ACT-America MFLL Level–2 Data Product Catalog

MFLL Weighting Function Product

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1. Introduction

The ACT-America (Atmospheric Carbon and Transport – America) project is a NASA Earth Venture Suborbital-2 mission designed to study the transport and fluxes of greenhouse gases (GHGs), particularly atmospheric carbon dioxide (CO_2) and methane (CH_4), across the eastern United States. It has three specific objectives: 1) quantification and reduction of uncertainty in simulations of atmospheric transport of CO_2 and CH_4; 2) quantification and reduction of uncertainty in prior flux estimates of CO_2 and CH_4; and 3) evaluation of the ability of the OCO-2 satellite to capture regional-scale, lower tropospheric patterns of column CO_2 (XCO_2). For these purposes, key priorities of the ACT-America field campaigns are devoted to observations of CO_2 distributions and their related synoptic weather systems. Within various GHG observing sensors used by ACT-America, the intensity-modulated continuous-wave (IM-CW) CO_2 lidar, namely Multifunctional Fiber Laser Lidar (MFLL), is the crucial instrument onboard the NASA C-130 aircraft in measuring column CO_2. This lidar was jointly developed and demonstrated for the capability of remote column CO_2 measurements by the NASA Langley Research Center and the Harris Space and Intelligence Systems Corp in preparing for the future NASA ASCENDS (Active Sensing of CO_2 Emissions over Nights, Days, and Seasons) mission [1-3]. The released MFLL data were collected during the first four ACT-America field campaigns: summer 2016, winter 2017, fall 2017 and spring 2018. That is, they covered all four seasons. The current released product is the normalized weighting functions of MFLL XCO_2 retrievals at the time and location of the instrument measurements for all individual flights during the four field campaigns. Note that for carbon science community and general end-users, MFLL XCO_2 measurements from the four ACT-America field campaigns can be found from the MFLL Level-2 Lite or other Level-2 XCO_2 products publicly.

The MFLL lidar system transmits a laser beam with online and offline wavelengths simultaneously on the 1.57-μm CO_2 absorption line. The online wavelength is positioned on the CO_2 absorption line center at 1571.112 nm, and the two offline wavelengths are set to be ±50 pm on either side of the absorption line. Each wavelength is modulated with a unique orthogonal waveform before being combined for simultaneous transmission through the atmosphere [4-6].

The individual wavelengths are then separated from the combined received signal through cross correlating the received signal by each orthogonal waveform. The result of this cross-correlation allows the determination of a backscatter profile for each wavelength. From this, range to a scattering surface and signal amplitude are determined. The MFLL instrument currently uses orthogonal linear swept frequency waveforms. A systematic method for choosing these waveforms has been developed [4]. CO_2 column differential absorption optical depth (DAOD) values are estimated from combined online and offline measurements using the Integrated Path Differential Absorption (IPDA) approach [1-3, 7]. The DAOD measurements, then, are converted to XCO_2 values based on the pressure, temperature and humidity meteorological conditions and assumed vertically uniformly distributed CO_2 profiles at the measurement time and location and on pre2016 HITRAN spectroscopic model [7].

The evaluation of ACT-America field campaign data [7] has shown that the lidar CO_2 measurements are consistent from season to season and have an absolute calibration uncertainty (standard deviation) of 0.80 ppm. The CO_2 measurement precisions for 0.1-s, 1-s, 10-s, and 60-s averages are found to be 3.4 ppm, 1.2 ppm, 0.43 ppm, and 0.26 ppm, respectively, and the drift in XCO_2 over one-hour of flight time is very small and below 0.1 ppm. Because of the unprecedented high stability, accuracy and precision, the ACT-America MFLL data have been used for many mission science analysis [e.g., 8].

2. MFLL Normalized Weighting Function

The XCO_2 product release of the ACT-America MFLL level-2 data [7, 9] is targeted at the end-users of CO_2 observing, modeling and other sciences, society and public applications. The MFLL level-2 data products and their related detailed descriptions can be found in ACT-America data archive center [9]. Because of the distinct spectral characteristics of MFLL online and offline wavelengths, the MFLL measured column averaged CO_2 values have certain distinct vertical weights on CO_2 profiles depending on the pressure, temperature and humidity meteorological conditions and the wavelengths used at the measurement time and location [7]. The wavelengths were recorded by MFLL during its flight periods, and the meteorological data were obtained from the Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA−2) weather product of the NASA Goddard Space Flight Center (https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/). Furthermore, the vertically averaged CO_2 retrievals from MFLL measurements are also influenced by the measured ranges from the CO_2 remote sensor to the backscatter. This vertical weighting feature (or weighting function) is unique for MFLL retrieved XCO_2 values. The weighting functions of individual CO_2 measurement profiles were calculated with an assumption of a uniform CO_2 vertical profile of 400 ppm, and their related calculated DAOD values were used as the scaling factor for the MFLL measured DAODs for MFLL XCO_2 retrieval. The weighting coefficients in the weighting functions were reported in atmospheric vertical pressure coordinate and normalized by their averages. Since some end-users of the product may not be familiar with the normalized

weighting functions, in order to make the CO_2 observational product more friendly to broad end-users in the science and application communities, the MFLL working group of the ACT-America project provides this weighting function product for the end-users. The normalized weighting functions were given at the observational time and location of MFLL XCO_2 measurements and calculated in the same way as that during the MFLL XCO_2 retrieval [7] (also, c.f., the previous brief discussions).

The sampling rate of the provided weighting function product is 10-s, which is equivalent to a horizontal spatial resolution about 1.3 km under the nominal C-130 aircraft cruising speed of 250 knots. As of the reported MFLL XCO_2 values in the MFLL Level-2 Lite product the weighting functions represent the normalized weights along the nadir direction from the MFLL instrument onboard of the ACT-America C-130 aircraft to the main backscatters for the lidar as indicated by the MFLL range measurements. The vertical profiles of these weighting functions are calculated based on air pressure coordinator [7] with 30-m vertical resolution. Thus, the total number (M) of weights for a specific vertical profile is the number of the multiples of 30 meters from the range plus one due to the residual of 30-m on the range. That is, if $R = 30 \times m + d$, where R is the range, d is the residual of R on 30, and m is the multiple of 30, the total number M of the weights in a particular vertical profile, then, equals to m plus 1, or, $M = m + 1$. The reported weighting profiles in this weighting function product are the weighting function values normalized by the averages of their corresponding weighting profile values as indicated in reference [7]. Note that when a range measurement at a particular time and location during an ACT-America flight was not available, the closest available neighboring range within a time window of one second or instrument flight altitude values were used in the weighting function calculation. So, for the end-user's convenience, the range measured by MFLL is also provided in this normalized weighting function product. The details in calculating the weighting functions reported can be found in reference [7].

The weighting function product is organized in HDF5 format. The information on the day that their corresponding MFLL data were collected is provided as a part of filename, following the ACT-America file naming convention [10]. Each weighting function file contains 4 parameters for each 10-s profile sample. A complete list of the data file contents is provided in Table 1 in the parameter information section. The time and location were recorded by the Global Positioning System (GPS) instrument of the C-130 aircraft, and the range values were directly obtained from MFLL ranging measurements as in the MFLL Level-2 Lite and other Level-2 products. Detailed information on the MFLL data can be found in references [7][9].

3. Parameter Information for Weighting Function Product

The parameters provided by the MFLL weighting function product are MFLL sampling time and location (longitude, latitude and altitude) determined by the C-130 GPS system, as a part of the REVEAL data of NASA aircraft data sets (c.f., Ancillary data in next section). The range measurements are reported as nadir values. Table 1 lists these parameters. Users also can find

their related information from the documentations of MFLL data processing [7] and MFLL level 2 product [9].

Table 1 Parameter Information

Parameter Name	Units	Dimension	Description
Time_UTC	second	N	The time of the instrument taking measurements in the second of the day in UTC
Position	(degree, degree, meter)	N × 3	Latitude, longitude and altitude of the instrument at the time taking measurements
Range_Nadir	meter	N	The range from the instrument onboard the C-130 aircraft to the backscatter in nadir direction
Weighting_Pressure	N/A	M × N	Normalized weighting function values calculated from air pressure coordinate for individual vertical profiles at flight tracks

Note: N and M are the total numbers of the samples in an ACT-America weighting function product file and of the normalized weights in vertical profiles, respectively.

4. Ancillary Data Information

Ancillary data that were used in the ACT-America MFLL normalized weighting function calculations are shown in Table 2. These data are interpolated to the flight time and location of individual MFLL measurements with the spatiotemporal resolution discussed in previous section.

Ancillary data products

1. REVEAL data from the NASA aircraft data archive at https://asp-archive.arc.nasa.gov/ or the ACT America Housekeeping data product at https://www-air.larc.nasa.gov/cgi-bin/ArcView/actamerica.2016
2. Modern-Era Retrospective analysis for Research and Applications version 2 (Merra 2), weather data available at https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/
3. Global Land One-kilometer Base Elevation (GLOBE) GLOBE Task Team and others (Hastings, David A., Paula K. Dunbar, Gerald M. Elphingstone, Mark Bootz, Hiroshi Murakami, Hiroshi Maruyama, Hiroshi Masaharu, Peter Holland, John Payne, Nevin A. Bryant, Thomas L. Logan, J.-P. Muller, Gunter Schreier, and John S. MacDonald), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical

Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A. Digital data base on the World Wide Web (URL: http://www.ngdc.noaa.gov/mgg/topo/globe.html) and CD-ROMs.

Table 2 Ancillary data

Data name	Description
REVEAL	NASA aircraft data; For the MFLL data processing of ACT-America field campaign measurements, they were records of C-130 aircraft during campaign flights
MERRA-2	Meteorological profiles of the NASA Goddard GMAO official product of the Modern-Era Retrospective analysis for Research and Applications version 2
DEM	Global digital elevation model used in evaluating lidar returns from surface or clouds during MFLL XCO_2 retrieval. For lidar retrieval, Global Land One-kilometer Base Elevation (GLOBE) product is used.

References

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