TEMPO public early release Level 1, Level 2 and Level 3 products README document

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Disclosure statement

This README document serves as a guide to the February 2024 mini-release of TEMPO products. Future releases will be accompanied by updated README documents. Given the quick turnaround of TEMPO product improvements at the current stage of the mission, we strongly advise against using this README after the official public release scheduled for February 2024 (level 1b) and April 2024 (level 2 and level 3) respectively. This is an early, limited release of unvalidated TEMPO data products. The primary purpose of this release is for users to gain familiarity with the file format and content of TEMPO products. These TEMPO products should be considered preliminary and unvalidated. Users should refrain from making conclusive public statements regarding science and applications of the TEMPO data products, and the data should not be used in publications or presentations.

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Introduction

This **README** file provides a quick guide for the TEMPO DRK, IRR(R), RAD, CLDO4, NO2, HCHO, and O3TOT products in this early (pre-public) release. The products are generated by the Science Data Processing Center (SDPC) at the Smithsonian Astrophysical Observatory (SAO).

All products are pushed to ASDC from SAO after production by the SDPC. Under rare circumstances, Level 2 and 3 product files are missing when corresponding L1b files exist because of failed INR (Instrument Navigation and Registration) processing and its lack of geolocation information.

TEMPO products are in the commonly-used self-explanatory NetCDF format. The content of a NetCDF file can be listed by “ncdump -h filename.nc” on Linux systems or explored on a graphical interface using Goddard Institute for Space Studies Panoply (https://www.giss.nasa.gov/tools/panoply/).

TEMPO Level 1

1. Algorithm overview

The TEMPO Level 1 (L1) products collectively refer to dark exposure (L1a), solar irradiance (L1b), and geolocated Earth radiances (L1b). The nominal data sampling frequencies of the three respective products are twice a day (dark), once every seven days (solar), and once every hour (Earth). The Earth scanning frequency given here represents the nominal operation during most daylight hours; the sampling frequency may be higher for optimized scanning during early morning (eastern North America) and late afternoon/evening (western North America). Different settings are possible for special observations.

Since October 17th, all L1 products have been pushed to the ASDC. Under rare circumstances, geolocated Earth radiance files are missing; INR has sometimes failed under special conditions (e.g., due to a lot of missing data, missing spacecraft ephemeris, etc.).

The Level 0-1 processor for TEMPO adapts elements from OMI, TROPOMI, and GEMS. Figure 1 shows a simplified flow chart of the main procedures in the TEMPO L0-1 processing. The processor uses three types of L0 data inputs: radiance, irradiance, and dark current. The digital counts stored in L0 files are converted to current (in units of electrons s^{-1}), regardless of data type. The dark current processing ends at this stage, while radiance and irradiance data are processed further to derive the number of photons (in units of photons s^{-1} cm^{-2} nm^{-1} (sr^{-1})). Then, the radiance processing employs additional steps, including INR, to generate radiance L1b outputs. The photon derivation in the irradiance processing is followed by several steps, including correction for the bidirectional transmittance distribution function (BTDF) of the diffusers and spectral calibration, to produce irradiance L1 outputs.

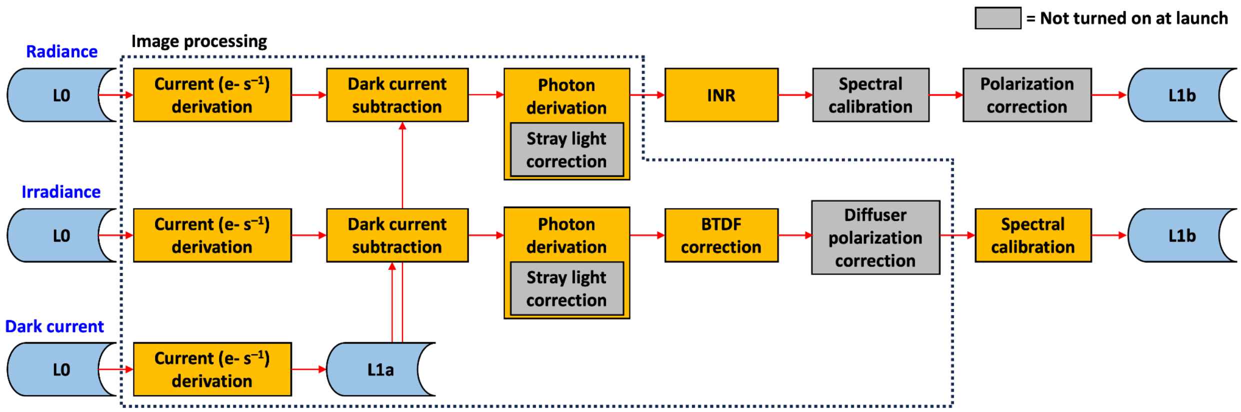


Figure 1. Flow chart of the TEMPO L0-1 processor.

2. File format

2.1 Filename format

The TEMPO dark exposure and irradiance filenames have a format of "TEMPO_{PPP(P)}_L1_V01_{YYYY}{MM}{DD}T{HH}{NN}{SS}Z.nc", with YYYY (year), MM (month), DD (day), HH (hour), NN(minute), and SS (second) denoting the GMT time stamp at the beginning of the time period covered by the file. The segment PPP(P) represents the product type, which is DRK for dark exposure, IRR for solar irradiance with the working diffuser, and IRRR for solar irradiance with the reference diffuser. (The curly brackets are added here for display purposes; they don't exist in actual filenames.) The TEMPO radiance filenames have a format of "TEMPO_RAD_L1_V01_{YYYY}{MM}{DD}T{HH}{NN}{SS}Z_S{XXX}G{YY}.nc", with XXX denoting the scan number and YY denoting the granule number.

2.2 Wavelength grids

The irradiance files provide two variables related to the wavelength registration: (a) nominal_wavelength; and (b) wavecal_params. It is recommended to use the latter because it is the output from a spectral calibration performed for each solar exposure, while the former is a fixed wavelength grid derived from the first-light solar measurements (August 1, 2023).

The TEMPO instrument has two charge-coupled device (CCD) detectors: one for ultraviolet (UV, 290-490 nm) and the other for visible (VIS, 540-740 nm) (Zoogman et al., 2017). Each CCD has 2048 (spatial) $\times$ 1028 (spectral) photoactive pixels.

The TEMPO spectral calibration algorithm provides a set of Chebyshev polynomial coefficients for each spatial position in each CCD. The results are stored in the 'wavecal_params' variable with a dimension of (1, 2048, 2). The first dimension represents the mirror step, the second depicts the number of spatial CCD pixels, and the third corresponds to the number of

Chebyshev polynomial coefficients. (The current version of the algorithm uses first-degree polynomials with two coefficients.)

The ‘wavecal_params’ variable is stored in both ‘band_290_490_nm’ and ‘band_540_740_nm’ groups to represent the UV and VIS CCDs, respectively. The wavelength grid for each spatial CCD pixel can be reconstructed separately for each CCD, using the Chebyshev polynomial formula with 1028 spectral grid pixels.

The Chebyshev polynomials $T(x)$ are obtained from the recurrence relation with a variable x on the interval [-1, 1]:

$T_0(x) = 1$

$T_1(x) = x$

$T_{n+1}(x) = 2xT_n(x) - T_{n-1}(x)$ (where $n \geq 1$).

For the TEMPO wavelength-grid reconstruction, x should be calculated on a regular grid from -1 to 1 with 1028 points (including the two boundaries, i.e., $-1 \leq x \leq 1$). The final wavelengths $w(x)$ are determined by

$$w(x) = \sum_{i=0}^{n} \left[c_i \times T_i(x)\right],$$

where n represents the polynomial degree (which is 1 in the current algorithm setting), and c_i is the coefficient from the ‘wavecal_params’ variable.

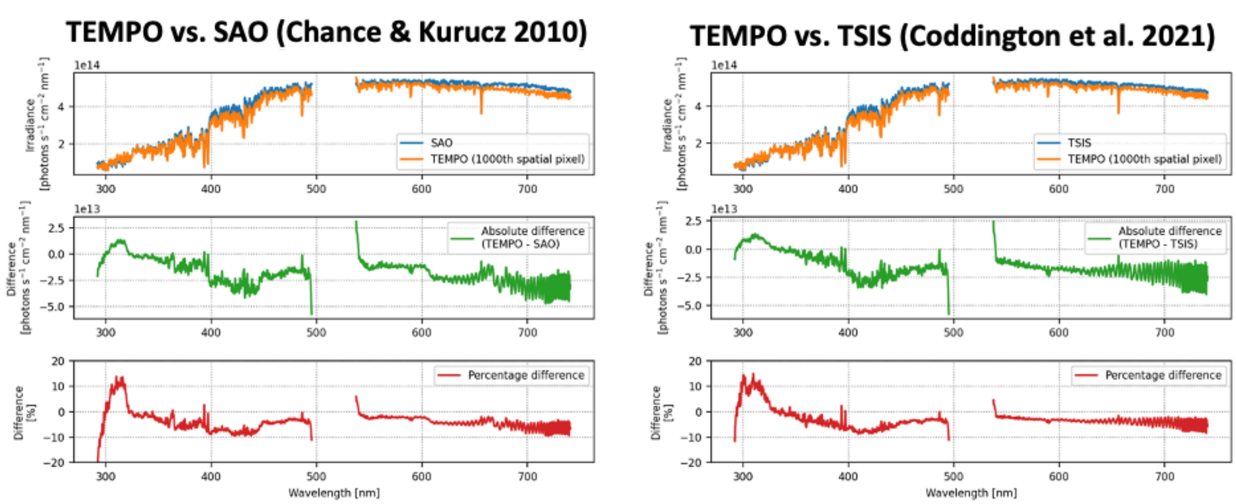
Please find an example of Python code for wavelength-grid reconstruction (wavelength_registration.py) in the Google Drive folder linked below. In this code, $T(x)$ and x in the equations above are represented by variables ‘t’ and ‘x’. The Chebyshev polynomial of every order is stored (appended) in the variable ‘t_arr’ for the recursive construction. The other files in the folder are (a) the output figure of the code (wavecal.png) and (b) the reconstructed wavelengths (wavecal.nc) for the IRR file from October 12, 2023 (TEMPO_IRR_L1_V01_20231012T040123Z.nc).
(Note: the Python netCDF4 package might not be able to open TEMPO irradiance files, depending on its version. A more robust option would be to use the h5py package, as shown in the example code.)

- Google Drive link: https://drive.google.com/drive/folders/1Xyb1nG6Mp0qwu_OmPhv-eMSZeAd-oOPy?usp=drive_link

3. Known issues

Several issues of the current version of L1 products are listed below. They are planned to be updated in future L1 product versions. The SAO science team welcomes and appreciates your report of any problems you may find in the products.

(1) Stray light correction has not been applied (see Fig. 1).
(2) Polarization correction has not been applied (see Fig. 1).
(3) Spectral calibration has not been applied for radiance data (see Fig. 1).
(4) Azimuth-angle dependence of the diffuser BTDF is not fully accounted for. A scattering-angle-based correction will be implemented.
(5) TEMPO irradiances show discrepancies from theoretical references even at the center (spatial), where BTDF shows little dependence, likely related to errors in the derived radiometric calibration coefficients However, the normalized radiance might not be affected much due to cancellation. Also, etaloning structures are found at wavelengths > 650 nm. Further radiometric calibration is underway.



(6) Fill_values are found in the 'ground_pixel_quality_flag' variable due to the absence of land cover information over the ocean in the data we employed. This issue will be resolved.
(7) There are faint "rings" visible in the snow/ice fraction at values close to one (to be resolved, but likely interpolation issues). These also appear in the snow/ice fraction in Level 2 products.

Future updates will also include electronic offset removal, smear correction, and dark current correction accounting for temperature dependence.

TEMPO CLDO4

1. Algorithm overview

The CLDO4 algorithm is mainly based on Vasilkov et al. [2018], which assumes Lambertian clouds with an albedo of 0.8. This simple assumption is consistently made in the TEMPO trace gas Air Mass Factor (AMF) calculations and is practical for processing the large volume of TEMPO data. Effective cloud fraction (ECF) is derived from the spectral reflectance at 466 nm. Cloud optical centroid pressure (OCP) is based on the cloud fraction and the O_2-O_2 Slant Column Density (SCD) retrieved from the TEMPO L1b spectrum between 439 nm and 488 nm. The slant column retrieval employs the Smithsonian Astrophysical Observatory's spectral fitting code [Gonzalez Abad et al., 2015] that is shared among all molecules of interest (O_2-O_2, NO_2, HCHO). The details of the cloud retrieval algorithm will be covered in the Algorithm Theoretical Basis Document (ATBD). Note, due to the complex spatial, temporal, and spectral dependence of cloud information, as well as the differences in the assumptions made, cloud products from other instruments cannot be directly used by TEMPO trace gas algorithms without further investigation.

The ancillary inputs for the released CLDO4 product include GEOS-CF forecast (instead of replay), surface GLER based on MODIS kernels, and pre-computed Look Up Tables based on US standard air. Currently, only the ECF and OCP in the CLDO4 product are used by the SDPC for trace gas AMF calculations; other output variables (e.g., cloud radiance fractions, scene albedo, scene pressure, and variables in the support group) are currently for information only and are not used.

2. File format

For the TEMPO Level 2 product in this release, the filename is in the format of "TEMPO_CLDO4_L2_V01_YYYYMMDDTHHNNSSZ_SXXXGYY.nc", with YYYY (year), MM (month), DD (day), HH (hour), NN(minute), SS (second) denoting the GMT time stamp at the beginning of the time period covered by the file, XXX denoting the scan number, and YY denoting the granule number. For the TEMPO Level 3 product in this release, the filename is in the format of "TEMPO_CLDO4_L3_V01_YYYYMMDDTHHNNSSZ_SXXX.nc". Additional metadata can be found in the corresponding text file with a .nc.met filename extension. Variables with all fill values (e.g., GLER40) are placeholders.

A 16-bit processing quality flag is provided to indicate any errors or warnings encountered during processing. The meaning of each bit is listed in the attribute of the variable. Users are advised to use bitwise testing to interpret this flag, instead of integer values of bit combinations.

Error estimates for CLDO4 have not yet been implemented in the current SDPC processing.

3. Known issues

Several issues of the CLDO4 product were noticed during the TEMPO commissioning and are listed below. The SAO science team welcomes and appreciates reports of any problems you may find in the product.

(1) Smoke from wildfires is aliased into clouds. RGB color images can be used as additional information to distinguish smoke plumes from clouds.

(2) Cloud fraction histogram statistically peaks at 0.05. The shift from zero could be partially related to the L1 radiance calibration, surface GLER, and/or background aerosol. This could affect scattering weights (and therefore AMF) of trace gases under relatively clear conditions, the effect of which is being investigated.

(3) GLER over liquid water surface may have large errors, especially when the sun is low on the horizon. This will cause invalid cloud retrievals, which in turn affect scattering weights and AMF for trace gases.

(4) Patterns resembling surface features in the mountainous region are seen in cloud fraction maps, and appear to be more noticeable in some hours than others during the day, indicating possible local-time-dependent GLER problems. Although the time dependent GLER effect is more noticeable in the mountainous area, it may also exist in other areas.

Furthermore, although GEOS-CF surface pressure is adjusted for scene topography in the CLDO4 code, meteorology in the mountainous regions is challenging to model at the coarser spatial resolution than the TEMPO pixel size, time variable meteorological errors will propagate into the retrieved cloud fraction and cloud pressure.

(5) Cloud shadows are noticed for large solar zenith angles, and show up often in the morning scans in the east and evening scans in the west.

(6) Cloud pressure retrieval is skipped when (a) cloud fraction does not exist; (b) cloud fraction is zero; (c) O_2-O_2 Slant Column Density (SCD) fails or is bad.

(7) O_2-O_2 SCD retrieval fails when (a) there is a significant saturation problem in the retrieval window, which tends to show up as patches or scattered pixels over very bright clouds; (b) wavelength calibration failure along the scan direction, which shows up as a horizontal stripe of fill values in the O_2-O_2 SCD field.

(8) In general, the relative fitting uncertainties for O_2-O_2 SCD (and by extension, the relative uncertainties for cloud pressure) are larger for smaller cloud fractions (i.e., relatively clear conditions). This is also the case for high-altitude (low-pressure) clouds.

(9) Cloud information near the corners of the TEMPO field of regard, especially in the northeast and northwest, appears to be distorted.

(10) As the cloud information is derived using the GEOS-CF forecast, errors in the forecasted surface pressure and temperature-pressure profile will propagate into cloud fraction and cloud pressure.

(11) The SCD_MainDataQualityFlags in the product is for O_2-O_2 slant column density (SCD) only, thus, it does not directly apply to the cloud information. Currently, this flag is set to 0 (good) when the retrieval has converged and the retrieved value is within twice the fitting uncertainty, which is not very restrictive to prevent filtering out too many retrievals before entering cloud pressure retrieval. In practice, additional checks for

reasonable values are employed. Some unphysical O_2-O_2 values next to saturated cloudy pixels are noticed.

TEMPO NO_2 and HCHO Level 2 and 3

1. Algorithm overview

The trace gas algorithm used for both NO_2 and HCHO is mainly based on Gonzalez Abad et al. [2015]. The algorithm has three major processing steps:

1. Spectral fitting to calculate slant column densities
2. Air mass factor calculation and correction to derive vertical column densities
3. NO_2: Stratosphere-troposphere separation algorithm
   <u>or</u>
   HCHO: Background correction of retrieved columns accounting for the use of radiance reference instead of solar irradiance as the initial spectrum guess during the spectral fitting.

Slant columns are derived using least-squares minimization to directly fit a modeled radiance to the observed spectrum. The NO_2 retrieval uses a solar irradiance spectrum as a reference and uses a 405 - 465 nm fitting window. The NO_2 spectral fit also simultaneously fits ozone, water vapor, oxygen dimer and liquid water absorption, as well as a Ring spectrum, undersampling correction, wavelength shift with respect to the reference spectrum and closure polynomials.

The HCHO retrieval uses a modeled radiance built around a mean radiance reference derived for each line position as the average of the radiance for a whole scan (all East-West positions) and retrievals for each scan are performed against its own derived radiance reference.The HCHO spectral fit uses a 328.5 - 356.5 nm fitting window. Besides the HCHO signal, other trace gasses considered in the fit include ozone, nitrogen dioxide, bromine monoxide and oxygen dimer absorption. The fit also considers a Ring spectrum, undersampling correction, wavelength shift with respect to the reference spectrum and closure polynomials.

The air mass factor calculation uses precomputed tables of scattering weights at forty seven vertical layers parameterized as functions of viewing geometry, ozone profile, surface albedo and surface pressure. The treatment of cloudy pixels uses the information derived from the TEMPO CLDO4 product and the independent pixel approximation [Martin et al., 2002]. Other ancillary data used include GEOS-CF gas and temperature profiles, surface pressure and wind fields, and a monthly and hourly climatology of GLER values derived from MODIS BRDF observations. The combination of the air mass factors with the GEOS-CF forecast is used to derive the HCHO background correction. Further details will be soon available in the ATBD documents which are in the final stages of preparation and revision.

2. File format

For the TEMPO Level 2 product in this release, the filename is of the format "TEMPO_HCHO_L2_V01_YYYYMMDDTHHNNSSZ_SXXXGYY.nc", with YYYY (year), MM (month), DD (day), HH (hour), NN(minute), SS (second) denoting the GMT time stamp at the beginning of the time period covered by the file, XXX denoting the scan number, and YY denoting the granule number. For the TEMPO Level 3 product in this release, the filename is of the format "TEMPO_HCHO_L3_V01_YYYYMMDDTHHNNSSZ_SXXX.nc".

The main variables are included in the *product* group.
For NO_2, these are:

vertical_column_total
vertical_column_total_uncertainty
vertical_column_troposphere
vertical_column_troposphere_uncertainty
vertical_column_stratosphere
main_data_quality_flag

For HCHO, these are:

vertical_column
vertical_column_uncertainty
main_data_quality_flag

We recommend using only pixels with *main_data_quality_flag* equal to 0 (see below in known issues for further details on the status of the *main_data_quality_flag*). The *geolocation* and *support_data* groups contain variables necessary to interpret the observations. The *support_data* group contains the variable *amf_diagnostic_flag*, a 16-bit bitwise flag indicating different assumptions/issues in the air mass factor calculation.

The vertical pressure levels (layer edges) are defined on the same levels as the GEOS-CF model used as input to the retrievals. These pressure levels can be regenerated for each ground pixel using the variable *support_data/surface_pressure* and the *Eta_A* and *Eta_B* values which are attributes of the surface pressure variable. The pressure at each altitude level *z* can be calculated using:

$$Pedge(z) \ = Eta\_A(z) + Eta\_B(z) \ * \ \ Psurface$$

Error estimates for NO_2 and HCHO are limited to fitting uncertainty. An offline estimate of other uncertainty sources will be provided in the ATBD document to be released soon.

3. Known issues

<u>Common to NO_2 and HCHO</u>

a. The precision and accuracy of the retrieval deteriorates in the presence of clouds. We recommend filtering pixels with cloud fractions larger than 0.3 or 0.4. Pixels with larger cloud fractions should be used with caution. The precision is affected by scene inhomogeneity associated with partially cloudy pixels. This effect starts to appear at effective cloud fractions between 0.1-0.2, peaks between 0.3-0.4 and stabilizes and/or reduces its influence for effective cloud fractions larger than 0.4.

b. Note that there are several unresolved issues in the cloud retrieval (discussed above), including a slight high bias in the cloud fractions for clear or nearly-clear sky pixels. Errors in the cloud retrieval may propagate to the NO_2 and HCHO AMFs, resulting in potential biases in the trace gas values.
c. The accuracy of the retrieval deteriorates at large solar zenith angles (SZA). For now we recommend limiting the analysis to SZA < 70 or treat pixels with SZA > 70 with great caution. Investigating the performance of TEMPO early morning/late afternoon observations is an ongoing effort.
d. GLER look-up-tables minimum value over land is 0.01.
e. There are discontinuities in ocean surface reflectance between granules at very high SZA.
f. A small number of main data quality flag values need to be updated to suspect or bad to account for unphysical spectral fitting results and missing information during air mass factor calculations.
g. TEMPO spectra saturate over very bright clouds. This affects the cloud retrieval (see above) and also the NO_2 and HCHO retrievals at high cloud fractions. Most are correctly flagged in the main data quality flag but there may be some erroneously flagged as "good".
h. Near-surfaces masses are being excluded in the air mass factor calculation when the "adjusted surface pressure" is lower than the GEOS-CF prior surface pressure (reported by Barron Henderson).
i. V01 data from January 1-14 2024 have bad GLER values and as a result are often missing scattering weights. This is due to a bug in interpolating between GLER climatologies that span the new year. A fix has been implemented for future reprocessing.
j. Some measurements in the late evening in the West at times around 22:00-23:00 UTC have bad albedos and as a result are missing scattering weights. This is due to some missing times in the GLER look-up tables. These measurements should not be used as the vertical columns will be incorrect. These are not properly flagged by *main_data_quality_flag* but are flagged in the variable *support_data/amf_diagnostic_flag* by the flag *no_scattering_weights*. Users should use the *no_scattering_weights* flag to exclude these observations.
k. The presence of snow/ice is not always reflected in the final albedo in areas without persistent snow cover at certain times of the year. This issue is likely due to the snow/ice GLER climatologies that are currently implemented and is being investigated.

Affecting NO_2 only

a. There is mild striping along the North-South direction. A fix for this will be implemented at a later stage.

b. The *amf_cloud_fraction* (radiance cloud fraction) for NO_2 seems to be higher than expected, even when the high bias in the cloud retrieval is considered. This is being investigated.
c. The AMF for the total NO_2 (*amf_total*) in V01 is calculated without the temperature correction (the correction is applied for *amf_troposphere* and *amf_stratosphere* correctly). This will be fixed in future versions.
d. There is a bug in the code in how the vertical layer at the tropopause pressure is found. This causes several layers of the stratosphere to be erroneously categorized as the troposphere in the tropospheric and stratospheric AMF calculations. As a result, the NO_2 tropospheric AMF will be overestimated relative to the truth, and the stratospheric AMF will be underestimated. The total NO_2 AMF calculation is not affected. This will be fixed in future versions.

Affecting HCHO only

a. The radiance reference used for the retrieval of the dSCDs considers pixels with large HCHO signals.
b. Scans with a small number of granules (optimized morning and evening scans), may have a limited number of available observations for radiance reference calculation resulting in East-West striping and artifacts, particularly at Northern latitudes.

TEMPO total ozone Level 2 and 3

1. Algorithm overview

The total ozone algorithm is mainly based on the OMTO3 V8.5 algorithm (called TOMS V8.5). The theoretical basis of the TOMS algorithm was using 2 wavelengths (317.5 nm for ozone and 331.2 nm for the reflectivity) in the Huggins ozone absorption band (310 nm ≤ λ ≤ 370 nm) (Dave and Mateer (1967)). The longer of the two wavelengths is used to derive effective cloud fraction based on the Mixed Lambert Equivalent Reflectivity (MLER) model that was developed to model the effect of clouds on Rayleigh scattering. In this MLER model, the scene consists of a clear-sky scene of surface reflectivity of 0.15 and a cloudy scene of cloud reflectivity of 0.8 based on the independent pixel approximation:

$$I = I_{clr} \times (1 - f_c) + I_{cld} \times f_c$$

where I, I_{clr}, and I_{cld} are the overall, clear and cloudy scene radiances, respectively. When f_c becomes less than zero or when there is snow/ice, we assume that no cloud is present and use the Lambert Equivalent Reflectivity (LER) model to derive the clear scene reflectivity R. When f_c exceeds 1, we assume 100% cloud cover and derive cloud reflectivity using the LER model. Given the f_c / R, the shorter (strong ozone-absorbing) wavelength is used to derive total ozone.

The effective cloud-top pressure is taken from the retrieved Optical Cloud Centroid Pressure (OCCP) inferred from the newly implemented TEMPO O_2-O_2 cloud algorithm when available. Otherwise, it is taken from the climatological Optical Cloud Centroid Pressure (OCCP) from the OMCLDRR product. In either the MLER or LER model, the retrieved ozone column is the weighted ozone column above surface and OCCP by Cloud Radiative Fraction (CRF), defined as $f_c * I_{cld} / I$. To estimate the total column amount, the "un-measured" or ghost column below OCCP (also weighted by CRF) is estimated using an ozone climatology and added to the retrieved ozone column.

The algorithm also calculates the absorbing Aerosol Index (AI) from the radiance residuals at 360 nm. We recommend that only the AI values larger than +1 should be used for aerosol studies and areas contaminated by sea-glint should be avoided completely. Since absorbing aerosols cause the ozone derived from the basic ozone retrieval algorithm to be overestimated, a parametric relationship based on AI is used to correct the initial retrieved ozone column. This relationship also appears to remove a large portion of errors caused by sea-glint. Other than the three primary wavelengths mentioned above, the total ozone algorithm uses additional wavelengths for quality control and error correction in more restricted geophysical situations. These include correction for ozone profile shape errors at large solar zenith angles using 312.6 nm measurements, and the detection of strong sulfur-dioxide contamination using multiple wavelength pairs.

Table 1. Ancillary inputs used in the TEMPO total ozone algorithm are summarized.

Input	***Source***
Cloud-top pressure	TEMPO O_2-O_2 cloud product Defaults to a cloud pressure climatology (OMI-derived) if cloud retrieval is unavailable.
Cloud fraction	Retrieved based on the MLER. If f_c <= 0 or >= 1, it is set to 0 or 1, R_s or R_{cld} is retrieved instead.
Ozone profiles	TOMS V8 climatology (total ozone dependent, monthly / 10° zonally mean)
Temperature profiles	TOMS V8 climatology (monthly / 10° zonally mean)
Surface albedo	15% or directly retrieved as R_s if $f_c = 0$
Snow/ice fraction	Climatology at 1° × 1° from the TOMS V8.5.
Terrain height pressure	Climatology at 1 / 3° × 1 / 3° from the TOMSV8.5.
Aerosols	Not explicitly treated, but an aerosol correction is included.

2. File format

For the TEMPO Level 2 product in this release, the filename is of the format "TEMPO_O3TOT_L2_V01_YYYYMMDDTHHNNSSZ_SXXXGYY.nc", with YYYY (year), MM

(month), DD (day), HH (hour), NN(minute), SS (second) denoting the GMT time stamp at the beginning of the time period covered by the file, XXX denoting the scan number, and YY denoting the granule number. For the TEMPO Level 3 product in this release, the filename is of the format "TEMPO_O3TOT_L3_V01_YYYYMMDDTHHNNSSZ_SXXX.nc".
A 16-bit processing quality flag is provided to indicate any errors or warnings encountered during processing. The meaning of each bit is listed in the attribute of the variable. Users are advised to use bitwise testing to interpret this flag, instead of integer values of bit combinations.

The main variables are included in the *product* group:

column_amount_o3
quality_flag
uv_aerosol_index

We recommend using only pixels with *quality_flag* equal to 0. The *geolocation* and *support_data* groups contain variables necessary to interpret the observations. The *support_data* group contains the variable *algorithm_flags*, *surface_reflectivity_at_331nm*, and *surface_reflectivity_at_360nm*.

3. Known issues

Several issues of the O3T product were noticed during the TEMPO commissioning and are listed below.

a. The changes made to adapt TOMS V8.5 for TEMPO are small, mainly include:
    i. The original look-up tables have been updated:
        1. Expand viewing geometry by adding viewing zenith angles of 77, 81, 84, 86, and 88° to accommodate TEMPO's larger observing VZA.
        2. Update slit functions from Bass-Paur cross sections with a triangular slit function of 0.45 nm Full Width at Half Maximum (FWHM) to BDM cross sections with a triangular FWHM of 0.6 nm.
    ii. The total ozone algorithm uses retrieved optical centroid cloud pressure from the new TEMPO O2-O2 algorithm.
b. Note that the total ozone algorithm is based on L1 data which is subject to large radiometric calibration updates. Currently, further radiometric calibration (e.g., BTDF correction, stray light correction) is underway as discussed in the L1 section.
c. In large VZA/SZA regions, especially left-top and right-top of the TEMPO field of regards, total ozone columns show discontinuity, which is due to the switching of the retrieval wavelength pair due to the large ozone slant column density.

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References

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