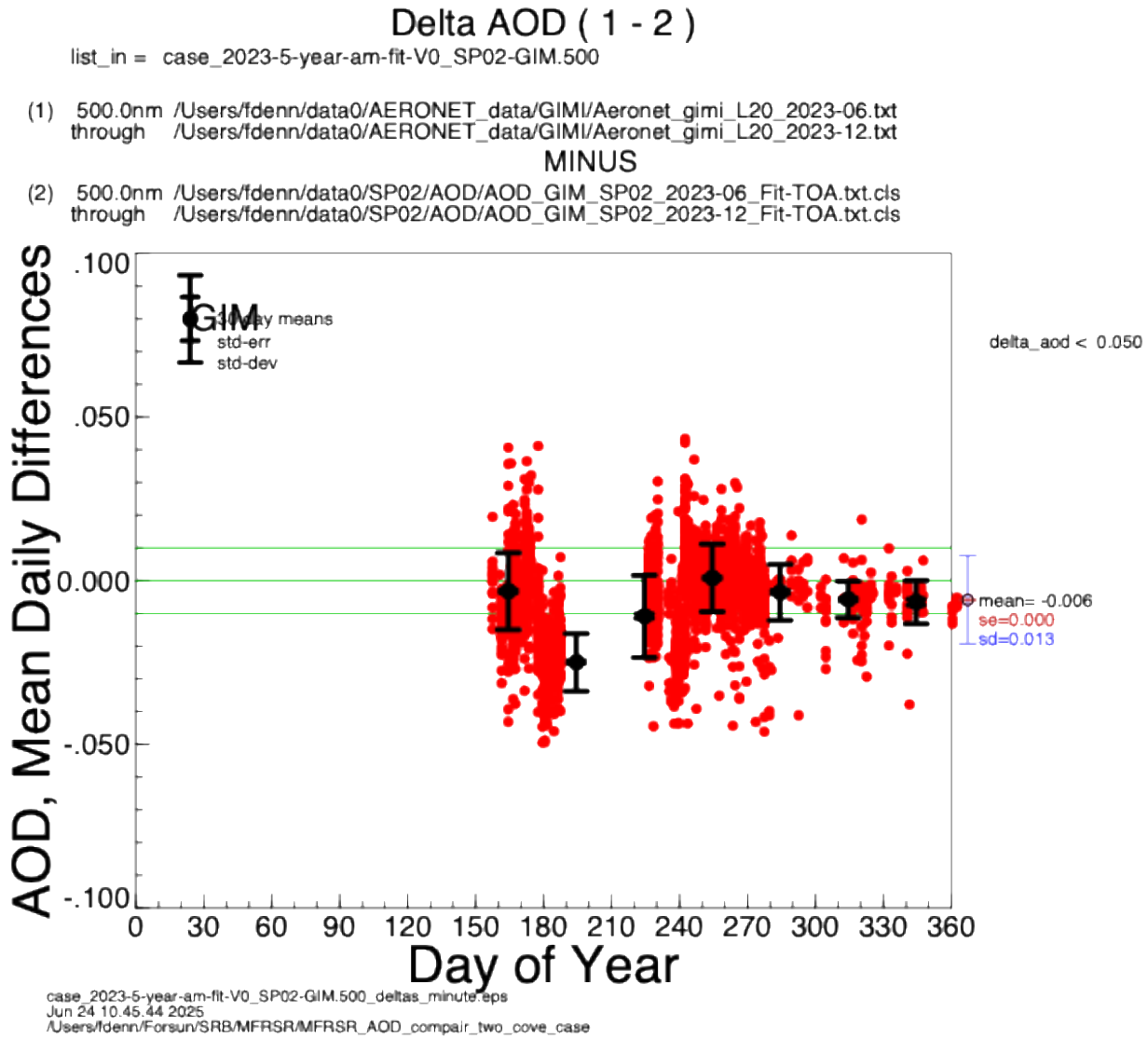


Figure 16. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2023, for the 676nm channel located at GIM.

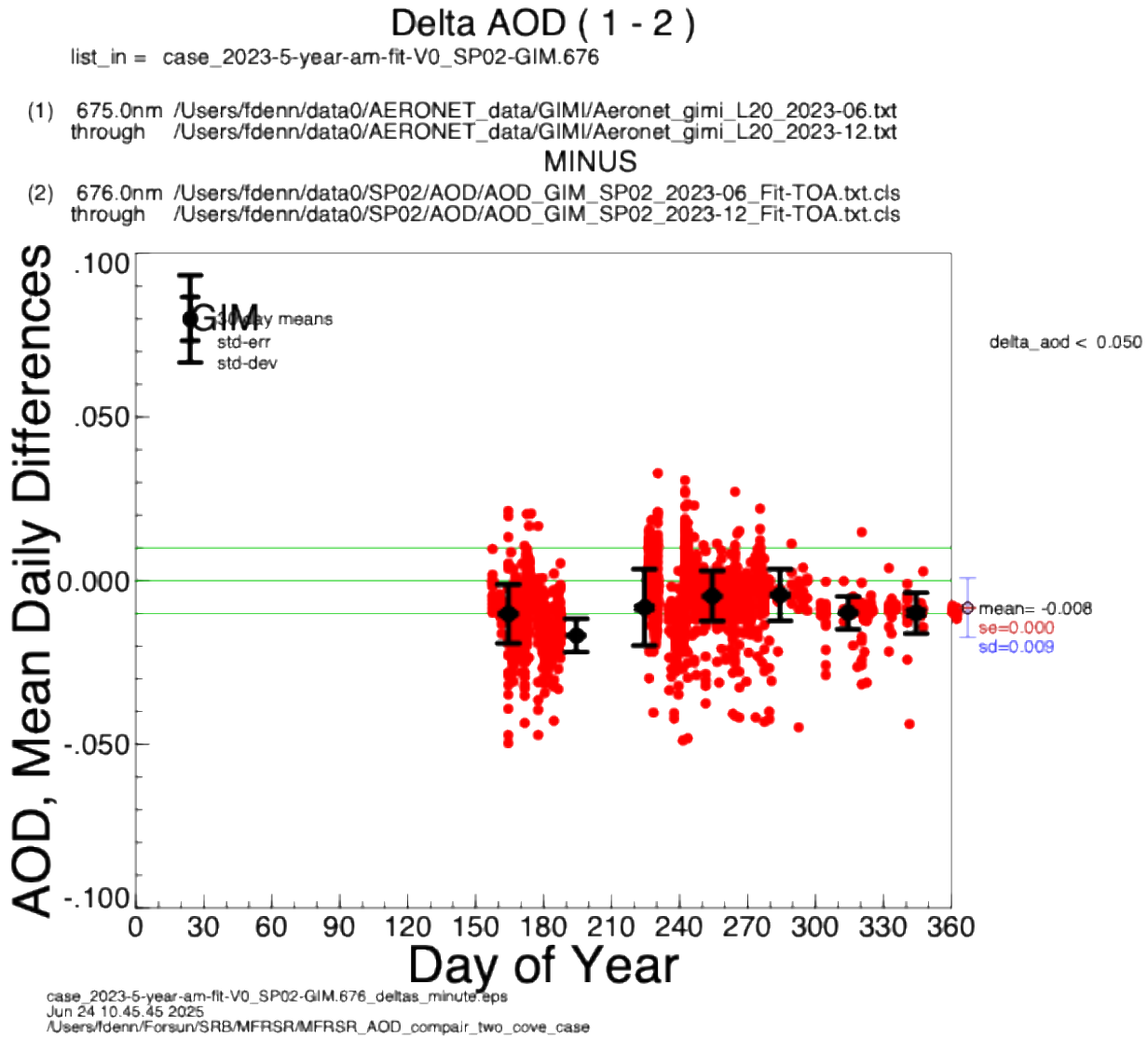


Figure 17. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2023, for the 870nm channel located at GIM.

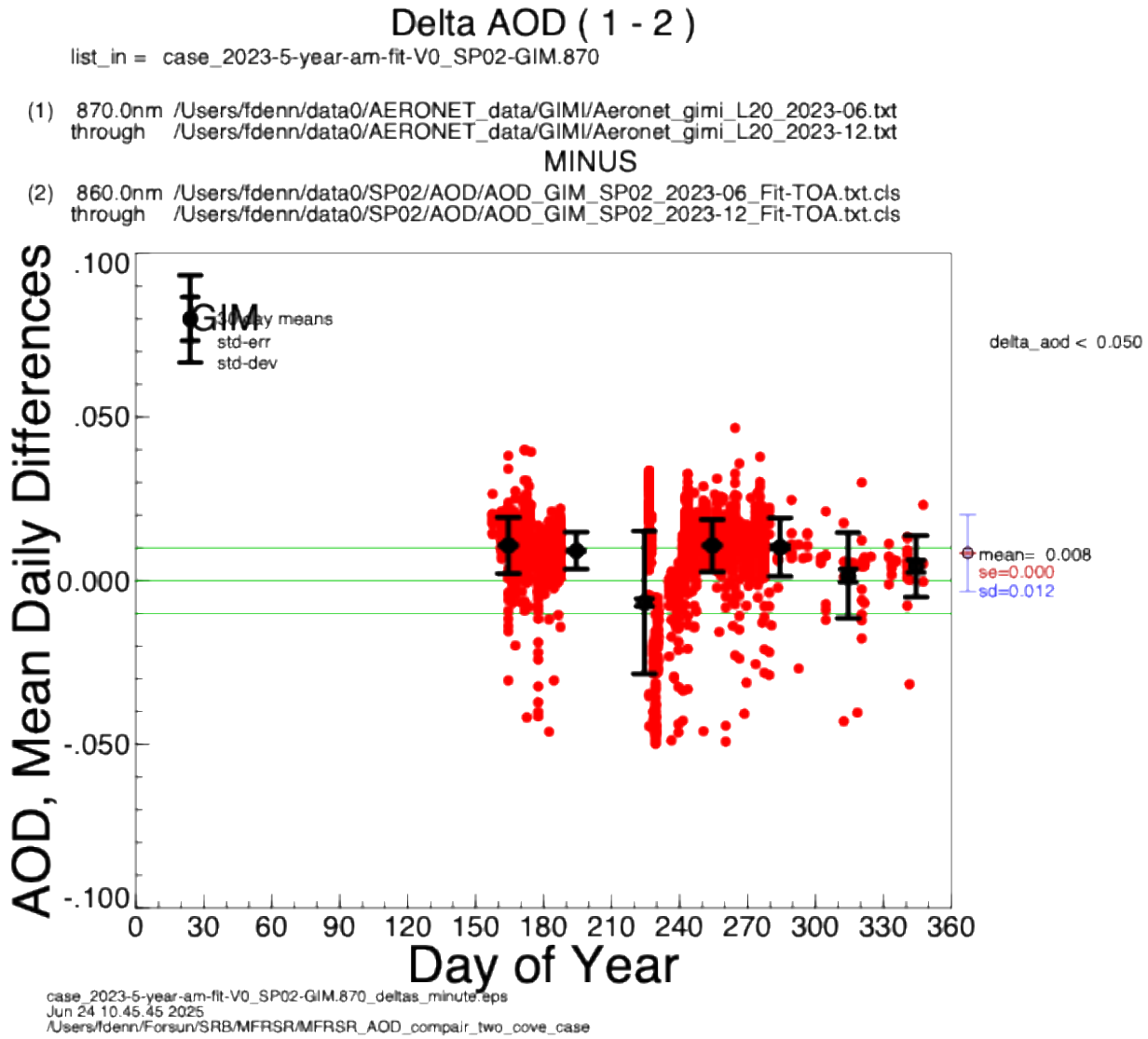


Figure 18. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2024, for the 500nm channel located at GIM.

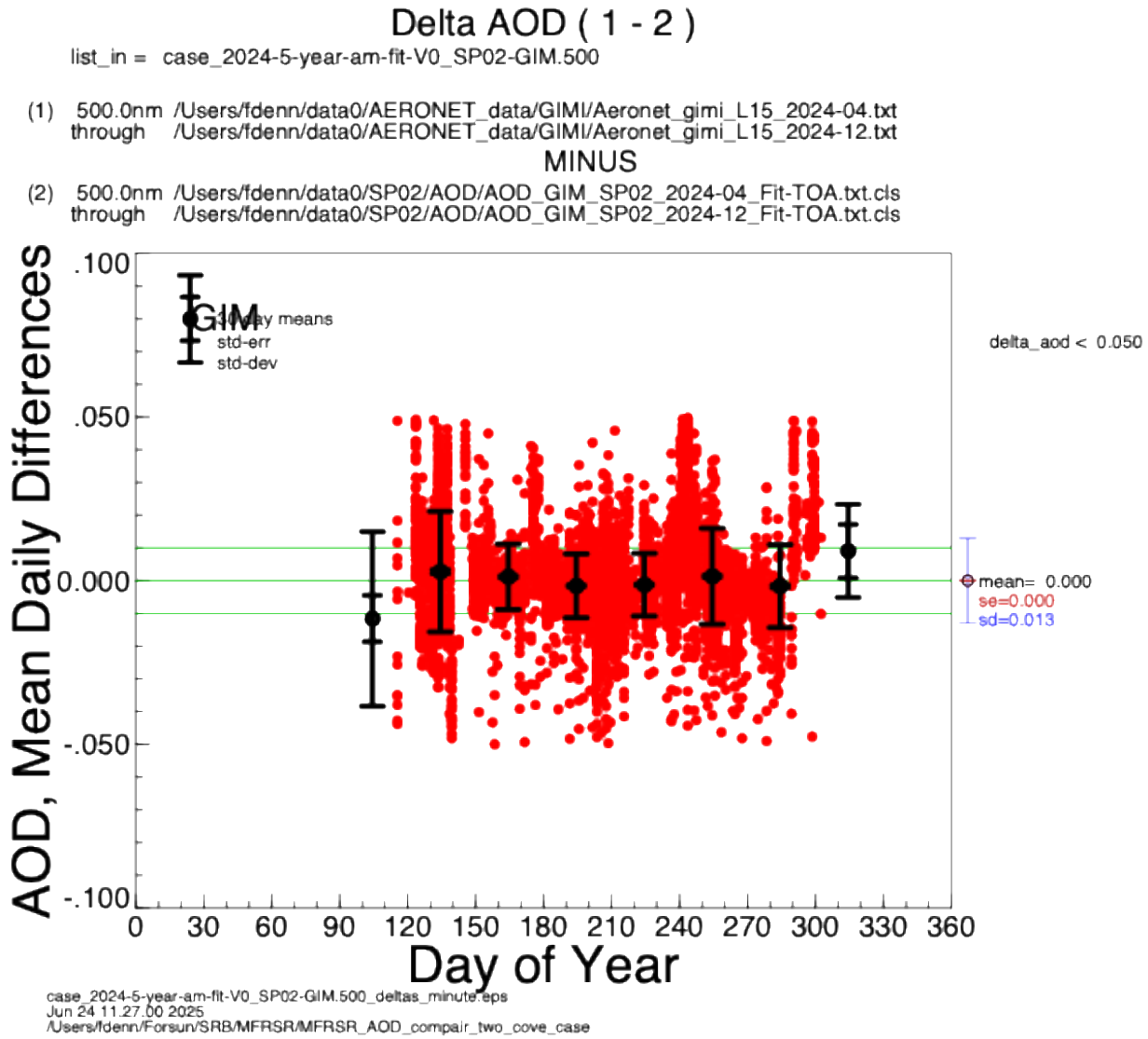


Figure 19. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2024, for the 676nm channel located at GIM.

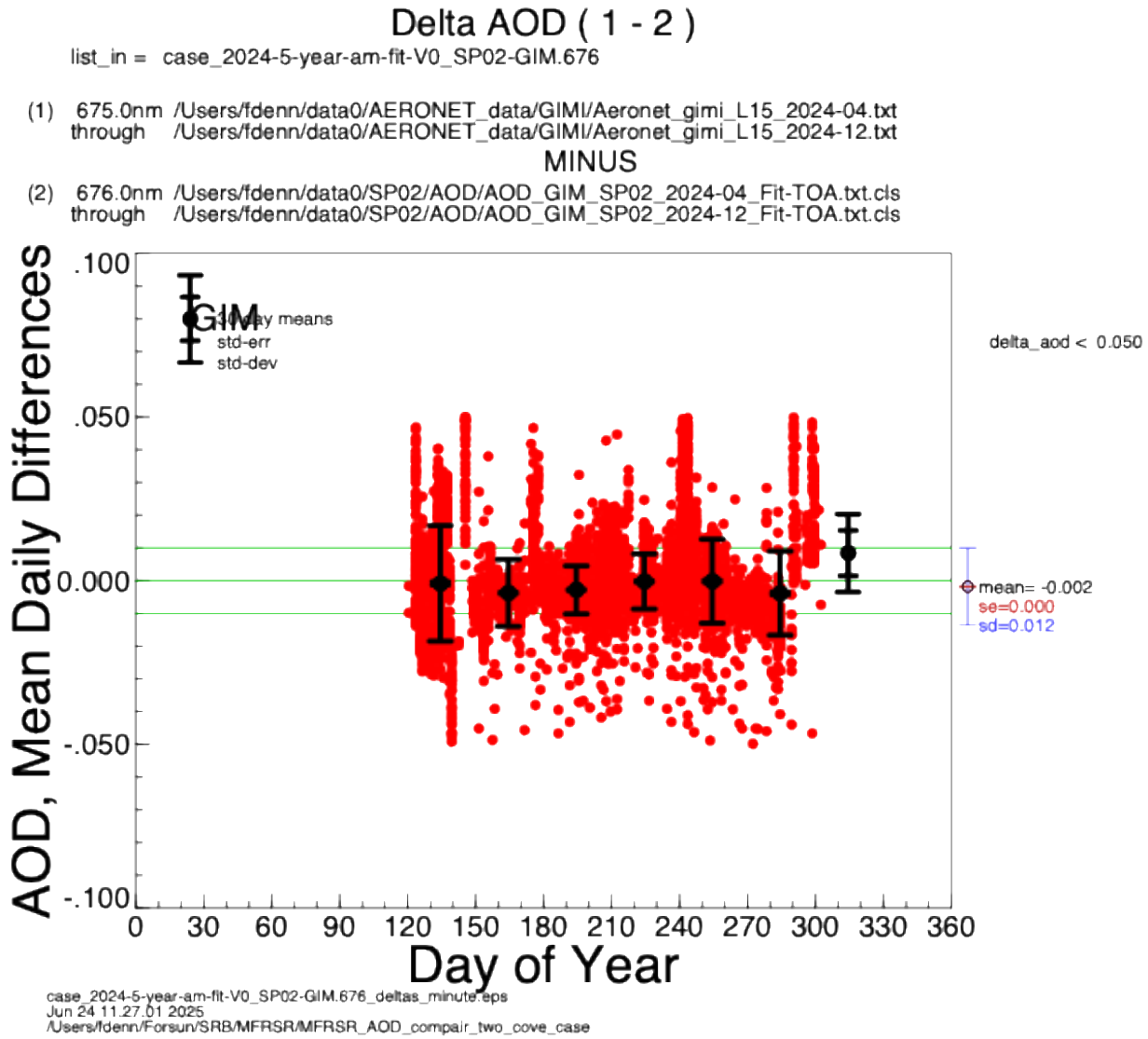
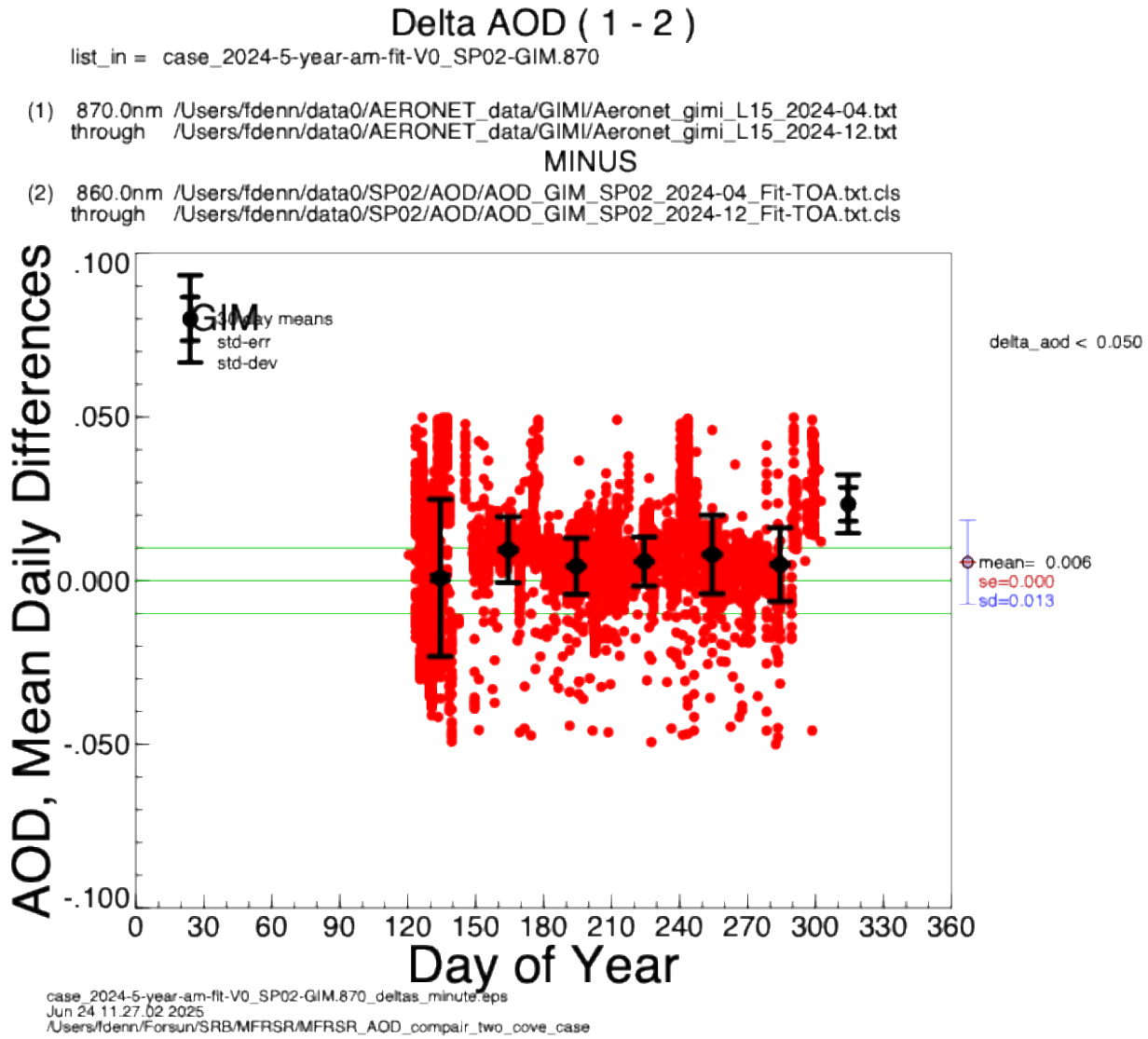


Figure 20. AOD Differences (AERONET minus SP02) using the SP02 multi-year fit V0 values. This is for year 2024, for the 870nm channel located at GIM.



The end