MOPITT
(Measurements of Pollution in the Troposphere)
Version 5 Product User's Guide

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1 MOPITT Version 5 Product Highlights

This guide describes the MOPITT Version 5 (V5) Level 2 product for tropospheric carbon monoxide (CO) and discusses appropriate analysis methods. This document will be occasionally updated as the V5 products are elevated from "beta" to "provisional" and finally to "validated" status and when the V5 Level 3 product becomes available. Updates will be announced on the MOPITT News webpage at www.acd.ucar.edu/mopitt/news.shtml.

Although there are many similarities between the V4 and V5 products, there are also major changes. Therefore, all users of the new V5 product are encouraged to familiarize themselves with this document. For product features which have not changed, the *V4 User's Guide* may contain more details than are provided in this guide.

Major features of the V5 product include:

- **Representation of "geophysical noise" processes as a source of random retrieval error. Details in Sec. 3.1.**
- **A new time-dependent radiative transfer model which explicitly represents gradual long-term changes in the gas correlation cells' operating parameters, which may have been responsible for long-term bias drift in earlier MOPITT products. Details in Sec. 3.2.**
- **Two new classes of retrieval products, including a near infrared-only (NIR-only) product and a "multispectral" joint thermal infrared/near infrared (TIR/NIR) product. Details in Sec. 3.3.**
- **An improved cloud detection algorithm which reduces the average number of mis-assigned MODIS pixels by approximately a factor of two. Details in Sec. 3.8.**
- **A simpler scheme for mapping MOPITT retrieval levels and atmospheric layers (but which requires changes in methods used to compare MOPITT retrieval products with either in-situ data or model output). Details in Sec. 4.2.**

2 Review of Earlier MOPITT Products

Following the launch of Terra near the end of 1999, the MOPITT Version 3 product became available in 2000 [1]. It was the first satellite dataset for tropospheric CO featuring global coverage. This product was followed in 2009 by the Version 4 (V4) product [2]. Significant improvements first introduced in the V4 product included (1) variable a priori based on the chemical transport model MOZART, (2) representation of CO variability by log-normal statistics, (3) extensions of the forward radiative transfer model MOPFAS to simulate much higher CO concentrations, and (4) improved observation-based a priori values for surface emissivity.

3 Features of the MOPITT Version 5 Retrieval Algorithm

As described in the following sections, V5 retrieval products are significantly different than earlier products, and offer users a choice of three distinct products depending on their requirements: (1) a TIR-only product, qualitatively similar to the V4 product, (2) a NIR-only product, similar to the SCIAMACHY CO product [3] and (3) a TIR/NIR "multispectral" product, which represents a unique capability of MOPITT. In this document, especially significant changes in the V5 product (with respect to both scientific content and format) are emphasized in **bold** text.

3.1 L1 Observation-Dependent Noise

For MOPITT's Length Modulation Cell (LMC) measurements (including the 5A and 5D TIR radiances and the 6A and 6D NIR radiances), the method of calculating Level 1 noise values has changed significantly [4]. For earlier V3 and V4 MOPITT products, noise was calculated from low-level instrument data acquired while the instrument was pointed to space, and represented instrumental noise only. **Recently, however, investigations have shown that actual radiance errors include both instrumental and geophysical components. These studies have also led to a new method for quantifying radiance errors while accounting for both instrumental and geophysical sources. The new method is only applicable to MOPITT LMC measurements (i.e., the method is not useful for the Pressure Modulation Cell or PMC radiances 7A and 7D). The new noise values for 5A, 5D, 6A, and 6D are described as "observation-dependent" (O.D.) noise since they are calculated individually for each MOPITT observation. Over land regions, O.D. noise values can be much larger (even by orders of magnitude) than instrument-only noise values. O.D. noise values also exhibit strong geographical variability. In the MOPITT maximum a posteriori retrieval algorithm [1], the use of O.D. noise yields more accurate retrieval uncertainties, but generally also results in greater "smoothing error" (i.e., averaging kernels are often weaker and retrievals are constrained more by the a priori). O.D. noise values over the ocean (and large bodies of water) are typically similar to the instrument-only noise values used in V4.**

3.2 Radiative Transfer Modeling

The MOPFAS operational radiative transfer model incorporates models of the physical states of the MOPITT PMCs and LMCs in order to simulate channel radiances. For V4, MOPFAS was based on "static" instrument parameters representing the mean instrument state over the entire mission. **For V5, both the PMC and LMC models have been revised to explicitly represent observed long-term changes in the LMC and PMC cell pressure and temperature values. Specifically, MOPFAS is now based on monthly-mean values for the cell parameters. Validation results indicate that the new time-dependent radiative transfer model reduces long-term bias drift observed in earlier MOPITT products, particularly for upper-tropospheric CO and for CO total column retrievals. This change in the retrieval algorithm should particularly benefit users interested in analyzing long-term trends in tropospheric CO.**

3.3 New NIR-only and TIR/NIR Level 2 Products

For the first time, MOPITT V5 retrieval products include information from the NIR gas correlation radiometer (Channel 6). For daytime observations over land, the exploitation of collocated NIR and TIR measurements considerably improves sensitivity to CO near the earth's surface [5]. However, features of the new TIR/NIR product will not necessarily benefit all potential MOPITT users. Therefore, to serve the needs of the broadest number of potential users, the V5 retrieval product includes three variants based on different radiance basis sets.

Three distinct V5 Level 2 products will be operationally produced and made available separately:

- **A TIR-only product, based on the 5A, 5D, and 7D radiances, similar to the MOPITT V4 product. This product will initially be released as "provisionally validated." Compared to V4, this product offers improved long-term stability and more accurately accounts for random errors due to geophysical noise.**
- **A new NIR-only product, based on the 6A and 6D radiances, qualitatively similar to the ENVISAT SCIAMACHY CO product [3]. This "beta" product will be available only for daytime observations over land. Users should be very cautious in using this product, and are encouraged to collaborate with MOPITT science team members to exploit it properly. Compared to earlier TIR-based MOPITT products, this product exhibits larger random errors and may require significant spatial and/or temporal averaging.**
- **A new multispectral TIR/NIR product, based on the 5A, 5D, 6A, 6D, and 7D radiances, featuring enhanced sensitivity to CO in the lower-most troposphere [5]. In this "beta" product, information from the NIR channels is limited to daytime observations over land. Users should be very cautious in using this product, and are encouraged to collaborate with MOPITT science team members to exploit it properly. Compared to earlier TIR-based MOPITT products, this product exhibits larger random errors and may require significant spatial and/or temporal averaging.**

These three variants will be distinguishable through both their filenames and self-contained metadata. TIR-only Level 2 filenames begin with "MOP02T." NIR-only Level 2 filenames begin with "MOP02N." Multispectral (joint TIR/NIR) Level 2 filenames begin with "MOP02J."

3.4 Retrieval Sensitivity

In order to fully exploit the information in the NIR radiances in both the NIR-only and TIR/NIR products, the V5 retrieval algorithm has been adapted to shift the balance between "smoothing error," which tends to constrain the retrieval towards the a priori profile and "retrieval noise," which results from errors in the radiances or forward model [4]. Retrieval sensitivity is enhanced by reducing smoothing error at the expense of increased retrieval noise. In contrast to previous V3 and V4 products, new NIR-only and TIR/NIR retrieval products are "sub-optimal" in the sense that the total error (from both smoothing error and retrieval noise) is not minimized. Thus, compared to the V4 retrieval product (and V5 TIR-only product), V5 NIR-only and TIR/NIR products may exhibit substantially larger random errors. Retrieval averaging may be required to effectively reduce these random errors.

The V5 TIR-only product, like the V4 product, is still a true optimal estimation retrieval. In terms of sensitivity and random retrieval error, this product is fundamentally similar to the V4 product.

In the V5 TIR/NIR product, retrieval sensitivity to CO in the lower-most troposphere (LMT) can vary substantially (even within a relatively small region) as the result of several geophysical effects [5]. Generally, sensitivity to lower-tropospheric CO is greatest for observations characterized by relatively uniform NIR surface reflectance (i.e., small NIR O.D. noise values) and weak thermal contrast conditions (for which the NIR and TIR weighting functions exhibit the least amount of overlap). Users who are particularly interested in exploiting the TIR/NIR product for studying CO in the LMT must analyze the retrieval averaging kernel matrix along with the actual retrieved profiles in order to assess retrieval performance. Data filtering (Sec. 5.3) may be useful for

excluding retrievals exhibiting poor sensitivity in the LMT.

3.5 A Priori

The MOPITT retrieval algorithm is based on the maximum a posteriori solution [1], which depends explicitly on both the a priori state vector, which represents the statistically most probable geophysical state, and the a priori covariance matrix, which describes the statistical variability relative to that state. A priori information is required for all elements of the state vector, i.e., the CO profile, surface temperature, and surface emissivity. For V5, a priori data for CO concentrations, surface temperature, and surface emissivity are produced in the same manner as for the V4 product. Users should consult the *V4 User's Guide* for more details regarding the a priori.

3.6 Meteorological Data

For each individual MOPITT observation, the retrieval algorithm requires profiles of both temperature and water vapor. Meteorological profiles are spatially and temporally interpolated from NCEP operational analysis products. Meteorological data used for V5 processing are the same as for the V4 product - users should consult the *V4 User's Guide* for details regarding the meteorological data.

3.7 Retrieval Convergence

Retrieval convergence rates for V5 products vary somewhat for the three retrieval variants. For the TIR-only and NIR-only products, retrieval failure rates (averaged over an entire day) are typically less than one percent. For the V5 TIR/NIR product, retrieval failure rates are typically between one and three percent, but locally can be much larger. For this product, failed retrievals occur most commonly in daytime observations over land, and particularly land regions presenting high thermal contrast. The majority of unsuccessful retrievals fail to converge within the maximum allowed number of iterations (see next paragraph). Retrievals failing this way tend to occur in isolation, i.e., are not clustered spatially. A smaller number of retrievals fail because they yield retrieved profiles outside of the acceptable range of MOPFAS.

The criteria used to determine retrieval convergence in V5 (and V4) products is based on the root-mean-square change (over the ten-level profile) of $\log_{10}$(VMR), in comparison with the previous iteration. If this value is 0.01 or less, the retrieval is considered to be converged. If the value exceeds 0.01, iterations continue. In practice, retrievals usually converge in four iterations or less. The maximum allowable number of iterations is set at 20.

3.8 Cloud Detection

Prior to the retrieval algorithm, the location of each MOPITT observation is determined to be either clear or cloudy. Observations determined to be cloudy are not processed further. This clear/cloudy determination is based on both the MOPITT radiances themselves and a "cloud mask" produced from near-simultaneous observations by the Terra/MODIS ("MODerate resolution Imaging Spectroradiometer") instrument. **The cloud detection algorithm ("MOPCLD") used for V5 processing has been substantially revised. Whereas the earlier version of MOPCLD (used in V3 and V4 products) relied on an empirically-derived parametrization to identify the set of MODIS pixels located within the boundaries of a given MOPITT pixel, the updated version of MOPCLD**

exploits a predetermined set of offset indices relative to the MODIS pixel closest to the center of the MOPITT pixel. With respect to the average number of MODIS pixels which are incorrectly assigned to each MOPITT pixel, the skill of the revised version of MOPCLD has improved by approximately a factor of two. The new algorithm is also computationally more efficient than the earlier version. Possible outcomes of the cloud detection module (with corresponding "Cloud Description" values in the L2 product in parentheses) include (1) "MOPCLD only clear, thermal only," (2) "MOPCLD and MODIS cloud mask agree on clear," (3) "MODIS cloud mask only clear," (4) "MOPCLD overriding MODIS cloud mask over low clouds" and (5) "MODIS cloud mask only, clear over polar regions." Like the previous cloud detection algorithm, the V5 cloud detection algorithm accepts MOPITT pixels with up to 5% cloudiness as effectively clear and passes those observations on to the retrieval algorithm.

For V5, a new standard diagnostic is also provided for each retrieval (in the Level 2 product file) to statistically describe the set of MODIS Cloud Mask pixels matched to each MOPITT pixel. These diagnostics may be of use for analyzing potential retrieval biases associated with particular types of clouds. Elements of the 10-element "MODIS Cloud Diagnostics" floating point vector indicate:

(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 .

4 Product Format

4.1 Level 1 Data

The format of the HDF files containing the MOPITT calibrated radiances, i.e., the Level 1 data product, is mostly unchanged for V5. **The only L1 product change is the addition of the variable "Level0 Std Dev" which contains the LMC-channel observation-dependent noise values (as described in Sec. 3.1). In addition, the actual radiance values contained in the L1 files have changed (relative to the V4 product), as the result of changes in the V5 instrument model and operational radiative transfer model MOPFAS (see Sec. 3.2).**

4.2 Level 2 Data

Like previous MOPITT products, the MOPITT V5 Level 2 product is stored in HDF-4 format data files. However, MOPITT data users will notice numerous differences between the V4 and V5 products. **The data and diagnostic fields contained in the V5 Levels product files are tabulated in Appendix A. In addition to all of the standard content in the V4 Level 2 product, the V5 product offers the following new variables and diagnostics for each retrieved profile:**

- **'Retrieval Error Covariance Matrix' – also known as the "a posteriori covariance matrix," describing the uncertainties and inter-level correlations of the retrieved $\log_{10}$(VMR) profile;**
- **'Level 1 Radiances and Errors' – a two-dimensional array containing the actual radiances and uncertainties (including observation-dependent noise values for the LMC channels) used as the basis of each retrieval, in units of (W/m^2Sr); array is dimensioned 2 by 12, with the first index indicating radiance or noise, and the second index indicating the specific MOPITT channel in the sequence (7A, 3A, 1A, 5A, 7D, 3D, 1D, 5D, 2A, 6A, 2D, 6D);**
- **'DEM Altitude' – altitude at location of retrieved profile as determined from a Digital Elevation Model, in meters;**
- **'MODIS Cloud Diagnostics' – a ten-element vector containing results of various MODIS cloud tests (see Sec. 3.8), dimensionless;**
- **'Signal Chi2' – signal chi-squared diagnostic, dimensionless;**
- **'Swath Index' – a vector of three integers containing the pixel, stare and track indices, dimensionless.**

V5 retrieved profiles are expressed on the same ten-level grid (surface, 900 hPa, 800 hPa, ...) used for V4, although the level-layer associations have been simplified for V5. For V4, each retrieval level was assigned to a layer centered on that level, with a weighting that tapered to zero at the adjacent retrieval levels. In contrast, for V5 products, each retrieval level simply corresponds to a uniformly-weighted layer immediately above that level. For example, the V5 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 MOZART model climatology and are fixed.) Quantitatively, this change in V5 will be most important when comparing MOPITT products to model output or *in-situ* data exhibiting strong vertical gradients in the CO profile.

Retrieved profiles are separated into (1) the "Retrieved CO Surface Mixing Ratio" and (2) the "Retrieved CO Mixing Ratio Profile," formed by the retrieved CO VMR at the nine fixed-level pressures (beginning with the level closest to the surface). Corresponding to each ten-level retrieved profile is a ten-by-ten "Retrieval Averaging Kernel Matrix." Users should note that V5 (and V4) averaging kernels describe the sensitivity of retrieved $\log_{10}$(VMR) to actual $\log_{10}$(VMR). The reported averaging kernels, unlike the retrieved profile, are not divided into separate surface and fixed-level components. Thus, the first row of the reported averaging kernel matrix describes the sensitivity of retrieved $\log_{10}$(VMR) values at the surface to actual $\log_{10}$(VMR) changes at all ten levels in the retrieval grid (beginning with the surface level).

For MOPITT retrievals where the surface pressure is less than 900 hPa, missing values will appear in both the "Retrieved CO Mixing Ratio Profile" and "Retrieval Averaging Kernel Matrix" at all unrealized levels. For example, retrievals where the surface pressure is between 600 and 700 hPa will exhibit missing values at 900, 800, and 700 hPa. In such situations, users must reformat these products to exclude the missing values present in these L2 products.

For both V4 and V5 products, "Surface Index" values of 0, 1, and 2 correspond to water, land, and mixed (e.g., coastline), respectively.

For product issues related to the ordering of multi-dimensional arrays in the V5 L2 product, readers should consult the V4 User's Guide. Users of the V5 product who have questions regarding array dimensioning using particular operating systems and analysis tools are encouraged to contact the MOPITT/NCAR team.

4.3 Level 3 Data

As this guide to the Level 2 product is being written, the V5 Level 3 product is still in development.

5 MOPITT Data Analysis

5.1 Data Averaging

Because of both geophysical and instrumental noise, individual MOPITT retrieved profiles do not provide a strong basis for scientific analysis. This is especially true for the new 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 errors associated with random radiance errors (such as geophysical noise and instrumental noise) decrease as the square root of the number of retrievals in the ensemble.

The V5 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(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.

5.2 Data Quality and Inclusion of A Priori

Besides retrieval noise, a variety of effects influence MOPITT data quality. For example, the relative weight of the a priori profile x_a in the retrieval x_{rtv}, which ideally should be as small as possible, is quantified by the retrieval averaging kernel matrix according to

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

where x_{true} is the true profile, A is the averaging kernel matrix, and I is the identity matrix. Inclusion of a priori information is associated with all remote sensing methods based on optimal estimation. The optimal estimation method exploits a priori information to "fill-in" those parts of the retrieved profile where the actual observations are insensitive. This effect is well understood. **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 [1,2]. For the V5 product, users must make this transformation in terms of $\log_{10}$(VMR). V5 users should also observe the simplified level-layer associations described in Sec. 4.2.

Other effects have less quantifiable influence on retrieval data quality. Examples of such effects include 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.

5.3 Data Filtering

Because of the potential variability of MOPITT data quality, as discussed above, users may wish 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, as discussed in the V4 User's Guide, 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. 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-based retrievals than nighttime conditions.

For V5 products, MOPITT data quality also varies strongly because of the variability of both NIR and TIR O.D. noise values (see Sec. 3.1). Retrievals characterized by large O.D. noise values will tend to be more dominated by a priori information and exhibit lower DFS values than retrievals with relatively small O.D. noise values. O.D. noise values are determined primarily by surface heterogeneity, and are not significantly affected by CO concentrations in the atmosphere. Therefore, filtering based on O.D. noise values should provide a means of excluding low-quality MOPITT retrievals without imposing retrieval bias. Such filters should be based on the signal-to-noise ratio for the LMC radiances used as the basis of a particular retrieval.

So, for example, an O.D. noise-based "observation quality index" (OQI) could be defined for the V5 TIR-only product as

$$OQI_T = \left((\sigma_{5A}/R_{5A})^2 + (\sigma_{5D}/R_{5D})^2 \right)^{-1/2} \qquad (2)$$

where σ_{5A}, R_{5A}, σ_{5D}, and R_{5D} are the 5A O.D. noise value, 5A radiance, 5D O.D. noise value, and 5D radiance, respectively. Increasing retrieval quality (and decreasing dependence on a priori) corresponds to increasing values of OQI. Both the radiances and O.D. noise values necessary to calculate OQI are available in the V5 retrieval diagnostic 'Leve1 1 Radiances and Errors.'

Similarly, for the NIR-only and multispectral V5 products, OQI could be defined as

$$OQI_N = \left((\sigma_{6A}/R_{6A})^2 + (\sigma_{6D}/R_{6D})^2 \right)^{-1/2} \qquad (3)$$

and

$$OQI_M = \left((\sigma_{5A}/R_{5A})^2 + (\sigma_{5D}/R_{5D})^2 + (\sigma_{6A}/R_{6A})^2 + (\sigma_{6D}/R_{6D})^2 \right)^{-1/2} \qquad (4)$$

Eq. (4) should only be applied for daytime retrievals over land (since only these retrievals exploit both TIR and NIR radiances). Appropriate OQI filter thresholds will depend on a variety of

considerations and will generally be different for different applications.

5.4 Analysis of Retrieved CO Total Column Values

For users interested in quantitatively comparing MOPITT retrieved CO total column values with other datasets (and model output), special methods are required. These methods are generally described in Appendix 7.4 of the V4 User's Guide. **For the V5 product, however, users must modify the data analysis code provided in the V4 User's Guide to reflect the simplified level-layer scheme (See Sec. 4.2). Specifically, the vector of layer pressure-widths (Δp) must be revised. V5 Δp values are simply the pressure differences (in hPa) between each retrieval level and the level immediately above. The Δp value for the topmost level at 100 hPa is an exception. The "partial column" for the layer between 100 hPa and 0 hPa is actually composed of (1) a fixed value based on MOZART climatological VMR values from 0.2 to 50 hPa and (2) a uniform-VMR layer from 50 hPa to 100 hPa. For total column comparisons, the layer from 100 hPa to 0 hPa can be represented as an "equivalent layer" with pressure width 74 hPa and the retrieved VMR at 100 hPa; this approximation yields total column values which are within a few percent of the actual retrieved total column values.**

Thus, the general methodology described in Appendix 7.4 of the V4 User's Guide may be applied to V5 products if the following convention is adopted for Δp (where the index of the surface level is isfc):

$$\begin{aligned} \Delta p_i &= (p_{sfc} - p_{isfc+1}) \quad (\text{for } i = isfc) \\ &= 100\ hPa \quad (\text{for } isfc + 1 < i < 10) \\ &= 74\ hPa \quad (\text{for } isfc = 10) \end{aligned} \tag{5}$$

6 References

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Appendices

A. Content of V5 Level 2 Product Files

Original Content (same as V4)	*Array Size*[1]	*New Content*	*Array Size*[1]
Seconds in Day (s)	ntime	Retrieval Error Covariance Matrix	10,10,ntime
Pressure Grid (hPa)	9	Level 1 Radiances and Errors (W/m^2Sr)	2,12,ntime[4]
Solar Zenith Angle (deg)	ntime	DEM Altitude (m)	ntime
Satellite Zenith Angle (deg)	ntime	MODIS Cloud DIagnostics	10, ntime
A Priori Surface Emissivity	2,ntime	Signal Chi2	ntime
Surface Pressure (hPa)	ntime	Swath Index[2]	3, ntime
Retrieved Surface Temperature (K)	2,ntime		
Retrieved Surface Emissivity	2,ntime		
Surface Index[2]	ntime		
Cloud Description[2]	ntime		
Retrieved CO Total Column (mol/cm^2)	2,ntime		
Retrieved CO Mixing Ratio Profile (ppbv)	2,9,ntime		
Retrieved CO Surface Mixing Ratio (ppbv)	2,ntime		
A Priori Surface Temperature (K)	2,ntime		
A Priori CO Mixing Ratio Profile (ppbv)	2,9,ntime		
A Priori CO Surface Mixing Ratio (ppbv)	2,ntime		
Retrieved CO Total Column Diagnostics	2, ntime		
Retrieval Averaging Kernel Matrix	10,10,ntime[3]		
Degrees of Freedom for Signal	ntime		
Water Vapor Climatology Content	ntime		
Retrieval Iterations[2]	ntime		

[1] Array indices ordered according to IDL convention. ntime = number of retrievals (varies), ordered chronologically; for data fields including associated uncertainty, first element is the parameter and second element is uncertainty.

[2] Integer-valued product (all others floating point)

[3] Dimensions of Retrieval Averaging Kernel Matrix are ordered (nrow, ncolumn, ntime)

[4] First index of Level 1 Radiances and Errors corresponds to radiances/errors; second index corresponds to channel (in sequence 7A, 3A, 1A, 5A, 7D, 3D, 1D, 5D, 2A, 6A, 2D, 6D).