ACT-America MFLL Data Product Catalog

Level 2 Lite XCO_2 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 in measuring column CO_2. This lidar was jointly developed and demonstrated for the capability of remote CO_2 column 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 current 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 MFLL lidar system transmits 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 calibrated through an experimental series including ground short-path instrument calibration and spiral flight testing with in-situ CO_2 and meteorological profiling [7]. The calibrated DAOD values are converted to XCO_2 values based on DAOD scaling from an assumed vertically uniform 400 ppm CO_2 profile under the pressure, temperature and humidity meteorological conditions at the MFLL DAOD measurement time and location and the pre2016 HITRAN spectroscopic model [7]. 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/).

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 has been used for many mission science analysis [e.g., 8].

2. MFLL Lite Data Product

The data of this MFLL Lite product release is targeted at the end-users of CO_2 observations for sciences and applications. It is a direct subset of the ACT-America MFLL level-2 product [7, 9]. Details about the MFLL level-2 product can be found in ACT-America data archive center [9]. Here, the Lite product only reports the MFLL measurements of range and XCO_2 at the native 10 Hz resolution, along with the measurement time and location information. Since the nominal cruising speed of the ACT-America C-130 aircraft is about 250 knots, the equivalent spatial resolution of the 10 Hz data is about 13 m. All the reported values represent measurements along the nadir direction from the MFLL instrument onboard of the ACT-America C-130 aircraft to the main backscatters for the lidar. For the end-user's convenience, the data quality of XCO_2 retrievals is also provided in this Lite product.

This Lite product is organized in HDF5 format. The information on the day that the data were collected is provided as a part of filename, following the ACT-America file naming convention [10]. Each Lite file contains 5 parameters for each 10-Hz MFLL 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 C-130 Global Positioning System (GPS). Range and XCO_2 values were retrieved from MFLL measurements, along with the flag about the data quality of individual MFLL sample. Detailed information on the data quality flag is given in Table 2 in the parameter information section.

3. Parameter Information for the MFLL Lite Product

The parameters provided by the MFLL level 2 Lite product are MFLL sampling time and 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 data quality is depending multiple factors: MFLL signal strength, aircraft attitude and clear/cloudy weather condition, as well as their related digital elevation model data (c.f., Ancillary data in next section) for return signal discrimination as from surface or clouds. The range and XCO_2 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
Flag_quality_control	digit number	N	Measurement data quality flag. See Table 2 for details
Range_Nadir	meter	N	The range from the instrument onboard the C-130 aircraft to the backscatter in nadir direction
XCO2	ppm	N	Column CO_2 along nadir direction from the sensor onboard C-130 aircraft to the backscatter

Note: N is the total number of samples in an ACT-America CO_2 lidar level 2 Lite product file.

Within the Table 1, the flag, Flag_quality_control, provides the CO_2 lidar measurement data quality. This flag is organized in various measurement and environment conditions, including a signal amplitude threshold, airplane pitch and roll angles and weather conditions. Table 2 lists the flag values and their corresponding information.

Table 2 Information on the Data Quality for the Flag: Flag_quality_control

Value	Signal strength	Pitch angle < 5 deg & Roll angle < 5 deg	Clear sky	Description
1	Good	Yes	Yes	Good data; clear column condition; normal retrieval
2	Good	Yes	Yes	clear column condition; normal retrieval; use with caution
3	Good	Yes	No	Single layer cloudy condition; normal retrieval; use with caution
4	Good	Yes	No	Multi-layer cloudy condition; normal retrieval; use with caution
0	Good	No	Yes or No	Normal retrieval under large pitch/roll angle and potential cloudy conditions; Not suggested to use
-9999	N/A	N/A	N/A	Bad data

4. Ancillary Data Information

Ancillary data that used in the ACT-America MFLL level-2 and level-2 Lite data processing are shown in Table 3. These data are interpolated to the flight time and location of individual MFLL measurements.

Table 3 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.

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.

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