# MOPITT V8 Level 2 Data Quality Summary

**The following information applies to MOPITT Level 2 (L2) data, Version 8 (V8; L2V18.0.x), first released December, 2018**

Further details on MOPITT Data Quality and recommended analysis methods may be found in the updated V8 User's Guide, which is available on the MOPITT Publications page.

Several significant retrieval algorithm and product format changes have been introduced in the V8 product. Details can be found in the V8 User's Guide. Featured improvements in the V8 retrieval product include (1) Parameterized radiance bias correction, with time and water vapor parameters, to mitigate temporal drift and latitude dependence of MOPITT retrieval biases, (2) use of the MODIS collection 6.1 cloud mask (consistently applied to the full MOPITT record), (3) updated spectroscopy for $H_2O$ and $N_2$ continua and (4) improved method for calculating total column averaging kernels.

# CO Retrieval Products

Similar to the releases of the V5 to V7 products, three different types of V8 Level 2 products are available based on different subsets of the MOPITT calibrated thermal- and near-infrared (TIR and NIR) radiances. The format and content of these three types of files are identical. The choice of which type of product to use for a particular application depends on the relative importance of sensitivity to CO in the boundary layer, long-term stability, required geographical coverage, and other factors. Users of MOPITT products are encouraged to contact members of the MOPITT Science Team for advice on the appropriate product for particular applications.

The V8 Level 2 products include:

- A **TIR-only** product. *Example filename: MOP02T-20010101-L2V18.0.1.he5.*
- A **NIR-only** product, which is produced only for daytime observations over land. This product exhibits relatively large random errors and may require significant spatial and/or temporal averaging. *Example filename: MOP02N-20010101-L2V18.0.2.he5*.
- A **TIR/NIR** product, which features the maximum sensitivity to near-surface CO. In this product, information from the NIR channels is exploited only in daytime observations over land. This product exhibits relatively large random errors and may require significant spatial and/or temporal averaging. *Example filename: MOP02J-20010101-L2V18.0.3.he5*.

CO layer average mixing ratio profiles are retrieved for clear-sky scenes on the 9 standard MOPITT pressure layers with level values: surface, 900, 800, 700, 600, 500, 400, 300, 200, and 100 hPa. Layer values are reported corresponding to the higher pressure level in each layer, e.g., the value reported for 900 hPa represents the uniformly weighted layer average CO mixing ratio

for 900 to 800 hPa.  This is the same CO profile representation as used for V5-V7, but is different from V4. Retrieved CO total columns are calculated by integrating the retrieved mixing ratio profile and are not retrieved independently. The horizontal footprint of each MOPITT retrieval is 22 km by 22 km at nadir. The contents of the Level 2 (MOP02) files are provided in the V8 User's Guide.

# Estimated errors

For CO vertical profiles, estimated errors (i.e., uncertainties) are available in the error field (second element) of the "Retrieved CO Mixing Ratio Profile" and "Retrieved CO Surface Mixing Ratio" variables of the MOP02 files. These values represent the cumulative error from smoothing error, model parameter error, forward model error, geophysical noise, and instrumental noise.

# Missing data when surface pressure < 900 mb

For the 'standard' case (when surface pressure exceeds 900 mb), there are 10 valid levels in the retrieved profile (including the surface-level retrieval), and the Retrieval Averaging Kernel Matrix A (provided in the Level 2 product) is a 10 by 10 matrix.

For the case where 800 mb < p_sfc < 900 mb, the surface level moves to the second row and column of A. In this case, the first row and column of A is populated by the value 0. For cases where there are even more missing levels (e.g., p_sfc < 800 mb), the surface level always skips down to replace the missing level closest to p_sfc.

For the vertical profile mixing ratios, the values at the standard retrieval levels that are greater than the surface pressure will be reported as "nodata" (-9999).

# Cloud detection

MOPITT retrievals are only performed for clear-sky scenes. The clear/cloudy determination is based both on MOPITT's thermal-channel radiances and the MODIS cloud mask. Since about 2010, electronic crosstalk affecting MODIS thermal-channel Bands 29 to 31 has resulted in a false trend towards increasing cloudiness, particularly for tropical nighttime scenes over the ocean. This issue affects MODIS products from both Collections 5 (used until February 2016 in MOPITT Versions 5 and 6) and 6 (used since March 2016 in MOPITT Versions 5 and 6). For the cloud detection algorithm used for MOPITT V8 products, two changes have been made. First, MODIS Collection 6.1 cloud mask files are used consistently for processing the entire MOPITT mission.(Differences between Collection 6 and Collection 6.1 MODIS cloud products are documented in: https://modisatmosphere.gsfc.nasa.gov/sites/default/files/ModAtmo/C6.1_Calibration_and_Cloud_Product_Changes_UW_frey_CCM_1.pdf).

*Cloud Description Value -> Basis of Clear-sky Determination*

*1 -> MOPITT clear / MODIS unused*
*2 -> MOPITT clear / MODIS clear*
*3 -> MOPITT cloudy / MODIS clear*
*4 -> MOPITT clear / MODIS 'low clouds'*
*5 -> High latitude, MOPITT unused / MODIS clear*
*6 -> Ocean scene, MOPITT clear / MODIS cloudy*

More detailed information regarding the MODIS cloud mask values corresponding to each MOPITT pixel are contained in the “MODIS Cloud Diagnostics” vector in the L2 product files.

# Data Interpretation

**Averaging Kernels**: Averaging kernels indicate the sensitivity of the retrievals to different levels of the atmosphere, and must be analyzed in order to properly interpret the retrieved data. For V8 (and earlier products), the "Retrieval Averaging Kernel Matrix" is provided for each retrieval. Details on properly applying the retrieval averaging kernels are included in the V8 User's Guide and MOPITT validation papers.

**High latitude data**: Retrievals south of 65S and north of 65N should be used with caution, because of potential problems with cloud detection and due to difficulties in performing retrievals over very cold surfaces. Moreover, TIR-only and TIR/NIR retrievals in these regions tend to have low information content as quantified by the "Degrees of Freedom for Signal" diagnostic because of poor thermal contrast conditions.

**Day-Night and Land-Ocean differences**: Due to the sensitivity of the MOPITT radiances to surface temperature, differences between day and night may appear in retrievals over land. This effect can be identified through analysis of the retrieval averaging kernels. At land-ocean boundaries, similar differences may be seen. These differences are the result of radiative transfer effects (e.g., thermal contrast variability) and should not be interpreted as changes in the atmospheric concentration of CO.

# Validation

Currently, the V8 product is considered unvalidated, since validation results have not yet been published. Validation studies are underway in which MOPITT CO mixing ratios will be validated with numerous aircraft profiles measured by NOAA/ESRL, as well as with datasets from field campaigns including HIPPO and ATom. A manuscript documenting the validation results for the V8 product is in preparation and will soon be submitted for publication.

# CO Retrieval Diagnostics

For V7 and V8, Level 2 diagnostics include

- 'TotalColumnAveragingKernel': This diagnostic allows users to properly compare MOPITT total column retrievals with total columns derived from in-situ profiles or model simulations. Use of the total column averaging kernel is discussed in Sec. 5.5 of the V8 User's Guide. Total column averaging kernels in V8 Level 2 files are not affected by a bug in V7 products which affected retrievals with less than ten valid levels (surface pressures less than 900 hPa).
- '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.
- 'DryAirColumn' and 'WaterVaporColumn': Along with the retrieved CO total column, these diagnostics facilitate the computation of the equivalent dry-air or moist-air mixing ratio averaged over the atmospheric column.
- 'SmoothingErrorCovarianceMatrix' and 'MeasurementErrorCovarianceMatrix': These diagnostics represent the two components of the Retrieval Error Covariance Matrix. Smoothing error represents the retrieval uncertainty due to the influence of a priori and the features of the weighting functions. Measurement error represents the retrieval uncertainty due to uncertainties in the measured radiances (including instrument noise).
- '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. This can occur, for example, in some nighttime/land scenes when the surface skin temperature is less than the temperature of the air immediately above the surface. 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.
- 'RetrievalErrorCovarianceMatrix': For each retrieval, a floating point array (10 x 10) containing the a posteriori covariance matrix in base-10 log(VMR).
- 'SurfaceIndex': For each retrieval, an integer equal to 0 for open water (oceans, seas and large lakes), 1 for land, and 2 for mixed (e.g., coastline).
- 'CloudDescription': For each retrieval, an integer describing the results of the MOPITT cloud detection algorithm, as described above.

- 'RetrievalAveragingKernelMatrix': For each retrieval, a floating point array (10 x 10) containing the matrix describing the sensitivity of the retrieved CO profile to the true CO profile.
- '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.
- 'Level1RadiancesandErrors': For each retrieval, a floating point array (2 x 12) containing the L1 radiances and corresponding radiance uncertainties. Radiance sequence is 7A, 3A, 1A, 5A, 7D, 3D, 1D, 5D, 2A, 6A, 2D, 6D. Radiances and uncertainties are in units of W/($m^2$Sr).
- 'DEMAltitude': Altitude of retrieval in m.
- '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.
- 'MODISCloudDiagnostics': For each retrieval, a ten-element floating point vector containing a variety of MODIS cloud mask statistics, as follows.

  element -> diagnostic
  (1) Number of "determined" MODIS pixels
  (2) Fraction of cloudy MODIS pixels
  (3) Fraction of clear MODIS pixels
  (4) Average value of "sun glint" MODIS flag
  (5) Average value of "snow/ice background" MODIS flag
  (6) Average value of "non-cloud obstruction" MODIS flag
  (7) Average value of "IR threshold test" MODIS flag
  (8) Average value of "IR temperature difference tests" MODIS flag
  (9) Average value of "visible reflectance test" MODIS flag
  (10) Fraction of "determined" MODIS pixels .

# Methane Retrieval Products

Methane ($CH_4$) retrievals are not available in this data version, or any previous version.