Software Design Document – Draft 4
CALIPSO Stratospheric Aerosol Product

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Introduction

The CALIPSO lidar signals in the stratospheric altitude are very weak so that the stratospheric aerosol was not the primary concern in the first 3 versions of output products. However, the new calibration strategy for the Version 4 data processing has improved significantly the quality of the LIDAR Level 1 (LL1) data so that now it is possible to generate a reliable stratospheric aerosol data product.

This software design document is based on the document “Design Specifications for CALIPSO Stratospheric Aerosol Product”.

This process will generate a product with equal angle grid of 5^0 in latitude and 20^0 in longitude and a uniform vertical grid of 900 meters for monthly averaged backscatter, extinction, and scattering ratio profiles.

Section 1 – The purpose of the Stratospheric Aerosol Product process

The purpose of the Stratospheric Aerosol Product process is to use the Version 4 LL1 output products to generate a monthly averaged 532 nm total backscatter, particulate backscatter, extinction, and scattering ratio profiles in equal angle grid and uniform vertical grid output products from altitude 8.3 km to 36 km. The output product contains two components; the first component will represent the background aerosols in the stratospheric and will utilize the background measurements below the layer detection threshold of CALIPSO algorithm, and the second component will incorporate aerosol layers which are detected by the level 2 feature finder. A color ratio filter will be used to remove the thin cirrus clouds for full aerosol component because the depolarization ratio will be large for the volcanic aerosols.

Section 2 – The high level entities of design

Figure 1 shows the top level of flow chart for this PGE.

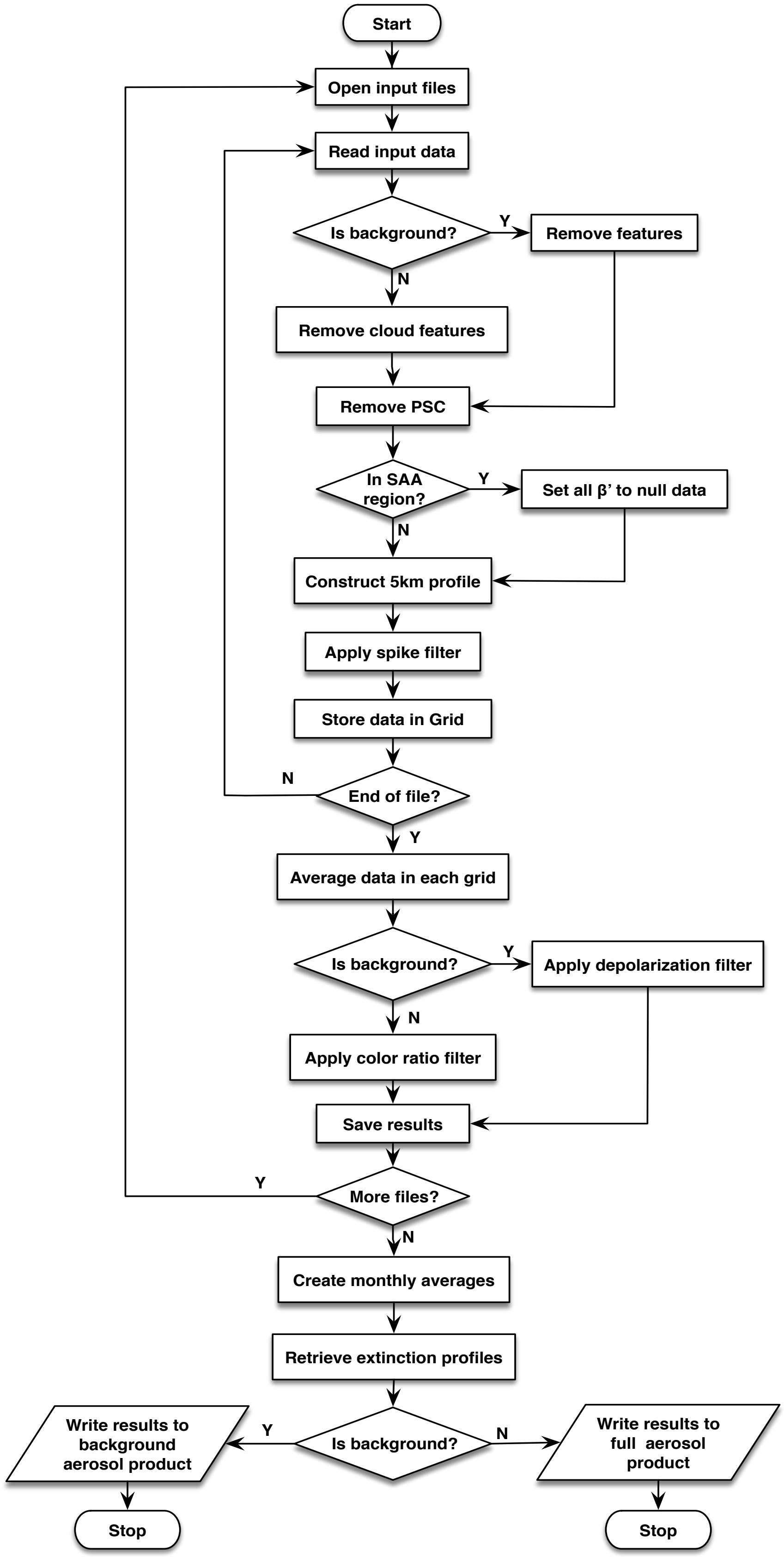

Figure 1 Stratospheric aerosol product process

The input files for this process include three products; LL1 1B files, LIDAR Level 2 (LL2) 5km Merged Layer files, and LL2 Polar Stratospheric Cloud (PSC) files. The first step of this process is to open all these three input files. A 5km Merged Layer file reports the locations of all cloud and aerosol layers (features) detected at both 5-km and single shot resolution, so that this file can be used to remove L1B backscatter data below the uppermost feature for background aerosol component, and below the uppermost cloud for the full aerosol component. The PSC file is used to remove L1B backscatter data below the uppermost polar stratospheric clouds.

The second step reads 5km data (15 profiles for L1B, 1 record for the two LL2 files) from the three input files and ensures that all the records are matched with time. For the background aerosol component, reset three backscatter coefficients values in the 15 L1B profiles to null data from the altitude of topmost feature found in the 5km Merged Layer record to the last bin and store these results to new datasets. For full aerosol component, reset three backscatter coefficients values in the 15 L1B profiles to null data (or fill data) from the altitude of topmost cloud feature found in the 5km Merged Layer record or tropopause height altitude (the higher altitude of these two altitudes) to the last bin. The next step is to remove the PSC features found in the PSC record by setting the backscatter coefficients values to null data in the 15 L1B profiles (both profiles from L1B input file and results from "remove all features" step) from the altitude of the uppermost PSC to the last bin.

The next step is to construct a 5km profile with the 15 L1B profiles by averaging the backscatter data in these 15 profiles. The latitude and longitude and time assigned to these averaged profiles will correspond to middle values (i.e., the 8th of the sequence of 15 values). Apart from the 3 backscatter coefficient profiles, the data required for later processes are also averaged; see Table 1 in Section 4 -Input and Output records.

After the 5km profile is constructed, a spike filter is applied to remove outliers that can cause strong biases at high latitude and high altitude. The spike filter design is discussed in section 3.7.

Based on the latitude and longitude value, this profile is assigned to the corresponding grid cell. The grids are constructed with 5°-latitude (85°N to 85°S), 20°-longitude (-180°E to 180°W), and 900-meter altitude bins (8.3 to 36 km).

The process repeats all the above steps for every 5km profile until all the profiles in one L1B (or LL2) file are processed. After processing the whole granule of data, average all the data in each grid points. The final step for one granule is to apply either depolarization filter to background aerosol data or color ratio filter to full aerosol data for each grid. These are described in sections 3.9 and 3.10, respectively.

The process repeats all the above steps until all input files have been processed. After one-month data are processed, these data are averaged to create one-month averaged gridded profiles. The final step is to pass these averaged gridded profiles to HERA module to obtain the final results and these results are written to final stratospheric aerosol output products.

Section 3 – The low level entities of design

This process can be broken into 13 steps. The following sections describe these steps.

3.1 Get Input files

The first step is getting the input files that include L1B, LL2 5km Merged Layer, and LL2 PSC files. Since this process requires one-month data, it requires reading data from multiple input files. The lists of these three types input files within one month are created by CAPS.
The PGE loops through all these input files to process the data. The PGE searches from the lists to find three types input files with matching times based on the L1B file. If it can find all the three files, it continues all the steps. If it cannot find all the three files, the PGE will stop the process and exit with an error status.

A LL2 5km Merged Layer file contains data from either one nighttime or one daytime granule that is derived from a corresponding L1B file. The time stamps in these two filenames should match exactly; for example, if the L1B filename is CAL_LID_L1-Standard-V4-10.2016-01-06T04-05-59ZN.hdf, the LL2 5km Merged Layer filename will be CAL_LID_L2_05kmMLay-Standard-V4-10.2016-01-06T04-05-59ZN.hdf). However, a PSC file contains all the nighttime orbits data in one day, and the time in this filename (for example, CAL_LID_L2_PSCMask-Prov-V1-01.2016-01-06T00-00-00Z.hdf) is different from the L1B file. When matching the L1B and PSC files, it compares the date portion only (yyyy-mm-dd).

After matching these three files, these files are open and started reading data. Each time a 5-km data are read and processed from step 3.2 to step 3.8 (filter and grid). The results are stored into memory for using in the steps after 3.8. This procedure loops through all the data in these files until they are reached at the end of files, then these files are closed. The procedure continues to next files if there are still files available, otherwise, continue to stage 2 (step 3.9).

Note that this PGE requires three different types files that from three different PGEs, as well as a known issue in CAPS for LL2 processing to select wrong input L1B file, during the PGE reading all the input filenames from these three lists, it will confirm the actual data time range in the file is matched with the time in the filename. It also sorts the filenames with the times in these filenames in an ascending order such that the PGE can match files correctly and in a correct order. There is also an option to verify all the input files. The verification process checks the time range of actual data is matched with the filename, all file types have same number of days' data files or same number of orbits' data files, and any duplicated data files. This option also synchronizes all the types of input files with removing any unmatched input files. If any mismatch file is found, the PGE will stop the whole process and have an option to write the new lists to output files.

The Figure 2 shows the flow chart for getting input files, Figure 3 shows the flow chart for verifying the input files, and Figure 4 shows the flow chart for synchronizing different type files.

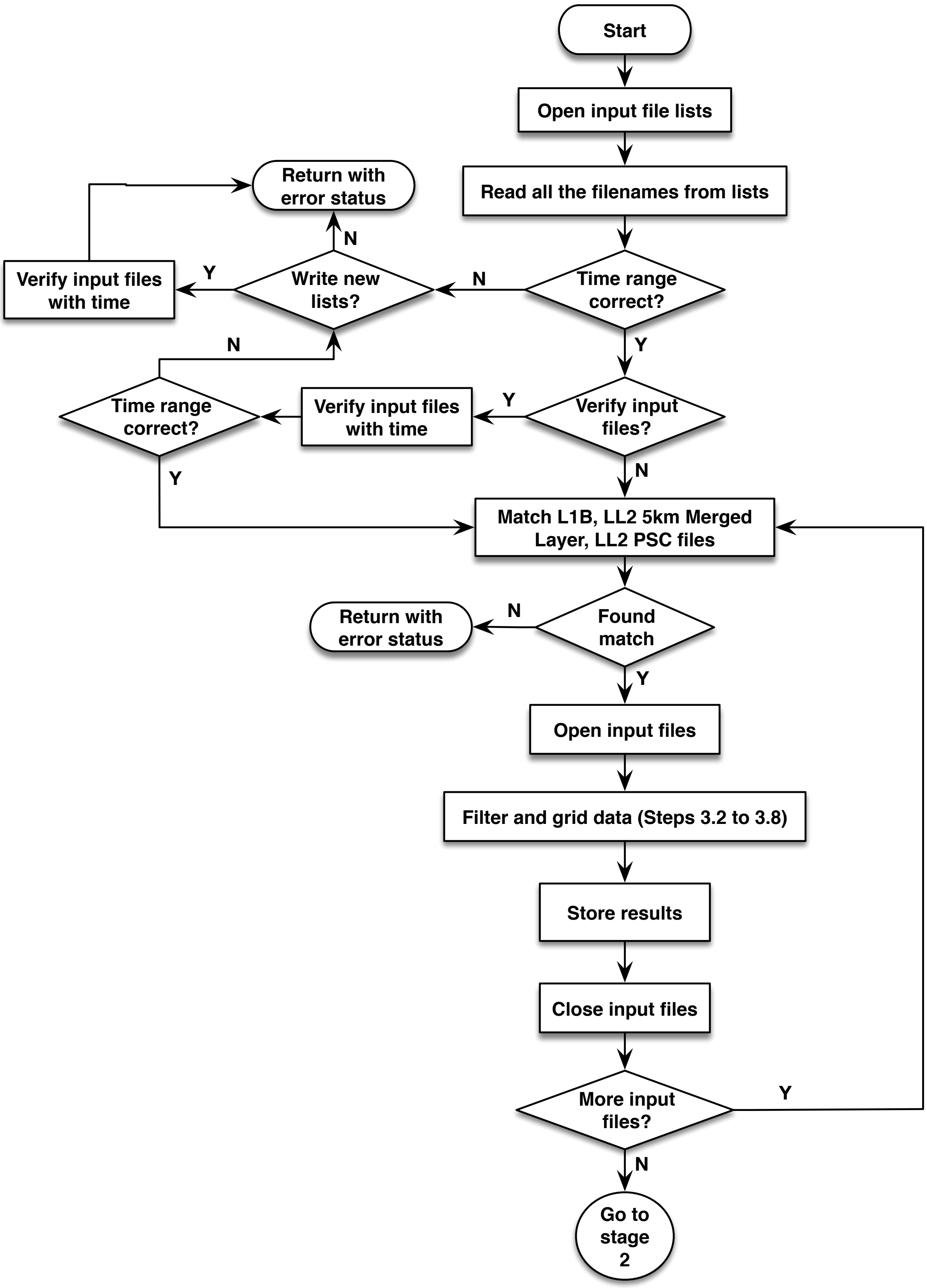

Figure 2 Flow chart for the input step

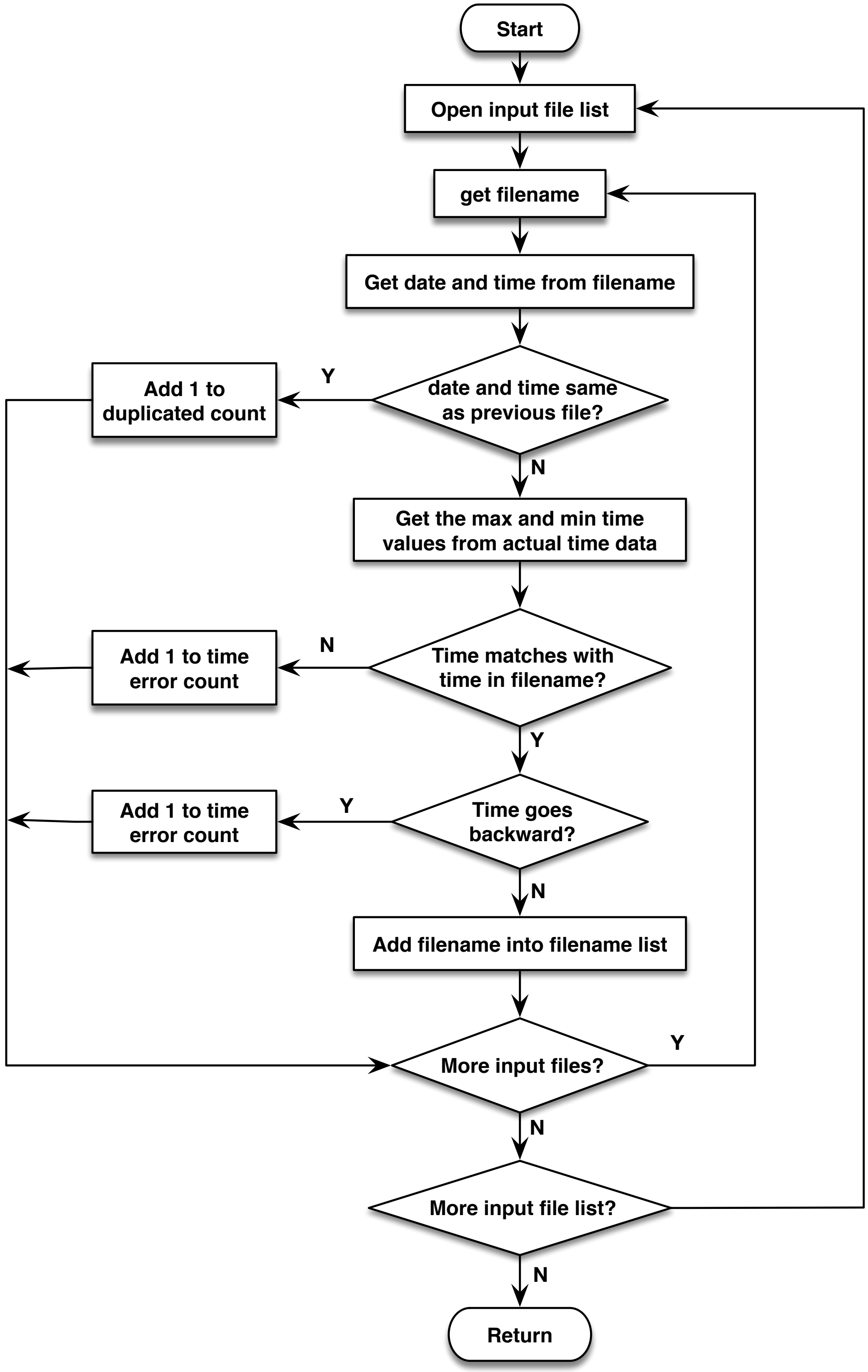

Figure 3 Flow chart for verifying input files

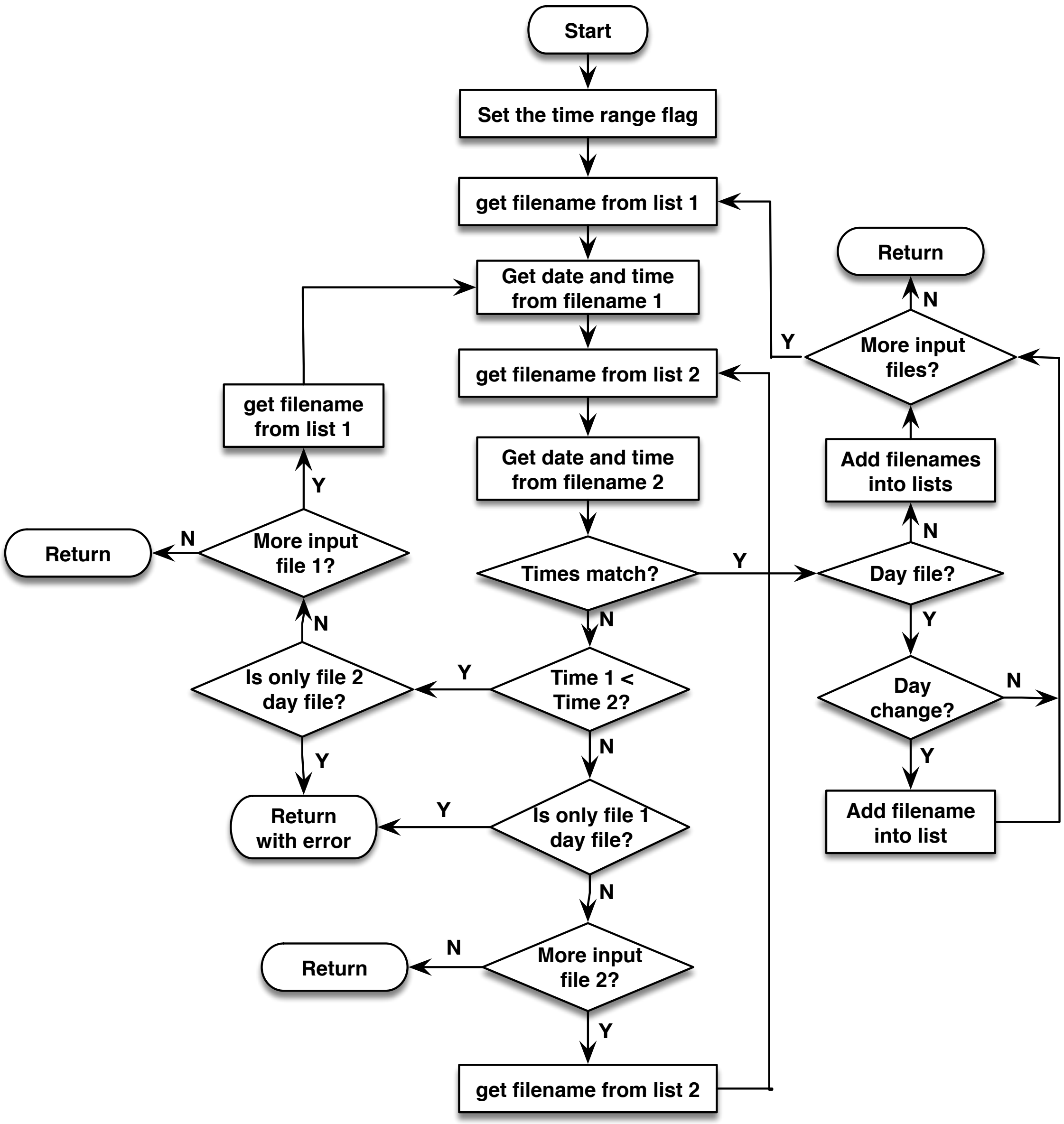

Figure 4 Flow chart for synchronizing different type files

3.2 Remove features (only for background aerosol component)

This step is applied only to background aerosol component. The task is to remove all the features found by LL2 layer detection algorithm, hence it requires the LL2 output product that contains all the feature information between 8.3 km to 30 km. The new 5km Merged Layer file contains both cloud and aerosol features so it can be used to remove all the features found.

Each record in the 5km Merged Layer file contains 5km horizontal resolution data. The required datasets include Profile_Time, Number_Layers_Found, Layer_Top_Altitude, Tropopause_Height and Lidar_Data_Altitudes. The Profile_Time (PTML) is used to match the record in L1B file. After the L1B is open, the whole Profile_Time (PT1B) dataset is read. The procedure loops through the PT1B array to match the PTML. If a match is found, the record number in the L1B file is the 8^{th} single shot profile for this 5km record from the 5km Merged Layer file. The procedure read the 15 single-shot profiles that are from seven before the located record number to seven after the located record number from the L1B file. However if a match is not found, something is wrong in these input files, exit the procedure.

After a 5km record is found, the Number_Layers_Found is used to determine if any features are found in this 5km data. If it is not equal to 0, the Layer_Top_Altitude is used to determine the altitude of the topmost feature, and the Lidar_Data_Altitudes array is used to locate the altitude index of the topmost feature.

Since the output data for the stratospheric aerosol product are included only in the stratospheric region, all the attenuated backscatter coefficients are set to null data below the top of tropospheric region. Hence, the altitude used to remove data is the higher altitude between the uppermost feature altitude and the tropopause height altitude.

After finding the location of the altitude, the attenuated backscatter coefficients for the three channels are set to null data from the index of this altitude to the last index (582). Note that this setting is required to apply to all the 15 L1B profiles that constructed this LL2 5km profile. The results are stored into new datasets that are used for the background aerosol component. The original datasets are used for the full aerosol component.

This procedure is continued until all the data in the LL2 file has been processed. If there are some L1B single-shot profiles that are not processed because they do not match any of the LL2 data, set all the attenuated backscatter coefficient values in these L1B single-shot profiles to null data. Note that this can happen at the start of the L1B granule, end of the L1B granule, as well as randomly within the L1B granule. The Figure 5 shows the flow chart for removing all the features from L1B attenuated backscatter coefficients.

The value of the null data is set to indicate the data are not going to be used in this process. This value will be set to a large negative value, such as -1.0E+35, to differentiate with fill data.

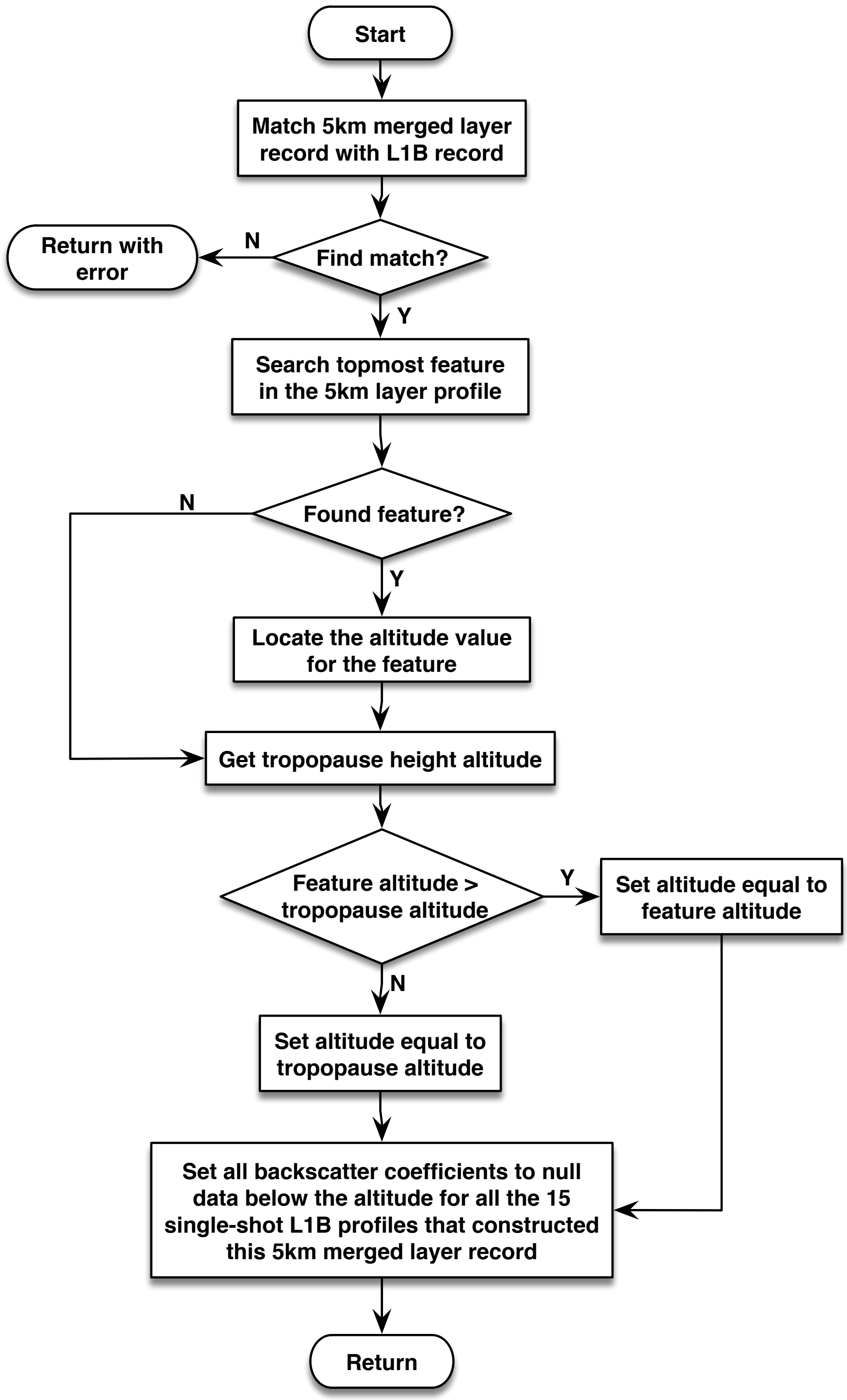

Figure 5 Flow chart for using LL2 5km Merged Layer file to remove features

3.3 Remove cloud features (only for full aerosol component)

This step is applied only to full aerosol component. The task is to remove all the cloud features found by LL2 layer detection algorithm in the stratospheric region. This step is similar with the 3.2 except this step only removes cloud features.

The flow chart for removing cloud features for full aerosol component is same as Figure 5 except the "Found feature" is changed to "Found cloud feature". The same function in step 3.2 can be used for this step by setting only cloud features are removed.

3.4 Remove PSC features (for both output components)

This step is to remove all the PSC features from the L1B attenuated backscatter coefficients**.** The input file is the LL2 PSCMask output product. One PSCMask file contains data from all nighttime orbit segments from a single day reported on a 5 km horizontal by 180-meter veridical grid. The required data from this file include Profile_Time, PSC_Feature_Mask, and Altitude. Again, the Profile_Time (PTPSC) is used to match the record in L1B file. Since the range of one PSCMask file is one day, firstly, the value of the PTPSC is verified that it is within the time range of the L1B file. If the PTPSC is within the current L1B input file, same as in Section 3.2, it loops through the array of PT1B to locate the record number in L1B that matched the time. Once a match is found, again this L1B record number is the 8^{th} profile of the 15 profiles that created this 5km PSC profile. These 15 L1B single-shot profiles are read from the L1B file. Again, if a match is not found, return to calling function with error.

After a match is found, the PSC_Feature_Mask is used to determine the PSC presented in this 5km profile. The PSC mask values are three digit numbers, $N_1N_2N_3$ where the first digit N_1 indicates PSC detected or not. When this digit is greater than 0, a PSC is detected in this 5km profile. If a PSC was detected, the Altitude SDS dataset is used to locate the index that corresponding the altitude value of this PSC feature.

After the index of the altitude is located, the attenuated backscatter coefficients for the three channels (both original and feature removed) are set to null data from the index of this altitude to the last index (582). This procedure continues to process all the data in the LL2 PSC file.

The Figure 6 shows the flow chart of removing PSC features.

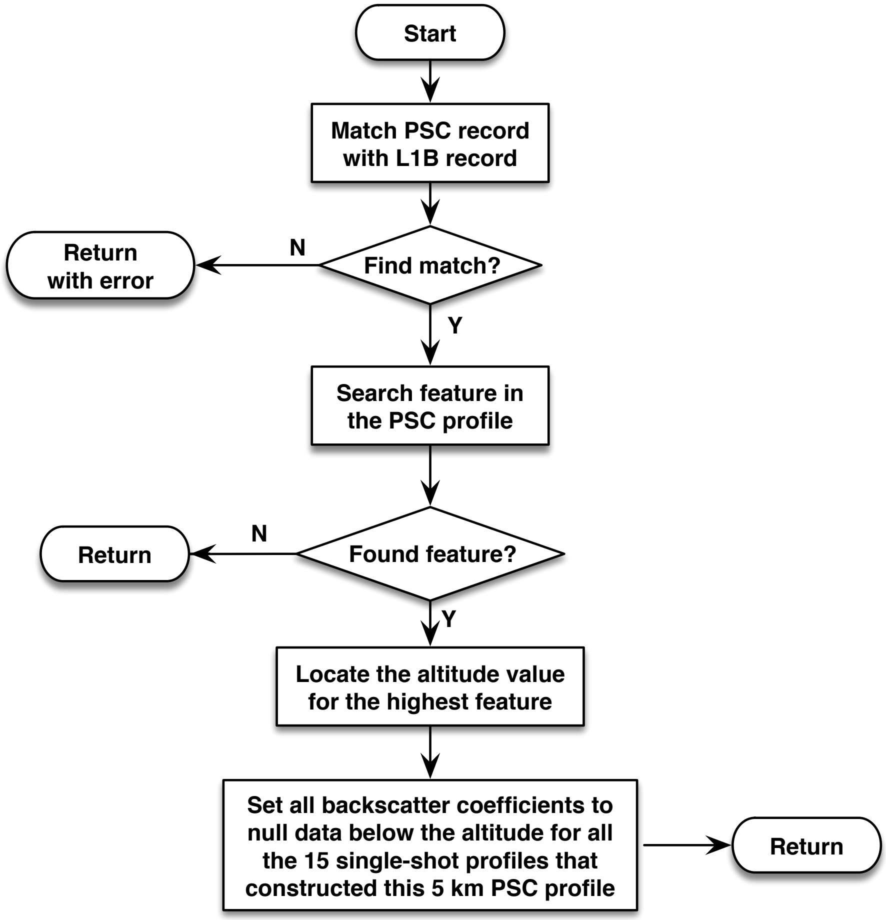

Figure 6 Flow chart for using LL2 PSCMask file to remove PSC features

3.5 Remove data within SAA region

This step checks any 15 L1B single-shot profiles within the South Atlantic Anomaly (SAA) region which is defined as latitude between 50^0 S to 5^0 N and longitude between 90^0 W to 30^0 E. If so, set all the attenuated backscatter coefficients in this profile to null data at all altitude bins.

Note that the SAA region defined as above may be too broad. Based on the nighttime RMS baseline values, the SAA region is defined as the followings:

SAA_lat = [-10;   0;   6;   7;   2; -10; -18; -25; -29; -31; -34; -47; -47; -39; -27; -10];
SAA_lon = [-94; -74; -50; -30; -18;   0; 20;   26; 20;   4;   -8; -40; -71; -84; -91; -94];

The algorithm to check the profile within the SAA region is based on the following link

https://www.codeproject.com/tips/84226/is-a-point-inside-a-polygon

The Figure 7 shows the region of SAA on a map.

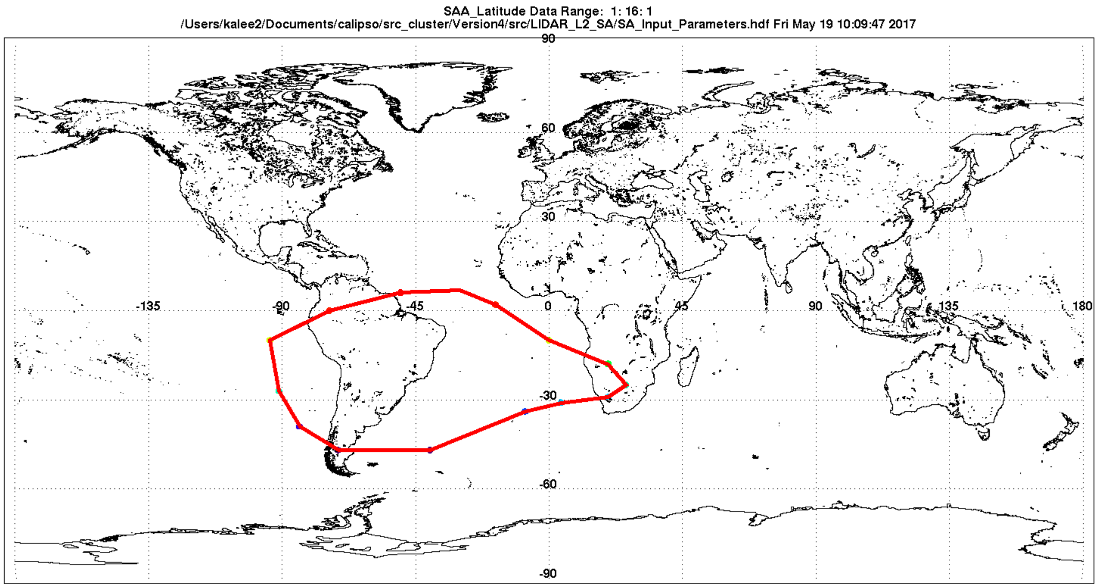

Figure 7 SAA region

3.6 Construct 5km profile

After filtering out the features (for background aerosol component) or cloud features (for full aerosol component) from LL2 5km Merged Layer files, PSC features from PSCMask files, and noisy data from SAA region from the 15 L1B single-shot profiles, the next step is to construct a 5km profile with these 15 profiles.

The attenuated backscatter coefficients for the three channels (both background and full aerosol components) are averaged within the 15 L1B single-shot profiles from first index (0) to the last index (582) of these profiles to generate one 5km profile. All the null data and bad data (fill data) are excluded for the averaging. The location and time of this 5km averaged profile use the mid-point latitude, longitude, and time.

In addition to the attenuated backscatter coefficients, the molecular number density, ozone number density, temperature, and pressure must also be averaged for subsequent processing. Since these meteorological data are stored in the L1B file as subsets (33 values) of the full altitude array (583 values), before averaging these data, these data are required to interpolate back to full altitude array. The molecular number density and pressure use the log values to do interpolation. After construct the 5km profiles of the molecular number density and ozone number density, calculate the molecular backscatter (β_m) and the ozone absorption coefficients (α_{O3}) from the molecular number density and ozone number density, respectively.

Also construct 5km averages for the tropopause altitudes, calibration coefficients, laser energy, amplified gain, noise scale factor (NSF), polarization gain ratio (PGR), and RMS baseline measurements. These values are required for spike filtering of the large and small outliers within this 5km averaged profile. Note that when averaging RMS values, sum the square of these individual values and then take the square root of the sum.

The Figure 8 shows the flow chart of construction of 5km profile.

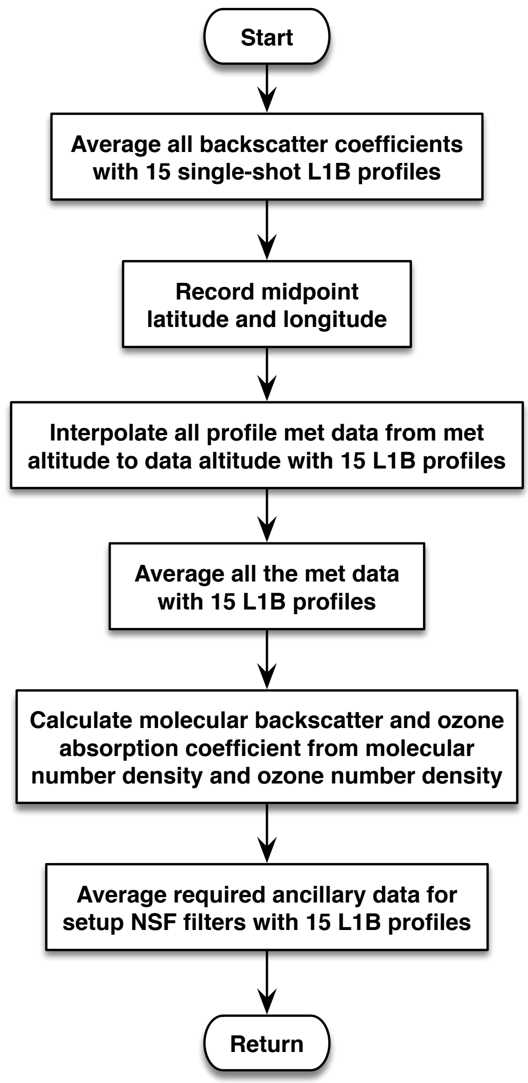

Figure 8 Flow chart for construction of 5km profile with 15 L1B single-shot profiles

3.7 Apply spike filter

After a 5km averaged profile is constructed, apply a spike filter to remove the large and small outliers that can cause strong biases at high latitudes and high altitudes. In the “Design Specifications for CALIPSO Stratospheric Aerosol Product” document, it suggests to use the same spike filter in 532 nm nighttime calibration coefficient harvester. As mentioned in Section

2, this algorithm may not be appropriate for this process. A new spike filter is suggested to use instead.

The new spike filter is going to use is described in section 2c " Establishing an initial threshold level" in "Fully Automated Detection of Cloud and Aerosol Layers in the CALIPSO Lidar Measurements", 2009. The range-dependent threshold is defined as the following equation:

$$\beta'_T(r) = \beta'_{GMAO}(r) + C_0\beta'_{BKG}(r) + C_1\sqrt{\beta'_{GMAO}(r_0)\beta'_{GMAO}(r)}$$

Where β'_{GMAO} is range-dependent model molecular attenuated backscatter coefficients that input from meteorology data, $\beta'_{BK\Gamma}$ is converted from the background noise measurements, the C_0 and C_1 are empirical values, and the r_0 is the range at the top of the profile.

The β'_{GMAO} is calculated based on the following equationn:

$$\beta'_{GMAO}(r) = \beta_{532,m}(r)\, T^2_{532,m}(r)\, T^2_{532,O}(r)$$

where $\beta_{532,m}$ is 532 nm molecular backscatter, $T^2_{532,m}$ is 532 nm molecular two-way transmittance and $T^2_{532,O}$ is 532 nm ozone two-way transmittance. These are available from the GMAO model data.

The range-dependent β'_{BKG} is converted from the range-invariant background noise measurements, P_{BKG}, with unit counts. These P_{BKG} is converted to units of attenuated backscatter coefficients, and an array of $\beta'_{BKG}(r)$ values is generated by scaling the converted P_{BKG} value according to the spatial averaging strategies employed in various altitude regimes.

The C_0 and C_1 are independent empirically determined scaling constants used to balance the contributions of the various noise components. Higher values are appropriate for more conservative search strategies that minimize the occurrence of false positives but simultaneously risk increasing the number of false negatives. These values are depending on the detection sensitivity desired and the amount of horizontal profile averaging done.

The $\beta'_T(r)$ can be transformed into the attenuated scattering ratio regime by dividing by $\beta'_{GMAO}(r)$, so that the attenuated scattering ratio threshold is expressed as the following equation:

$$R'_T(r) = \frac{\beta'_T(r)}{\beta'_{GMAO}(r)}$$

or

$$R'_T = 1 + C_0\frac{\beta'_{BKG}(r)}{\beta'_{GMAO}(r)} + C_1\sqrt{\frac{\beta'_{GMAO}(r_0)}{\beta'_{GMAO}(r)}}$$

Either the attenuated backscatter coefficients or attenuated scattering ratio threshold will be used for the spike filter to remove the large and small outliers.

3.8 Grid the data for each granule

The proposed stratospheric aerosol product will be monthly averaged gridded product in pre-assigned latitude, longitude, and altitude bins. For the first version of this product, these bins are set with 5^0 in latitude (from 85^0 N to 85^0 S), 20^0 in longitude (form 180^0 W to 180^0 E), and 900-meter altitude.

The considered range of the altitudes is from 36 km to 8.2 km that includes the altitude region 5 (33 X 300-meter bins), region 4 (55 X180-meter bins), and region 3 (200 X 60-meter bins). Note that the actual bin sizes depend on the off-nadir angle and they are not exactly equal to integer multiples of 30 meters. To avoid mixing two region resolutions, the altitude bins for the stratospheric aerosol product are constructed with 900-meter bins, set as follows:

1. **Region 5: 7 X (3 X 300-m bin) = 7 (from 30.2 km to 36.2 km; bin 33 to 13)**
2. **Region 4: 11 X (5 X 180-m bin) = 11 (from 20.3 km to 30.0 km; bin 88 to 34)**
3. **Region 3: 13 X (15 X 60-m bin) = 13 (from 8.5 km to 20.2 km; bin 283 to 89)**

Hence, the grids are constructed with 34 (5^0 in latitude) X 18 (20^0 in longitude) X 31 (900-m altitude).

Based on the mid-point latitude and longitude values, the 5 km averaged profile are assigned to the corresponding grid.

After all the 5km averaged profiles within a single granule are assigned to the corresponding grids, average all the data within each grid to form grid profiles. Then use the grid-averaged temperature and pressure values in each grid to calculate the potential temperatures.

Figure 9 shows the flow chart for constructing gridded data for one single granule.

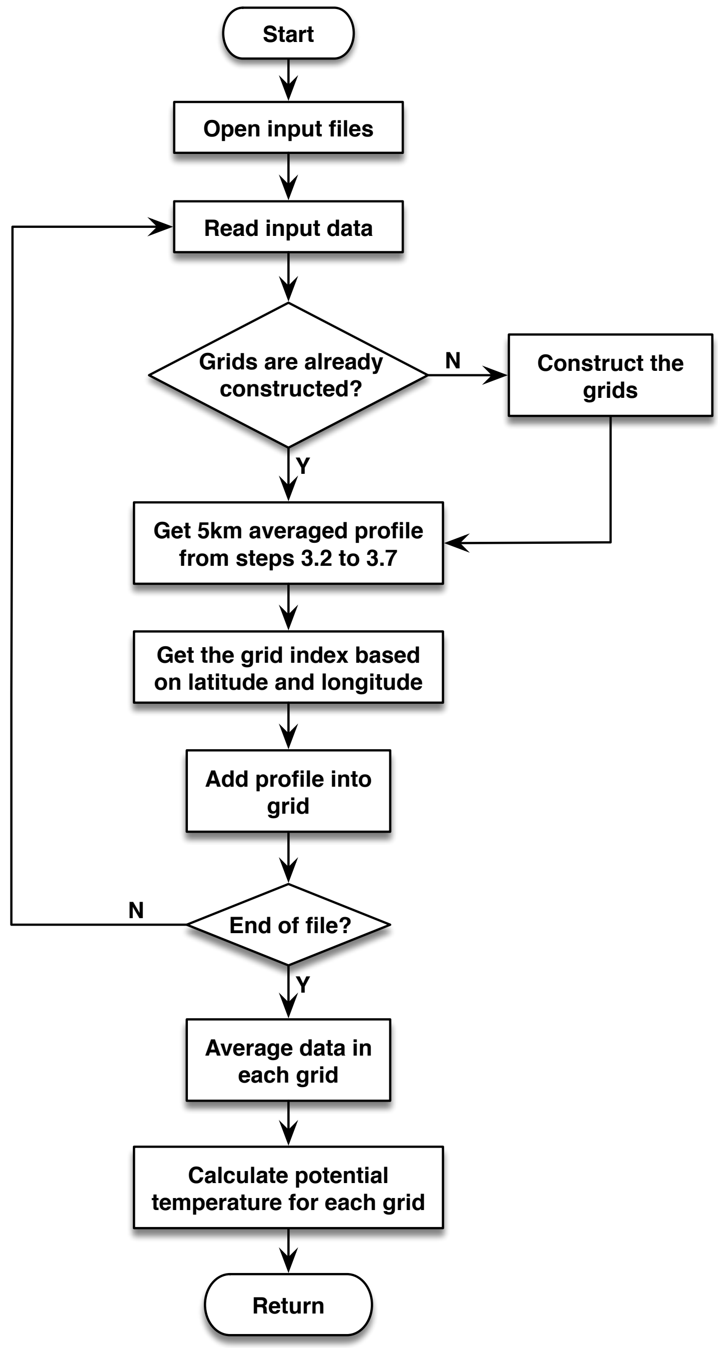

Figure 9 Flow chart for construction grid data for one granule

3.9 Apply depolarization filter (for background aerosol component)

This step is only applied to the background aerosol component. After all gridded profiles are created, these profiles are processed through the depolarization ratio (DR) filter to remove any previously undetected thin cirrus clouds which may be present near the tropopause height. Since these undetected thin cirrus clouds are near the tropopause height, the filter is applied only to range bins below 25 km. DR is calculated with 532 nm total attenuated backscatter coefficients and 532 nm perpendicular attenuated backscatter coefficients with the following equation

$$DR(z) = \frac{\beta_p'(z)}{\beta_t'(z) - \beta_p'(z)}$$

Where β'_t is 532 nm total attenuated backscatter coefficients and β'_p is 532 nm perpendicular attenuated backscatter coefficient. Set all the attenuated backscatter coefficients with DR greater than threshold value (0.05) to null data. Figure 10 shows the flow chart for applying DR filter to background aerosol component data.

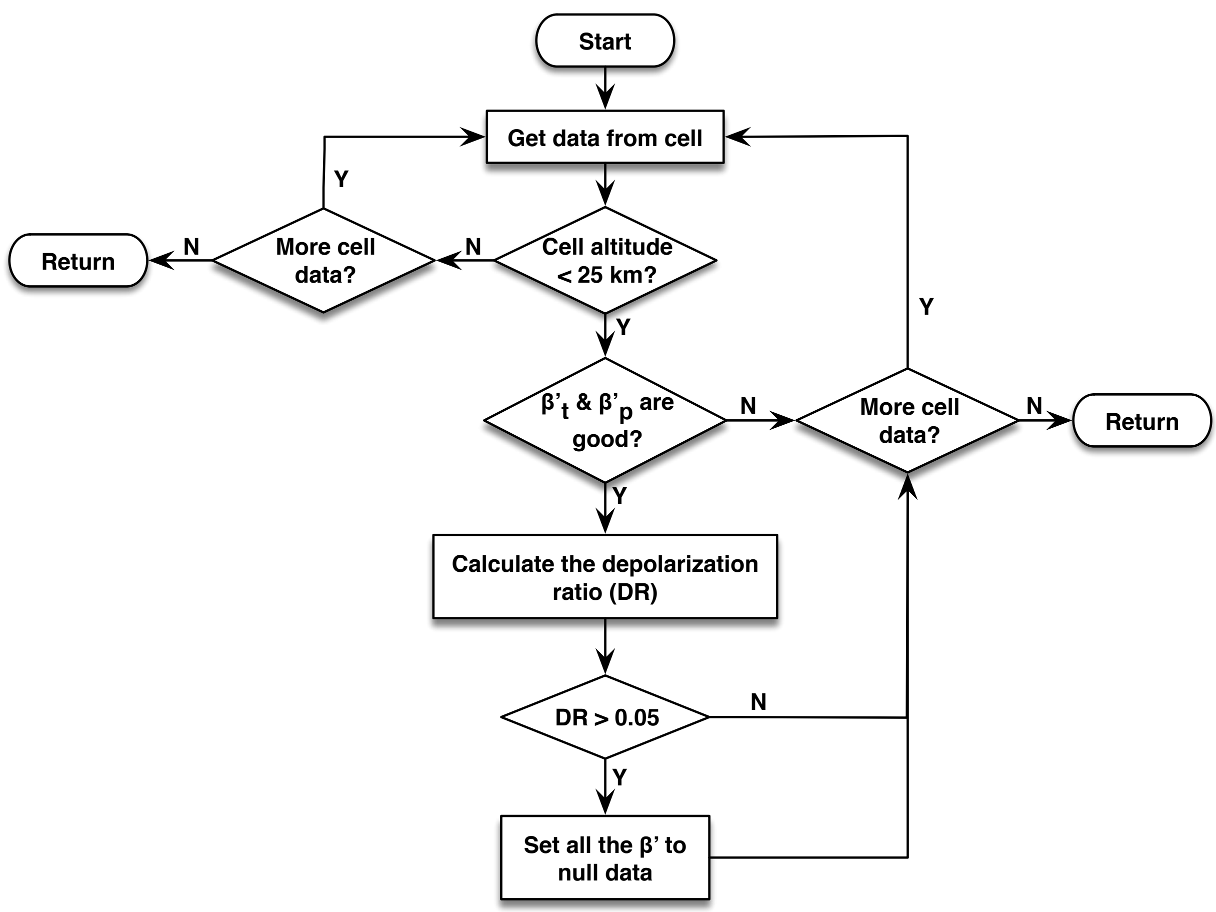

Figure 10 Flow chart for applying R filter to background aerosol component data

3.10 Apply color ratio filter (for full aerosol component)

This step is only applied to the full aerosol component. After all gridded profiles are created, these profiles are processed through the color ratio (CR) filter to remove the clouds from the stratospheric part of the data yet retaining the volcanic or smoke layers. Since these aerosol layers often have high DR, it is impossible to use DR filter to remove these layer. However, with CR filter with threshold value as 0.5, the ash layers can be retained and the clouds can be removed below 25 km. Therefore, this CR filter is also applied to only cell data below 25 km. The CR is calculated with 532 nm total attenuated backscatter coefficients and 1064 nm attenuated backscatter coefficients with the following equation

$$CR(z) = \frac{\beta'_{1064}(z)}{\beta'_{532}(z)}$$

Where the β'_{1064} is 1064 nm attenuated backscatter coefficient and β'_{532} is 532 nm total attenuated backscatter coefficient. Set all the attenuated backscatter coefficients with CR greater than threshold value (0.5) to null data. Figure 11 shows the flow chart for applying CR filter to full aerosol component data.

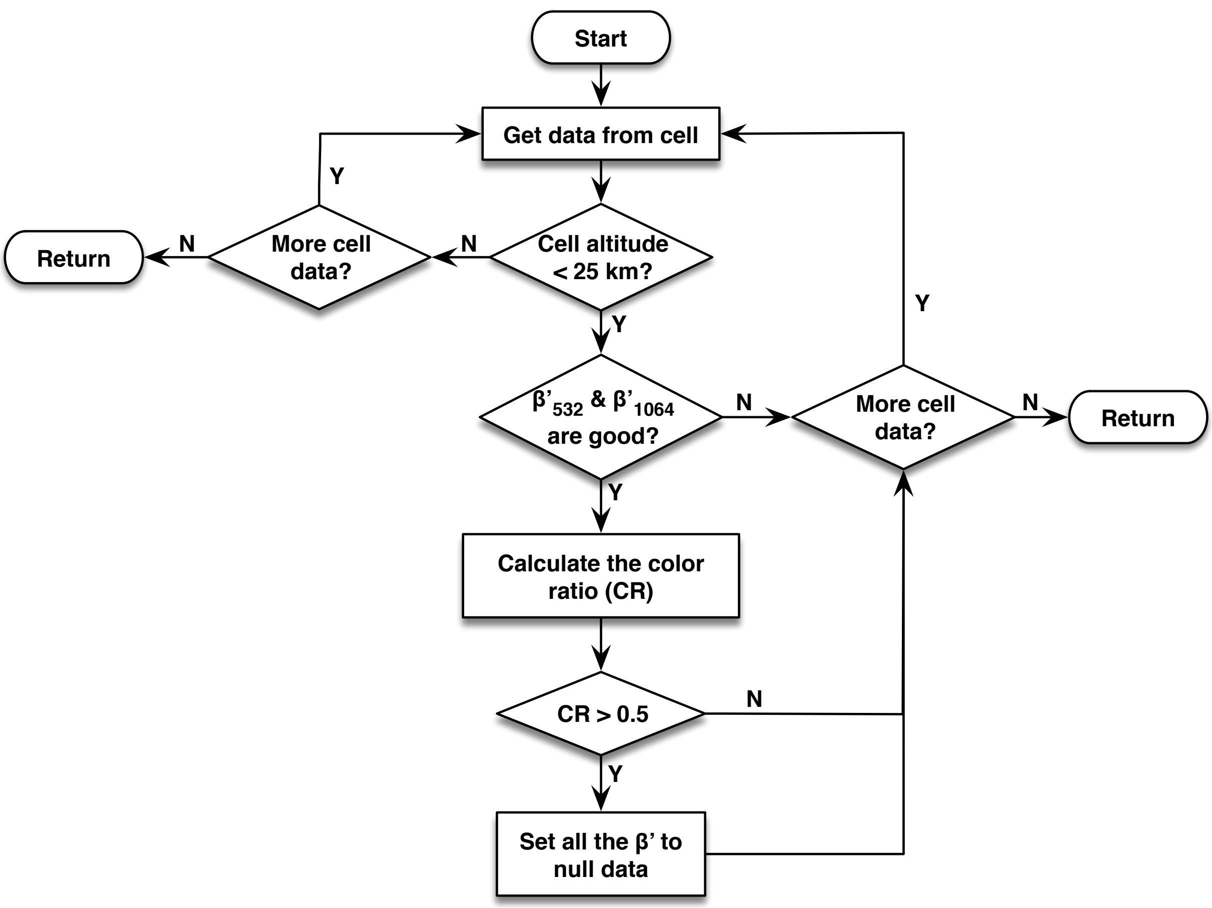

Figure 11 Flow chart for applying CR filter to full aerosol component data

3.11 Create monthly averages

After processing and generating one-month gridded profiles, create monthly averaged gridded datasets for attenuated backscatter coefficients, meteorological data, and ancillary data that are the required inputs to the extinction module in the next step. The mean values and standard deviation values for the monthly averaged gridded 532 nm total attenuated backscatter coefficients, molecular backscatter, and ozone absorption coefficients datasets are written to the output product.

Figure 12 shows the flow chart for constructing monthly averages:

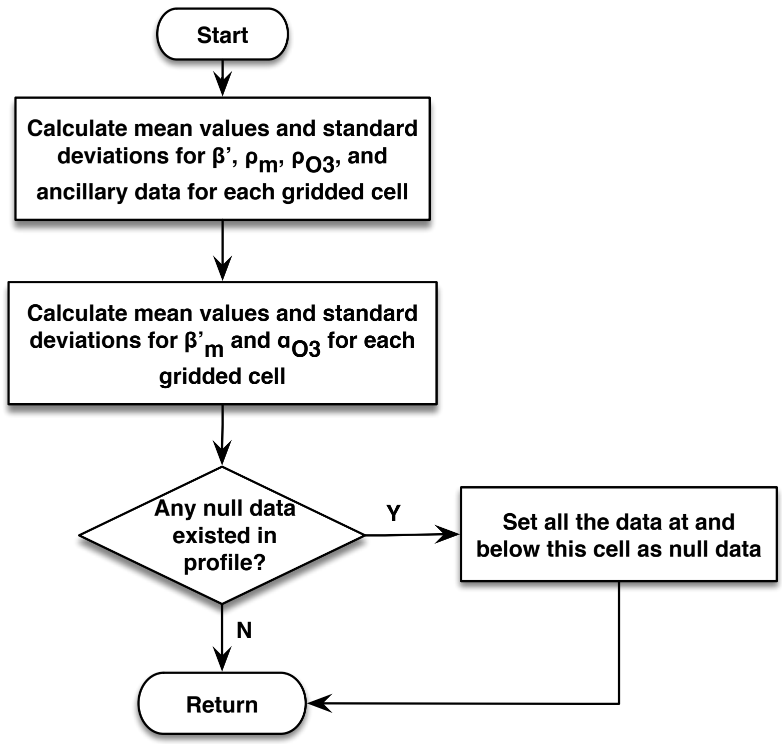

Figure 12 Flow chart for constructing monthly averages

3.12 Retrieve extinction profiles

This step calculates profiles of attenuated scattering ratio and attenuated scattering ratio uncertainties; retrieves profiles of particulate backscatter coefficients and particulate extinction coefficients and their associated uncertainties; and estimates stratospheric aerosol optical depth and its uncertainty. The procedure for doing this will use the new C++ version of the LL2 extinction module, so the details are not given in this document.

3.13 Write results to output file

After all the required results are obtained, the output parameters shown in Table 2 and Table 3 are written to the new stratospheric aerosol output file.

The new stratospheric aerosol output file will be in HDF4 file format that is consistent with the other CALIPSO output file format. Each output parameter in Table 2 is stored as an individual SDS dataset with name matched with standard naming with first character capitalized and with "_" to join words. Each SDS dataset will have the standard attributes that include unit, data format, valid range, and fill value.

For the metadata that shows in Table 3 will put into one vdata named as "metadata" and each parameter is one field into this metadata.

The name of the output filename will follow the standard Level 3 CALIPSO filename format since the new stratospheric aerosol product is monthly averaged product.

Section 4 – Input and Output records

The input files for this PGE include Version 4 Level 1B (L1B), Level 2 VFM (L2_VFM) or Level 2 5km Merged Layer (L2_5ML), and Level 2 PSCMask (L2_PSC) files. The input data required for this process are listed in the Table 1.

Table 1. Input parameters required for processing the stratospheric aerosol product.

Parameter	Variable	Units	Format	Source
Latitude	Lat	deg	32-bit float	L1B
Longitude	Lon	deg	32-bit float	L1B
Lidar Data Altitudes	z	km	32-bit float	L1B
Profile_Time	TAI	sec	64-bit float	L1B
Profile UTC Time	UTC	no unit	64-bit float	L1B
532 nm Total Attenuated Backscatter	β'	$km^{-1}.sr^{-1}$	32-bit float	L1B
532 nm Perpendicular Attenuated Backscatter	β'_p	$km^{-1}.sr^{-1}$	32-bit float	L1B
1064 nm Attenuated Backscatter	β'_{1064}	$km^{-1}.sr^{-1}$	32-bit float	L1B
Laser Energy 532	E	joules	32-bit float	L1B
Parallel Amplifier Gain 532	G_{par}	Volt/Volt	32-bit float	L1B
Perpendicular Amplifier Gain 532	G_{perp}	Volt/Volt	32-bit float	L1B
Noise Scale Factor Parallel 532	NSF_{par}	$\sqrt{}$count	32-bit float	L1B
Noise Scale Factor Perpendicular 532	NSF_{perp}	$\sqrt{}$count	32-bit float	L1B
Parallel RMS Baseline 532	RMS_{par}	count	32-bit float	L1B
Perpendicular RMS Baseline 532	RMS_{perp}	count	32-bit float	L1B
Depolarization Gain Ratio 532	PGR	No unit	32-bit float	L1B
Molecular Density	ρ_m	m^{-3}	32-bit float	L1B
Ozone Density	ρ_{O3}	m^{-3}	32-bit float	L1B

Parameter	Variable	Units	Format	Source
Temperature	T	^oC	32-bit float	L1B
Tropopause Altitude	T_p	km	32-bit Float	L1B
Pressure	P	mbar	32-bit float	L1B
Calibration Coefficient 532	C	km^3 sr counts	32-bit float	L1B
Profile_Time from PSC	PSC_TAI	sec	64-bit float	L2_PSC
Profile_UTC_Time from PSC	PSC_UTC	no unit	64-bit float	L2_PSC
PSC_Feature_Mask	PSC_mask	no unit	16-bit integer	L2_PSC
Altitude from PSC	PSC_alt	km	32-bit float	L2_PSC
Profile_Time from 5ML	5ML_TAI	sec	64-bit float	L2_5ML
Profile_UTC_Time from 5ML	5ML_UTC	no unit	64-bit float	L2_5ML
Layer_Top_Altitude	z_{top}	km	32-bit float	L2_5ML
Lidar_Data_Altitudes from 5ML	5ML_alt	Km	32-bit float	L2_5ML

The Table 2 shows the output parameters derived from this processing. All these parameters are derived from 532 nm signals. The grids are constructed with 36 (latitude) X 18 (longitude) X 31 (altitude). The output file format is in HDF4. Each output parameter is written as single SDS dataset. The table shows number of elements in each grid.

Table 2: Output parameters for the stratospheric aerosol product

Parameter	Variable	Units	Format	/Grid
Latitude (grid cell midpoint)[1]	Lat	deg	32-bit float	34
Longitude (grid cell midpoint)[1]	Lon	deg	32-bit float	18
Altitude (grid cell midpoint)[1]	Alt	km	32-bit float	31
Total Attenuated Backscatter Background	β'_{bg}	km^{-1} sr^{-1}	32-bit float	31
Standard Deviation Total Attenuated Backscatter Background	$\Delta\beta'_{bg}$	km^{-1} sr^{-1}	32-bit float	31
Total Attenuated Backscatter Full Aerosol	β'_{fa}	km^{-1} sr^{-1}	32-bit float	31
Standard Deviation Total Attenuated Backscatter Full Aerosol	$\Delta\beta'_{fa}$	km^{-1} sr^{-1}	32-bit float	31
Attenuated Backscatter Sample Counts Background	N_{bg}	no unit	32-bit unsigned integer	31
Attenuated Backscatter Sample Counts Full Aerosol	N_{fa}	no unit	32-bit unsigned integer	31
Attenuated Backscatter Rejected Sample Counts Background	$N_{bg,rej}$	no unit	32-bit unsigned integer	31
Attenuated Backscatter Rejected Sample Counts Full Aerosol	$N_{fa,rej}$	no unit	32-bit unsigned integer	31
Molecular Backscatter	β_m	km^{-1} sr^{-1}	32-bit float	31
Standard deviation Molecular Backscatter	$\Delta\beta_m$	km^{-1} sr^{-1}	32-bit float	31
Ozone Absorption Coefficient	α_{O3}	km^{-1}	32-bit float	31

Parameter	Variable	Units	Format	/Grid
Standard deviation Ozone Absorption Coefficient	$\Delta\alpha_{O3}$	km^{-1}	32-bit float	31
Attenuated Scattering Ratio Background	R'_{bg}	no unit	32-bit float	31
Attenuated Scattering Ratio Uncertainty Background	$\Delta R'_{bg}$	no unit	32-bit float	31
Attenuated Scattering Ratio Full Aerosol	R'_{fa}	no unit	32-bit float	31
Attenuated Scattering Ratio Uncertainty Full Aerosol	$\Delta R'_{fa}$	no unit	32-bit float	31
Particulate Backscatter Background	β_{pbg}	$km^{-1}\ sr^{-1}$	32-bit float	31
Particulate Backscatter Uncertainty Background	$\Delta\beta_{pbg}$	$km^{-1}\ sr^{-1}$	32-bit float	31
Particulate Backscatter Full Aerosol	β_{pfa}	$km^{-1}\ sr^{-1}$	32-bit float	31
Particulate Backscatter Uncertainty Full Aerosol	$\Delta\beta_{pfa}$	$km^{-1}\ sr^{-1}$	32-bit float	31
Extinction Coefficient Background	σ_{bg}	km^{-1}	32-bit float	31
Extinction Coefficient Uncertainty Background	$\Delta\sigma_{bg}$	km^{-1}	32-bit float	31
Extinction Coefficient Full Aerosol	σ_{fa}	km^{-1}	32-bit float	31
Extinction Coefficient Uncertainty Full Aerosol	$\Delta\sigma_{fa}$	km^{-1}	32-bit float	31
Potential Temperature	θ	^{0}K	32-bit float	31
Tropopause Altitude	T_p	km	32-bit float	1
Number Of Contributing Granules	N_g	no unit	16-bit integer	1
Stratospheric Optical Depth Background	OD_{bg}	no unit	32-bit float	1
Stratospheric Optical Depth Uncertainty Background	ΔOD_{bg}	no unit	32-bit float	1
Stratospheric Optical Depth Full Aerosol	OD_{fa}	no unit	32-bit float	1
Stratospheric Optical Depth Uncertainty Full Aerosol	ΔOD_{fa}	no unit	32-bit float	1
Calibration Coefficient Mean 532	C	km^3 sr count	32-bit float	1
Calibration Coefficient Standard deviation 532	C	km^3 sr count	32-bit float	1
Calibration Coefficient Sample Count	N_C	no unit	32-bit unsigned integer	1

1: These are dimension parameters

Table 3 shows the metadata record for the stratospheric aerosol product.

Table 3: metadata Record for stratospheric aerosol product

Parameter	Data Type	Units	Nominal Range	Elem/ Record	Size (bytes)
Product_ID	Char	no unit	N/A	1	80
Nominal_Year_Month	Char	no unit	N/a	1	6
Number_Of_Level1_Files_Analyzed	int16	no unit	0-500	1	2
First _Input_Filename	Char	no unit	N/A	1	160
Last_Input_Filename	Char	no unit	N/A	1	160
Lidar_Ratio_Used	int16	Sr	0-100	1	2
Lidar_Ratio_Uncertainty_Used	int16	Sr	0-100	1	2
Molecular_Backscatter_Cross_Section	Float32	m^2	TBD	1	4
Molecular_Extinction_Cross_Section	Float32	m^2	TBD	1	4
Ozone_absorption_Cross_Section	Float32	m^2	TBD	1	4

Section 5 – Benefits, assumptions, risks/issues

The benefits for the new CALIPSO stratospheric aerosol product can provide a reliable source for studying stratospheric aerosol due to the significant improvement of the LIDAR Level 1 calibration. This product can fill in the gap with good quality data between SAGE III and the SAGE III ISS.

This PGE require processing one-month data files (about 435 L1B files), so it may require long period execution time and large memory. To reduce these two issues, creating gridded profiles can be broken into one-granule or one-day granules processing, that can reduce the time and memory. However, this require to generate temporary files. Two extra steps (3.9 and 3.10) are required to add into the codes. This also has risk to process same granule more than one times.

Conclusion

The design of the Stratospheric Aerosol Product PGE can generate new stratospheric aerosol products from Version 4 LIDAR Level 1B files, LIDAR Level 2 VFM (or 5km Merged Layer) files and LIDAR Level 2 PSC files. These new products can provide a reliable source for studying stratospheric aerosol.

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