

MOPITT

(Measurements Of Pollution In The Troposphere)
Version 10 Product User's Guide

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1 MOPITT Version 10 Product Highlights

This guide describes new product features in the MOPITT Version 10 (V10) Level 2 products for tropospheric carbon monoxide (CO). This comprehensive version of the User's Guide is meant to serve as a “standalone” document, and includes relevant material from earlier User's Guides. Any updates to this document will be announced on the MOPITT News webpage at

<https://www2.acom.ucar.edu/mopitt/news>.

Features incorporated into the V10 retrieval product include:

- Radiance bias correction factors computed using the full MOPITT record.
- Updated N₂O concentrations for the forward model radiative transfer calculations.
- New field with lower tropospheric CO column estimates using only LMC channels.

2 Overview of Earlier MOPITT Products

Following the launch of Terra near the end of 1999, the MOPITT Version 3 (V3) product became available in 2000 [Deeter et al., 2003]. This was the first satellite dataset for tropospheric CO featuring global coverage. This product was followed in 2009 by the Version 4 (V4) product [Deeter et al., 2010]. Significant improvements first introduced in the V4 product included (1) temporally and geographically variable a priori for CO based on the chemical transport model MOZART, (2) representation of CO variability by log-normal statistics, (3) extension of the forward radiative transfer model MOPFAS to simulate much higher CO concentrations, and (4) improved observation-based a priori values for surface emissivity. Processing of the V4 product ended at the end of 2012. The V5 product became available in 2011 in three retrieval configurations: thermal infrared-only (“TIR-only”), near infrared-only (“NIR-only”) and multispectral (“TIR/NIR”). (The previous V3 and V4 products were TIR-only products.) V5 retrieval products also benefited from a new time-dependent radiative transfer model to reduce the influence of long-term instrumental changes on retrieval biases (i.e., “bias drift”). The V5 product was validated using a variety of in-situ and satellite datasets [Deeter et al, 2013, Martinez-Alonso et al., 2014]. The V6 product was released in 2013 and featured (1) correction of a systematic geolocation error, (2) use of the MERRA (Modern-Era Retrospective Analysis For Research And Applications) reanalysis for needed meteorological fields and (3) an updated model-based a priori for CO [Deeter et al., 2014]. Features introduced in the V7 product which became available in 2016 included (1) representation of increasing atmospheric concentrations of N₂O, (2) use of meteorological fields from the MERRA-2 reanalysis and (3) an improved NIR calibration method [Deeter et

al., 2017]. The V8 product, which was released in 2018, included the use of (1) updated spectroscopic data, (2) the MODIS Collection 6.1 Cloud Mask (instead of Collection 6.0), and (3) a more refined radiance bias correction scheme involving time-dependent and water vapor-dependent bias correction terms [Deeter et al, 2019]. The V9 product [Deeter et al., 2022]. made further improvements to the MOPITT forward model that reduced the dependence of the empirically calculated radiance bias corrections, along with more options to select alternate cloud masking for increased data coverage over land [Deeter et al., 2021] and corrections to the application of calibration data for the NIR channel.

3 Features of the MOPITT Version 10 Retrieval Algorithm

Algorithm improvements affecting the content of the V10 retrieval products are described in the following section. Significant changes in the V10 algorithms and/or products are emphasized in bold text.

3.1 Radiance Bias Correction

The MOPITT Level 2 processor exploits a set of radiance-bias correction factors to compensate for relative biases between (1) simulated radiances calculated by the operational radiative transfer model and (2) actual calibrated Level 1 radiances. Without some form of compensation, radiance biases produce biases in the retrieved CO profiles. Radiance bias correction factors compensate for a variety of potential bias sources including errors in instrumental specifications, forward model errors, spectroscopy errors, and geophysical errors. For V8, V9 and V10 products, radiance bias correction is based on a parameterization involving the date of observation and water vapor total column (derived from MERRA-2 water vapor profiles). V8 and V9 validation results [Deeter et al., 2019; 2022] demonstrated that this strategy successfully reduces long-term bias drift and retrieval bias geographical variability. Coefficients used to correct radiance biases and bias drift are obtained through a series of experiments in which biases are primarily evaluated using the large set of NOAA aircraft profiles (mainly over North America). Radiance bias correction factors used in the processing of each retrieved profile are reported in the L2 diagnostic “L2 Radiance Correction Factor” (see Appendix A). **For V10, these radiance bias correction factors were computed using the full MOPITT record so that there is no extrapolation from applying the values found for V9.** Validation results using the V10 radiance bias correction factors show either similar or improved biases compared to V9.

3.2 Radiative Transfer Modeling

The radiative transfer model [see MOPITT L2 ATBD, Francis et al., 2026] on which the MOPITT retrieval algorithm is based has been updated for V10 to account for more recent changes in the growth of atmospheric N₂O, which has changed significantly over the MOPITT mission. Because of the proximity of CO and N₂O spectral absorption lines in the TIR region, increasing N₂O concentrations contributed to long-term bias drift in previous MOPITT products. Accounting for the changes in N₂O concentrations improved the bias drift in V7 data and has been included in later data versions. However, assumptions about N₂O concentrations were based on observed growth from 2000 to 2015 at a rate of ~ 0.28%/yr. N₂O concentrations used for radiative transfer modeling have been updated to include more recent years as well as seasonal variability. N₂O distributions are from the CESM Community Atmosphere Model with Chemistry (CAM-chem) [Emmons et al, 2020] updated for the CMIP7 experiments [Zhang et al., 2025].

3.3 Retrieval Grid

V10 retrieved profiles are expressed on the same ten-level grid (surface, 900 hPa, 800 hPa, ..., 100 hPa) used for products since V4. For V4 products, each retrieval level was assigned to a layer centered on that level, with a weighting that tapered to zero at the adjacent retrieval levels. For all later products, in contrast, each retrieval level simply corresponds to a uniformly-weighted layer immediately above that level. For example, for retrievals where the surface pressure exceeds 900 hPa, the V10 surface-level retrieval product corresponds to the mean volume mixing ratio over the layer between the surface and 900 hPa. Thus, when comparing MOPITT profiles with model results, we suggest first applying simple (unweighted) averaging to the model results in the layers above each retrieval level. (For the topmost MOPITT retrieval level at 100 hPa, the uniform-VMR layer extends from 100 hPa to 50 hPa. Assumed VMR values in the layer from 50 hPa to TOA are based on the CAM-chem model climatology and are fixed.)

3.4 Meteorological Fields and A Priori

For each observation at a particular time and geographic location, the MOPITT retrieval algorithm requires temperature and water vapor profiles as well as a priori surface temperature values. For V7-V10 meteorological profiles are extracted from the MERRA-2 product (<https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/>). MOPITT retrieval products rely on variable a priori to represent the geographical and seasonal variability of “background” concentrations of CO. For the V4 and V5 products, the a priori was based on monthly CO climatologies for the years 1997–2004 as simulated with the MOZART chemical transport model. For the V6-V10 products, the CO a priori is based on monthly climatologies for the

years 2000–2009 simulated with the CAM-Chem model [Deeter et al., 2014]. MOPITT a priori $\log(\text{VMR})$ values vary by month, but do not vary from year to year; this simplifies the interpretation of long-term trends in the data. For all MOPITT product versions, model-based climatologies used to generate the a priori are gridded at one degree (lat/lon) horizontal resolution and monthly temporal resolution. Spatial and temporal interpolation are used to generate a priori values at each specific observation location and day.

3.5 Retrievals using information only from MOPITT LMC channels

Following the August, 2024 failure of the remaining TIR pressure modulated cell (PMC) channel 7, it was necessary to remove this channel in the retrieval so that it would no longer contribute measurement information. This was done algorithmically by deweighting that channel by several orders of magnitude compared to the length modulated cell (LMC) channels (channel 5, TIR, and channel 6, NIR). **The resulting retrieved vertical CO profiles after August 2024 contain mostly a priori information in the mid to upper troposphere where the PMC had more sensitivity due to its cell pressure and corresponding weighting functions. However, sensitivity to the lower troposphere, where the TIR LMC channel 5 is designed to observe, and to the total column with NIR LMC channel 6, was unchanged.** In fact, the LMC channels have been configured consistently over the entire MOPITT record, unlike PMC channel 7 that was adjusted after the optical bench failure in 2001 followed by failure in 2024. In order to exploit this full record consistency of LMC channels 5 and 6 for information in the lower troposphere, we have produced a lower tropospheric column quantity (described below in sec. 3.7) using retrievals that de-weight PMC channels for the full MOPITT record. Although the normal V10 TIR and TIR-NIR vertical profiles contain these discontinuities from the PMC channels in the MOPITT record, the associated averaging kernels provide characterization of the vertical sensitivity allowing accurate use in data assimilation and reanalysis to correct model CO distributions.

3.6 Cloud Detection

Only MOPITT observations made in clear sky conditions are used in Level 2 retrieval processing. The clear/cloudy determination is based both on MOPITT's thermal-channel radiances and the MODIS cloud mask. With respect to the MOPITT thermal-channel test, the ratio of the observed MOPITT Channel 7 Average radiance and the corresponding model-calculated value is compared to a predefined global threshold value. If the radiance ratio is less than the threshold value, clouds are indicated and that MOPITT observation is flagged as cloudy by the MOPITT test. For V9 and V10, the radiance ratio for each MOPITT retrieval is reported in the diagnostic "MOPCId Rad Ratio".

The overall outcome of the MOPITT cloud detection algorithm for a particular retrieval can be determined using the "Cloud Description" diagnostic in the Level 2 files. The Cloud Description diagnostic values (1-6) are defined as follows. A value of 1 means "MOPITT clear, MODIS cloud mask unavailable," a value of 2 means "MOPITT and MODIS cloud mask agree on clear," a value of 3 means "MOPITT cloudy, MODIS cloud mask clear," a value of 4 means "MOPITT clear, MODIS indicating low clouds," and a value of 5 means "polar regions, MODIS cloud mask clear." Finally, a value of 6 is assigned to observations where the MODIS cloud mask indicates that the area was cloudy but the test based on MOPITT's thermal-channel radiances finds that the area was clear. **For the 4 months of data following the failure of the PMC channel 7 in August 2024, cloud detection used MOPITT channel 5 for the MOPITT cloud mask in addition to MODIS.**

3.7 Lower tropospheric CO column estimates

From the retrievals that use LMC channels only, we compute a new L2 field for the lower troposphere column from the surface to 600hPa. For retrievals over the ocean, this includes the first 4 layers (surface to 900 hPa, 900-800 hPa, 800-700 hPa and 700-600 hPa). Array dimensions are the same as for the total column field to include the Lower Troposphere CO Column estimate and uncertainty for each retrieval scene, in molec/cm² (molecules per square centimeter). These new lower troposphere column fields (estimated column and uncertainty) are in addition to the normal MOPITT profile and total column products using all available channels.

4 Product Format and Content

The contents of the V10 Level 2 and Level 3 product files are described and tabulated in Appendices A and B respectively. Beginning with the MOPITT V6 products, the format of the archival Level 1, Level 2 and Level 3 data files switched from HDF-EOS2, based on HDF4 libraries, to HDF-EOS5, based on HDF5 libraries. V10 products are in the same HDF5 format as V6, V7 and V8 products and should be readable with analysis tools developed for those earlier products. HDF is a standard format for large datasets (<https://www.hdfgroup.org/>). The HDF-EOS format is an extension of HDF developed by the HDF-EOS group (<http://hdfeos.org/index.php>). Files distributed in the HDF-EOS5 format can be accessed with a wide range of software tools including IDL, NCL and MATLAB (<https://support.hdfgroup.org/products/>).

4.1 Level 1 Data

The format and contents of the Level 1 product files containing the MOPITT calibrated radiances is unchanged for V10. After the failure of the PMC in August 2024, some spacecraft performance metrics were out of expected range for operationally valid data.

For example, the motor current to the PMC was 0 because it was turned off. Processing filters flagged those current measurements and set the entire observation as invalid. This happened again when power to the half the instrument was turned off in December 2024. For V10 the filters were adjusted after August 2024 to allow valid data to be processed despite some of the instrument health readings to be out of range.

4.2 Level 2 Data

The contents of the V10 Level 2 product files are described in table form in Appendix A. Appendices C, D and E provide examples of IDL, NCL and Python code, respectively, used to open and read the contents of V10 Level 2 data files.

4.3 Level 3 Data

MOPITT Level 3 products are available as gridded daily-mean and monthly-mean files. Data averaging is performed on a one-degree latitude/longitude grid. Compared to Level 2 products, these gridded products typically are less affected by random retrieval errors (e.g., due to instrument noise or geophysical noise) and are packaged into much smaller HDF5 data files. Within each type of Level 3 file, data-averaged products are separately available for daytime and nighttime MOPITT observations. The contents of the V10 L3 files are described in Appendix B; for brevity, only daytime-overpass L3 fields are listed. V10 L3 files include several diagnostics first introduced in the V7 product, including the total column averaging kernel, dry air column, water vapor column, smoothing error covariance matrix and measurement error covariance matrix.

V10 Level 3 processing employs the same strategy for improving information content used for V7-V9. The method relies on both pixel filtering and signal-to-noise ratio (SNR) thresholds for Channel 5 and 6 Average radiances (i.e., 5A and 6A). SNR values for each observation are obtained using radiance and radiance uncertainty values contained in the diagnostic “Level1 Radiances and Errors” in the Level 2 data files. Observations from Pixel 3, one of the four elements of MOPITT's linear detector array, are excluded from TIR-only and TIR/NIR L3 products due to highly variable Channel 7 SNR values. Observations with relatively low SNR tend to yield retrievals weighted heavily by the a priori and generally result in low DFS. Excluding low-SNR observations from the Level 3 cell-averaged values raises overall mean DFS values. Specific filtering rules used for both the daily-mean and monthly-mean V10 Level 3 products are:

- V10 Level 3 TIR-only products exclude all observations from Pixel 3 in addition to observations where the 5A SNR < 1000
- V10 Level 3 NIR-only products exclude all observations where the 6A SNR < 400
- V10 Level 3 *daytime* TIR/NIR products exclude all observations from Pixel 3 in

addition to observations where both (1) the 5A SNR < 1000 *and* (2) the 6A SNR < 400

- V10 Level 3 *nighttime* TIR/NIR products exclude all observations from Pixel 3 in addition to observations where the 5A SNR < 1000.

5 Data Analysis Considerations

5.1 Data Quality

Compared to V7, validation results for V8 and V9 CO products indicated reduced long-term bias drift, weaker bias geographical variability and smaller biases overall [Deeter et al., 2019; 2022]. Initial validation results indicate the same for the V10 product and will be documented in an upcoming validation paper. One difference starting with V9 data was the use of beta products using extrapolated calibration until the subsequent calibration event. This is no longer applicable since V10 contains the complete MOPITT data record.

Retrieval data quality may also be affected by forward model error, errors in assumed meteorological profiles, and instrumental degradation. For these effects, robust estimates of the associated retrieval errors are not feasible. Quantifying such errors is also complicated because they may be highly variable in space and time.

5.2 Data Averaging

Because of both geophysical and instrumental noise, individual MOPITT retrieved profiles are not typically useful for scientific analysis. This is especially true for the NIR-only and TIR/NIR products. Instead, users should employ statistical methods applied to ensembles of retrievals. Simple data averaging is the most common statistical method for reducing the effects of random instrument noise. The tradeoff to this benefit is reduced spatial and/or temporal resolution. When averaging over an ensemble, retrieval uncertainties associated with random radiance errors (such as geophysical noise and instrumental noise) decrease approximately as the square root of the number of retrievals in the ensemble.

The retrieval state vector represents CO volume mixing ratio (VMR) variability as a log-normal quantity. This has important implications for data averaging. For MOPITT data subsets where the main source of retrieval variability is random retrieval noise (rather than CO variability), retrieved VMR values will follow a log-normal distribution. In such cases, the appropriate method for reducing the effects of instrument noise is to (1) convert individual VMR profiles into $\log(\text{VMR})$ profiles, (2) compute the mean, and (3) convert the mean

log(VMR) profile back to a VMR profile. Because of the asymmetry of the log-normal distribution, directly computing the mean VMR profile from a set of VMR profiles in such cases will produce a positive bias relative to “truth.” In contrast, when CO variability is the dominant source of retrieval variability (such as when averaging over large regions and temporal intervals), directly calculated mean VMR values are most meaningful.

5.3 Use of Averaging Kernels

For scientific analysis, users should understand the role of the a priori on the MOPITT retrieved profiles and total columns [Rodgers, 2000]. The relative weight of the a priori profile x_a in the retrieved profile x_{rtv} can be described by the relation

$$x_{rtv} \approx x_a + A (x_{true} - x_a) = A x_{true} + (I - A) x_a \quad (1)$$

where x_{true} is the true profile, A is the averaging kernel matrix, and I is the identity matrix. Both A and x_a are highly variable and are provided as ancillary data for each MOPITT retrieved profile. Averaging kernels indicate the sensitivity of x_{rtv} to different levels of the atmosphere and exhibit significant spatial variability, both vertical and horizontal. Inclusion of a priori information, as described by Eq. 1, is associated with all remote sensing methods based on optimal estimation. The retrieved profile is most heavily weighted by the a priori profile at levels where the actual measurements are least sensitive. An important consequence of this effect is that, when comparing MOPITT retrieved profiles against in-situ data or model results, users must transform these comparison datasets using Eq. 1, so that the comparison data exhibit the same degree of smoothing and a priori dependence as the MOPITT product [Deeter et al., 2003; 2010]. For the V10 products (like the earlier V5-V9 products), users must make this transformation in terms of $\log_{10}(\text{VMR})$ rather than VMR. Users should also observe the level-layer associations described in [Sec. 3.3](#). Users of the MOPITT total column product (rather than retrieved profiles) should refer to [Sec. 5.5](#).

5.4 Data Filtering

Because of the potential variability of MOPITT data quality, as discussed above, users may decide to exclude particular subsets of the Level 2 data in their analyses. This is a reasonable strategy, *unless such methods could impose retrieval bias*. For example, filtering based on the “Degrees of Freedom for Signal” (DFS) parameter tends to retain high-CO profiles and discard low-CO profiles, thereby imposing a positive retrieval bias on the filtered subset. Filtering on DFS, or other characteristics of the retrieval averaging kernels, is therefore not recommended.

Alternatively, filters based on geophysical criteria which are known to provide better conditions for remote sensing retrievals may be appropriate. For example, over land, daytime conditions typically provide better thermal contrast conditions for TIR- and

TIR/NIR-based retrievals than nighttime conditions.

5.5 Analysis of Retrieved CO Total Column Values

For users interested in quantitatively comparing MOPITT retrieved CO total column values with other datasets (or model output), the V10 Level 2 and Level 3 product files include the total column averaging kernel \mathbf{a} ; this vector quantifies the sensitivity of the retrieved total column to perturbations at each level of the CO profile. Thus, if C_{rtv} is the retrieved CO total column, and \mathbf{x} is the CO state vector comprised of CO $\log_{10}(\text{VMR})$ values, the total column averaging kernel element for level j in the CO profile is defined by

$$a_j = \partial C_{rtv} / \partial x_j^j \quad (2)$$

Given a comparison CO profile x_{cmp} (e.g., either from in-situ measurements or model output), the total column averaging kernel vector is used to simulate MOPITT total column retrievals using the equation

$$C_{sim} = C_a + \mathbf{a}(x_{cmp} - x_a) \quad (3)$$

where C_a is the a priori total column value corresponding to the a priori profile x_a . Both C_a and x_a are also provided in the V8 Level 2 product files for each retrieval.

For V8, V9 and V10 products, the method of calculating \mathbf{a} has been revised for consistency with Rodgers [12], Sec. 4.3. Specifically, the total column averaging kernel is now calculated as

$$\mathbf{a}^T = \mathbf{h}^T \mathbf{A} \quad (4)$$

where \mathbf{h} is the partial column operator (i.e., the vector of sensitivities of partial column values to $\log_{10}(\text{VMR})$).

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7 Appendices

A. Tabulated Contents of V10 Level 2 Product Files

DATA ARRAY DIMENSION TERMS

Dimension Name	Definition	Size
nTime	Number of retrievals	Varies with each granule
nChan	Number of channels of the instrument	8
nPix	The number of pixels (i.e., number of detector elements)	4
nTwo	For data fields which include associated uncertainty or variability, the first element is the parameter and second element is uncertainty/variability unless otherwise specified.	2
nPrs	Number of fixed pressure levels	9
nPrs2	Number of pressure levels, including the surface	10

GEOLOCATION FIELDS ('HDFEOS/SWATHS/MOP02/Geolocation Fields/...')

Field Name	Definition	Dimension	Units	Data Type
SecondsinDay	Time of the measurement in seconds from the beginning of the day.	nTime	s	F
Latitude	Geolocation of the pixel	nTime	deg	F
Longitude	Geolocation of the pixel	nTime	deg	F
Pressure	Pressure Levels	nPrs	hPa	F
Pressure2	Pressure Levels including the surface	nPrs2	hPa	F
Time	TAI Time of the observation	nTime	s	F

F = Floating Point **I** = Integer

RETRIEVED CO FIELDS ('HDFEOS/SWATHS/MOP02/Data Fields/...')

Field Name	Definition	Dimension	Units	Data Type
RetrievedCOMixingRatioProfile	CO Mixing Ratio for the layer above each pressure level	nTwo, nPrs, nTime	ppbv	F
RetrievedCOSurfaceMixingRatio	CO Mixing Ratio at the surface	nTwo, nTime	ppbv	F
RetrievedCOTotalColumn	CO Total Column	nTwo, nTime	molec/cm ²	F
RetrievedCOLowerTropColumn	CO Tropospheric Column from Surface to 600hPa. These use only channel 5 (TIR) and channels 5 & 6 (TIR/NIR)	nTwo, nTime	molec/cm ²	F

A PRIORI CO FIELDS ('HDFEOS/SWATHS/MOP02/Data Fields/...')

Field Name	Definition	Dimension	Units	Data Type
APrioriCOMixingRatioProfile	Temporally and geographically variable a priori CO profile based on a climatology for 2000-2009 simulated with the CAM-Chem model	nTwo, nPrs, nTime	ppbv	F
APrioriCOSurfaceMixingRatio	Temporally and geographically variable a priori surface CO based on a climatology for 2000-2009 simulated with the CAM-Chem model	nTwo, nTime	ppbv	F
APrioriCOTotalColumn	Temporally and geographically variable a priori total column CO based on a climatology for 2000-2009 simulated with the CAM-Chem model	nTwo, nTime	molec/cm ²	F

AVERAGING KERNEL FIELDS ('HDFEOS/SWATHS/MOP02/Data Fields/...')

Field Name	Definition	Dimension	Data Type
RetrievalAveragingKernelMatrix	For each retrieval, a floating point array (10 x 10) containing the matrix describing the sensitivity of the retrieved CO log(VMR) profile to the true CO log(VMR) profile. Dimensions of Retrieval Averaging Kernel Matrix are ordered (nrow, ncolumn, ntime)	nPrs2, nPrs2, nTime	F

AveragingKernelRowSums	This diagnostic provides a single scalar value for each row of the averaging kernel matrix equal to the sum of the elements in that row. Small row-sum values indicate retrieval levels heavily weighted by the a priori while values approaching unity indicate levels with relatively weak sensitivity to the a priori.	nPrs2, nTime	F
TotalColumnAveragingKernel	This diagnostic allows users to properly compare MOPITT total column retrievals with total columns derived from in-situ profiles or model simulations.	nPrs2, nTime	F
TotalColumnAveragingKernelDimless	This diagnostic allows users to properly compare MOPITT total column retrievals with total columns derived from in-situ profiles or model simulations based on partial columns instead of log(VMR).	nPrs2, nTime	F

CLLOUD FIELDS ('HDFEOS/SWATHS/MOP02/Data Fields/...')

These quantities are unitless

Field Name	Definition	Dimension	Data Type
CloudDescription	0 = clear, only MOPITT thermal and cloudtop used 1 = clear, only MOPITT thermal used 2 = MOPITT and MODIS cloud mask agree on clear 3 = MODIS cloud mask only clear (when MOPITT determines cloudy) 4 = MOPITT overriding MODIS cloud mask over low clouds (MODIS test flags used) 5 = MODIS cloud mask only, clear over polar regions and daytime 6 = Nighttime ocean scenes where the MODIS cloud mask-based test finds that the area was cloudy but MOPITT's thermal-channel radiances finds that the area was clear	nTime	I

MODISCloudDiagnostics	(1) Number of “determined” MODIS pixels (2) Percentage of cloudy MODIS pixels (3) Percentage of clear MODIS pixels, test 1 (4) Percentage of clear MODIS pixels, test 2 (5) Percentage of clear MODIS pixels, test 3 (6) Average value of “sun glint” MODIS flag (7) Average value of “snow/ice background” MODIS flag (8) Average value of “non-cloud obstruction” MODIS flag (9) Average value of “IR threshold test” MODIS flag (10) Average value of “IR temperature difference tests” MODIS flag (11) Average value of “visible reflectance test” MODIS flag (12) Fraction of “determined” MODIS pixels	12, nTime	F
MOPCldRadRatio	Ratio of observed Channel 7 Average radiance and corresponding model-calculated value (used for cloud detection)	nTime	F

SURFACE PROPERTY FIELDS (‘HDFEOS/SWATHS/MOP02/Data Fields/...’)

Field Name	Definition	Dimension	Units	Data Type
APrioriSurfaceEmissivity	A priori surface emissivity from static map	nTwo, nTime		F
APrioriSurfaceTemperature	A priori surface temperature from MERRA2 analysis	nTwo, nTime	K	F
DEMAltitude	Digital Elevation Model surface height	nTime	m	F
SurfaceIndex	0 = water 1 = land 2 = mixed (coastline)	nTime		I
SurfacePressure	Surface pressure from MERRA2 analysis	nTime	hPa	F
RetrievedSurfaceEmissivity	Surface emissivity from the retrieval	nTwo, nTime		F
RetrievedSurfaceTemperature	Surface temperature from the retrieval	nTwo, nTime	K	F

RADIANCE FIELDS ('HDFEOS/SWATHS/MOP02/Data Fields/...')

Field Name	Definition	Dimension	Units	Data Type
DailyGainDev	This diagnostic provides the standard deviation of the gain values used to calibrate the radiances for a particular channel and pixel on one day. In this case, nTwo is the Average and Difference signal gains.	nTwo, nChan, nPix		F
Level1RadiancesandErrors	First dimension corresponds to radiances/uncertainties; second dimension corresponds to channel (in sequence 7A, 3A, 1A, 5A, 7D, 3D, 1D, 5D, 2A, 6A, 2D, 6D).	nTwo, 12, nTime	W/m ² Sr	F
L2RadianceCorrectionFactor	Time- and water vapor dependent radiance correction factors applied to each radiance (same sequence as Level1RadiancesandErrors).	12, nTime		F

RETRIEVAL DIAGNOSTICS ('HDFEOS/SWATHS/MOP02/Data Fields/...')

These quantities are unitless

Field Name	Definition	Dimension	Data Type
DegreesofFreedomforSignal	For each retrieval, a floating point value describing the number of pieces of independent information in the retrieval, equal to the trace of the averaging kernel matrix.	nTime	F
MeasurementErrorCovarianceMatrix	Measurement error represents the retrieval log(VMR) uncertainty due to uncertainties in the measured radiances (including instrumental and geophysical 'noise').	nPrs2, nPrs2, nTime	F

RetrievalAnomalyDiagnostic	These flags are set to true when particular anomalous conditions are observed, suggesting that the retrievals should either be ignored or used cautiously. The first four flags (i.e., elements 1-4 of the Retrieval Anomaly Diagnostic array) are set to true (i.e., a value of 1) when one of the thermal channel weighting functions exhibits a sign change vertically. Elements 1-4 correspond respectively to the 5A, 5D, 7A, and 7D weighing functions. The fifth flag of the Retrieval Anomaly Diagnostic array is set to true when the retrieval averaging kernel matrix includes at least one negative element on the matrix diagonal.	5,nTime	I
RetrievalErrorCovarianceMatrix	For each retrieval, a floating point array (10 x 10) containing the posteriori covariance matrix in base-10 log(VMR).	nPrs2, nPrs2, nTime	F
RetrievalIterations	The number of retrieval algorithm iterations needed for convergence	nTime	I
SignalChi2	A measure of the retrieval's goodness of fit.	nTime	F
SmoothingErrorCovarianceMatrix	Smoothing error represents the retrieval log(VMR) uncertainty due to the influence of the a priori and weighting functions.	nPrs2, nPrs2, nTime	F
RetrievedCOTotalColumnDiagnostics	This two-element vector contains both the estimated smoothing error and measurement error contributions (in that order) to the total retrieval error for CO total	nTwo, nTime	F

	<p>column. Smoothing error represents the uncertainty in the retrieved total column due to the influence of the a priori and weighting functions. Measurement error describes the uncertainty due to random errors in the measured radiances.</p>		
--	---	--	--

**ATMOSPHERIC AND OBSERVATIONAL FIELDS
(‘HDFEOS/SWATHS/MOP02/Data Fields/...’)**

Field Name	Definition	Dimension	Units	Data Type
PressureGrid	Fixed pressure levels (i.e., 900, 800, 700, 600, 500, 400, 300, 200 and 100 hPa)	nPrs	hPa	F
SolarZenithAngle	Solar zenith angle	nTime	deg	F
SatelliteZenithAngle	Viewing angle of the satellite	nTime	deg	F
SwathIndex	For each retrieval, a three element integer vector containing the unique 'pixel' (varies from 1 to 4), 'stare' (varies from 1 to 29), and 'track' indices. 29 stares (equivalent to the mirror pivoting out and back) define one track.	3, nTime		I
DryAirColumn	Dry-air atmospheric column to facilitate the computation of the equivalent mixing ratio of CO averaged over the atmospheric column	nTime	molec/cm ²	F
WaterVaporColumn	Moist-air atmospheric column to facilitate the computation of the equivalent mixing ratio of CO averaged over the atmospheric column. This is computed from MERRA2 analysis	nTime	molec/cm ²	F

NOTES: Fill Values are -9999

B. Tabulated Contents of V10 Level 3 Product Files

All fields listed below reside in HDF5 directory 'HDFEOS/GRIDS/MOP03/Data Fields/...'. Find data field descriptions in Appendix A. Field names of nighttime-overpass L3 products, e.g., RetrievedCOMixingRatioProfileNight, are also included in L3 files but are not shown in tables below. All L3 fields are floating point, except for integer-valued fields SurfaceIndexDay, SurfaceIndexNight, NumberOfPixelsDay and NumberOfPixelsNight. L3 files also contain mean uncertainty and variability (i.e., standard deviation) statistics for fields in table marked with dagger symbol (†). For example, mean uncertainty and variability statistics for RetrievedCOMixingRatioProfileDay are included in L3 files as RetrievedCOMixingRatioProfileMeanUncertaintyDay and RetrievedCOMixingRatioProfileVariabilityDay .

GEOLOCATION FIELDS

Field Name	Definition	Dimension	Units
Latitude	Latitudes of grid cell centers	180	deg
Longitude	Longitudes of grid cell centers	360	deg
Pressure	Fixed pressure grid	9	hPa
Pressure2	Fixed pressure grid + surface pressure	10	hPa

RETRIEVED CO FIELDS

Field Name	Dimension	Units
RetrievedCOMixingRatioProfileDay†	Pressure, Latitude, Longitude	ppbv
RetrievedCOSurfaceMixingRatioDay†	Latitude, Longitude	ppbv
RetrievedCOTotalColumnDay†	Latitude, Longitude	mol/cm ²

A PRIORI FIELDS

Field Name	Dimension	Units
-------------------	------------------	--------------

APrioriCOMixingRatioProfileDay	Pressure, Latitude, Longitude	ppbv
APrioriCOSurfaceMixingRatioDay	Latitude, Longitude	ppbv
APrioriCOTotalColumnDay	Latitude, Longitude	mol/cm ²

AVERAGING KERNEL FIELDS

Field Name	Dimension
RetrievalAveragingKernelMatrixDay	Pressure2, Pressure2, Latitude, Longitude
TotalColumnAveragingKernelDay	Pressure2, Latitude, Longitude

SURFACE PROPERTY FIELDS

Field Name	Dimension	Units
RetrievedSurfaceTemperatureDay [†]	Latitude, Longitude	K
RetrievedSurfaceEmissivityDay [†]	Latitude, Longitude	
APrioriSurfaceTemperatureDay	Latitude, Longitude	K
APrioriSurfaceEmissivityDay	Latitude, Longitude	
DEMAltitudeDay	Latitude, Longitude	m
SurfaceIndexDay (integer-valued)	Latitude, Longitude	
SurfacePressureDay	Latitude, Longitude	hPa

RETRIEVAL DIAGNOSTICS

Field Name	Dimension
NumberOfPixelsDay (integer-valued)	Latitude, Longitude
DegreesofFreedomforSignalDay	Latitude, Longitude

RetrievalErrorCovarianceMatrixDay	Pressure2, Pressure2, Latitude, Longitude
MeasurementErrorCovarianceMatrixDay	Pressure2, Pressure2, Latitude, Longitude
SmoothingErrorCovarianceMatrixDay	Pressure2, Pressure2, Latitude, Longitude
RetrievedCOTotalColumnDiagnosticsDay	Latitude, Longitude
SignalChi2Day	Latitude, Longitude

ATMOSPHERIC AND OBSERVATIONAL FIELDS

Field Name	Dimension	Units
SolarZenithAngleDay	Latitude, Longitude	deg
SatelliteZenithAngleDay	Latitude, Longitude	deg
DryAirColumnDay	Latitude, Longitude	molec/cm ²
WaterVaporColumnDay	Latitude, Longitude	molec/cm ²

NOTES: Fill Values are -9999.

C. Sample IDL Code for Opening and Reading V10 Level 2 files

```

pro example_V10_lev2

; sample IDL code for opening and reading MOPITT Version 9 Level 2 files

; note different paths for 'Geolocation Fields' and 'Data Fields'

infile =

'/MOPITT/V10T/Archive/L2/200301/0101/MOP02T-20030101-L2V19.9.1.he5' print,

infile

print, 'open hdf5 file'
file_id = H5F_OPEN(infile)

; read latitudes into variable 'moplat'
print, 'read latitudes'
dataset_id = H5D_OPEN(file_id, '/HDFEOS/SWATHS/MOP02/Geolocation
Fields/Latitude') moplat = H5D_Read(dataset_id)
H5D_CLOSE, dataset_id

```

```

; read longitudes into variable 'moplon'
print, 'read longitudes'
dataset_id = H5D_OPEN(file_id, '/HDFEOS/SWATHS/MOP02/Geolocation
Fields/Longitude') moplon = H5D_Read(dataset_id)
H5D_CLOSE, dataset_id

; read retrieved profiles into variable 'rtvprofil'
print, 'read retrieved CO profiles'
dataset_id = H5D_OPEN(file_id, '/HDFEOS/SWATHS/MOP02/Data
Fields/RetrievedCOMixingRatioProfile') rtvprofil = H5D_Read(dataset_id)
H5D_CLOSE, dataset_id

; read averaging kernel matrices into variable 'avkrn'
print, 'read AK matrix'
dataset_id = H5D_OPEN(file_id, '/HDFEOS/SWATHS/MOP02/Data
Fields/RetrievalAveragingKernelMatrix') avkrn = H5D_Read(dataset_id)
H5D_CLOSE, dataset_id

H5F_CLOSE, file_id

; print lat and lon of first retrieval
print, moplat(0), moplon(0)
; print retrieved profile of first retrieval (fixed-levels only, surface retrieval
missing) print, rtvprofil(0,0:8,0)
; print AK matrix for first retrieval
print, avkrn(0:9,0:9,0)

return
end

```

D. Sample NCL Code for Opening and Reading V10 Level 2 files

```

;=====
==; ; example-mopitt-V10-lev2.ncl
;=====
==; ;
; Concepts illustrated:
; - For use with MOPITT CO version 9, level 2 TIR product
; - Loading CO data, AK, latitude and longitude from
; MOPITT level 2 hdf5 file
;
; To run type:
; ncl example-mopitt-V10-lev2.ncl
;
;=====;

```

begin

```

;-----
; MOPITT file location
;-----
indir = "/MOPITT/V10T/Archive/L2/200301/0101/"
fname = "MOP02T-20030101-L2V19.9.1.he5"
infile = indir+fname
print(infile)

;-----
; load file and extract data structures
;
; note: names of data structures
; determined from an ncl_filedump
;-----

print("load hdf5 file")
fin = addfile(infile, "r")

; extract longitude
moplon = fin->"Longitude_MOP02"$

; extract latitude

moplat = fin->"Latitude_MOP02"$

; extract profile
ret_profile = fin->"RetrievedCOMixingRatioProfile_MOP02"$

; extract averaging kernel
avkrn = fin->"RetrievalAveragingKernelMatrix_MOP02"$

;-----
; print data structure information
;-----
; Determine dimensions of data structures
printVarSummary(moplon)
printVarSummary(moplat)
printVarSummary(ret_profile)
printVarSummary(avkrn)

; print lat, lon of first retrieval

```

```

print("Latitude: "+ moplatt(0)+", Longitude: "+moplont(0))

; print first retrieved profile on fixed levels - surface retrieval is in a separate data
structure print(ret_profile(0,,:,0))

; print AK matrix for first retrieval
print(avkrrn(0,,:,))

end

```

E. Sample Python Code for Opening and Reading V10 Level 2 files

```

import mopittAccessFunctions as maf
import numpy
# https://docs.h5py.org/en/stable/
import h5py
import os.path
import sys

print("Using MOPITT Access Functions")
inFileName = sys.argv[1]
fName = os.path.basename(inFileName)

list = maf.listFields(inFileName)
#PRINT OUT THE LIST OF DATA FIELDS
print ("DATA FIELDS")
for field in list:
    print(field)

if (fName[0:5] == "MOP02"):
    ##### LEVEL 2 CO Retrievals at 22km resolution #####
    sampleFieldName = 'SurfaceIndex'
    print("SAMPLE FIELD " + sampleFieldName)

else:
    ##### LEVEL 3 CO Retrievals averaged onto a 1x1deg grid #####

    sampleFieldName = 'SignalChi2VariabilityDay'
    print("SAMPLE FIELD " + sampleFieldName)

# PULL A FIELD OUT AND USE IT
data = maf.getField(inFileName,sampleFieldName)

dataType = type(data)
print("DATA TYPE " + str(dataType))

```

```
dataShape = data.shape
print("DATA SHAPE " + str(dataShape))
```

```
# YOU CAN USE THIS PROGRAM TO ACCESS MOPITT DATA WITH PYTHON
```

```
import numpy
import h5py
import os.path
```

```
def listFields(inFileName):
    print("READING FILE " + inFileName)
    fName = os.path.basename(inFileName)
```

```
    try:
        inFile = h5py.File(inFileName,'r')
```

```
    except:
        print("ERROR: CANNOT OPEN " + inFileName)
        return 0
```

```
    structure = '/HDFEOS/SWATHS/MOP02/Data Fields/'
```

```
    if ("MOP03" == fName[0:5]):
        structure = '/HDFEOS/GRIDS/MOP03/Data Fields/'
```

```
    try:
        fieldList = inFile[structure]
    except:
        print("UNKNOW OBJECT " + structure)
        return 0
```

```
    fields = []
    for x in fieldList:
        fields.append(x)
    try:
        inFile.close()
    except:
        print("ERROR CANNOT CLOSE " + inFileName)
        return 0
    print(inFileName + " Closed")
    return fields
```

```
def getField(inFileName,fieldName):
    print("READING FILE " + inFileName)
    fName = os.path.basename(inFileName)
```

```
    try:
        inFile = h5py.File(inFileName,'r')
    except:
        print("ERROR: CANNOT OPEN " + inFileName)
        return 0
```

```
    structure = '/HDFEOS/SWATHS/MOP02/Data Fields/'
```

```
if ("MOP03" == fName[0:5]):  
structure = '/HDFEOS/GRIDS/MOP03/Data Fields/'
```

```
dataName = structure + fieldName
```

```
try:
```

```
dataF = inFile[dataName]
```

```
data = dataF[()]
```

```
except:
```

```
print("CANNOT READ " + dataName)
```

```
return 0
```

```
try:
```

```
inFile.close()
```

```
except:
```

```
print("ERROR CANNOT CLOSE " + inFileName)
```

```
return 0
```

```
print(inFileName + " Closed")
```

```
return data
```