

MAIRE24: MethaneAIR dataset description

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Title

MAIRE24 XCH₄ Segments and Mosaics

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1.0 Data Set Description

Introduction

MethaneAIR is a set of two passive near-IR imaging spectrometers that report methane (CH₄) column mean dry mole fraction that flew aboard the NSF G-V. The instrument was mounted on the floor, between L2 and R2, and used the fore nadir viewport. Shutters mounted on each spectrometer were used to perform on-demand dark calibrations throughout the flight.

Data version number and date

1.0 / 7 August 2024

Data Status

Final

Time period covered by the data

18 July 2024 – 22 July 2024

Physical location

Broomfield, CO

Data Frequency

Continuous

Data source

MethaneAIR spectrometer

Data set restrictions

No restrictions

2.0 Instrument Description

MethaneAIR (“MAIR”) is an imaging spectrometer observing reflected sunlight at 1.65 μm (CH_4 and CO_2). A second similar spectrometer centered at 1.27 μm ($\text{O}_2(^1\Delta_g)$ band) helps with cloud screening and determining the optical path. The following table provides a summary of the spectrometer specifications.

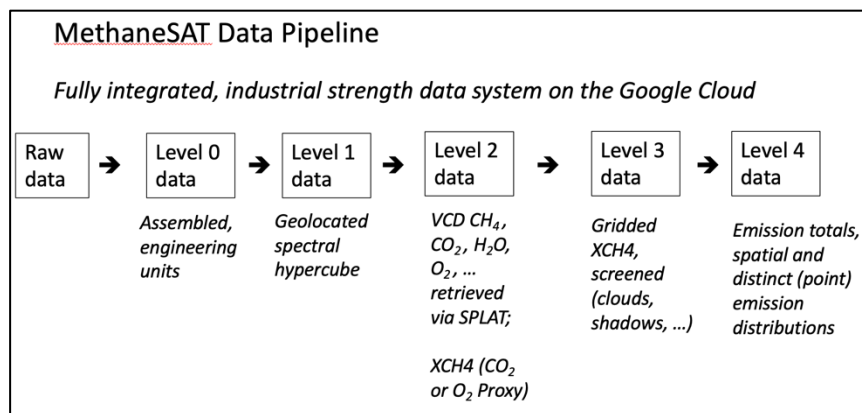
MethaneAIR and MethaneSAT Dual spectrometers: 1.65 μm (CO_2 and CH_4) and 1.27 μm ($\text{O}_2(^1\Delta)$)		
Specification	MethaneAIR	MethaneSAT
O_2 passband (nm)	1237–1319	1249–1305
O_2 dispersion (nm/pixel)	0.08	0.06
O_2 spectral FWHM (nm)	0.23	0.18
CH_4 passband (nm)	1592–1678*	1598–1683
CH_4 dispersion (nm/pixel)	0.10	0.08
CH_4 spectral FWHM (nm)	0.28	0.24
Field of view (swath, km)	4.7	200
Cross-track pixel [†] (m)	~ 5 at 12 km	~ 108
Along-track pixel [†] (m)	~ 25	~ 400
Point spread function (pixels)	2.5	1.8
Single pixel SNR [‡]	~ 110	~ 190
*MethaneAIR uses an InGaAs detector with reduced QE beyond ~ 1660 nm		
[†] Distance between pixel centers at nadir		
[‡] CH_4 band with nominal radiance of 1.4×10^{13} photons $\text{cm}^{-2} \text{nm}^{-1} \text{sec}^{-1} \text{sr}^{-1}$		
Flat images σ gridded (oversampled)	(ppb) 26 (10m x 10m) (5 px x 1 px)	19 (45m) (1 x 1 px)

Download capacity limits MethaneSAT to 30 200x200 kmxkm scenes per day

MethaneAIR measures absorption spectra with high spectral resolution, fine spatial resolution, wide swath, and high signal-to-noise ratio, enabling dramatically enhanced images of CH_4 column mean dry mole fraction compared to other airborne or spaceborne imagers. MAIR duplicates the spectroscopy of the MethaneSAT satellite (“MSAT”, launched March 2024). Development of the MAIR sensor and associated retrieval algorithms was supported by MethaneSAT LLC (a subsidiary of the Environmental Defense Fund). The modest cost compared to comparable sensors (800k for both spectrometers), plus the availability of MAIR’s extensive data processing and algorithm software, brings this technology within reach of a broad scientific community.

3.0 Data Collection and Processing

MethaneAIR data are processed in a data pipeline structured according to commonly used data “levels” for remote sensing by imaging spectrometers:



This data archive reports Level 3 (gridded) data, in two configurations.

1. Non-overlapping segments, representing ~4.7 km wide swaths, arranged sequentially in time and grouped by target (e.g. “CR” = controlled release, “priority target” = oil/gas production target area, or city target).
2. Mosaics of the non-overlapping segments covering the whole target. The mosaics provide the user with map-like images of methane concentrations (column mean dry mole fraction, XCH₄) and other quantities. They are created from the segments accounting for spatial oversampling by the sensors, using information about pixel corners as described in Chan Miller et al. (2024). *The mosaics need to be interpreted with care because they present averages of concentrations observed at different times.* This feature may be inconsequential for some applications, but confusing or invalidating for other uses. For example, resampling a point source may give rise to images of two methane plumes propagating from the source in divergent directions.

Level 0, Level 1b (gridded spectral hypercubes) and Level 2 (3-d concentration fields, averaging kernels, retrieval diagnostics) are too large to archive here. Each flight consists of ~ 1TB of data, at each level. These data products are freely available from the Google Cloud upon application to the PI (wofsy@g.harvard.edu) or to MethaneSAT.org. Requestors will need to register for a Google Cloud account, where they will be granted access to the requested buckets. Users are responsible for the cost of downloading as charged by Google. Raw data are export controlled and cannot be made available.

4.0 Data Format

The data file format is netCDF. The files are arranged in a tree structure like this example:

```
Filename = MAIR-E24_2024_07_18_RF01E24_po-1957_level3_5x1_segment_20240807T174439_po-1957_07_priority-target_10m_MethaneAIR_L3_segment_20240718T201418_20240718T202119_dpp.nc
```

MAIR-E24 = flight series

2024_07_18 = YYYY_MM_DD

RF01E24 = flight moniker

po-1957 = processing ID (MSAT pipeline unique processing identification)

5x1 = data aggregation (5 pixels across track by 1 pixel along track)
segment = data type (possible values, mosaic or segment)
20240807T174439_po-1957 = processing date on time (POSIX format, UTC) and proc ID
07_priority-target = target area moniker
10m = approximate grid spacing (possible values, **10m** or **30m**, corresponding 0.33 or 1 arc second; at 42N the pixels are 10.3 or 30.9m N-S by 7.6 or 22.9 m E-W)
MethaneAIR = sensor
L3 = data processing level
segment = data type (possible values, mosaic or segment)
20240718T201418_20240718T202119 = start and end time period covered in the data file (POSIX, UTC)

For the segment files, the start and end times represent the time for the first and last observation. The times are also given for each observation in the grid, within the file, representing the average time of the closely spaced level 2 data points going into the gridded data point.

For the mosaic files, the times cover the whole of the target survey time (up to several hours duration). It is not meaningful to give an observation time for an individual grid point.

The netCDF files are self-documenting, as provided in the examples below. The headers provide all the information needed to read the files and to determine definitions, units etc.

Important notes:

All XCH4 retrievals reported here use the CO₂ proxy algorithm (Chan Miller et al., 2024).

The num_samples variable in these tables represents the number of pixel values from Level 2 that went into the weighted mean for a Level 3 gridded pixel. Any pixels with num_samples < 0.5 should be set to NA. Users may need to check this feature. If any pixel with num_samples < 0.5 is set to a finite value in the data file, it should be set to NA or NaN by the user.

```

netcdf MAIR-E24_2024_07_18_RF01E24_po-1957_level3_5x1_segment_20240807T174439_po-1957_07_priority-
target_10m_MethaneAIR_L3_segment_20240718T201418_20240718T202119_dpp {
dimensions:
    lat = UNLIMITED ; // (8208 currently)
    lon = UNLIMITED ; // (4536 currently)
variables:
    int64 crs ;
        crs:grid_mapping_name = "latitude_longitude" ;
        crs:longitude_of_prime_meridian = 0. ;
        crs:semi_major_axis = 6378137. ;
        crs:inverse_flattening = 298.257223563 ;
        crs:crs_wkt = "GEOGCRS[\"WGS 84\", ENSEMBLE[\"World Geodetic System 1984 ensemble\", MEMBER[\"World
Geodetic System 1984 (Transit)\", MEMBER[\"World Geodetic System 1984 (G730)\", MEMBER[\"World Geodetic System 1984 (G873)\",
MEMBER[\"World Geodetic System 1984 (G1150)\", MEMBER[\"World Geodetic System 1984 (G1674)\", MEMBER[\"World Geodetic System
1984 (G1762)\", MEMBER[\"World Geodetic System 1984 (G2139)\", ELLIPSOID[\"WGS 84\",6378137,298.257223563,
LENGTHUNIT[\"metre\",1]], ENSEMBLEACCURACY[2.0]], PRIMEM[\"Greenwich\",0, ANGLEUNIT[\"degree\",0.0174532925199433]],
CS[\"ellipsoidal\",2], AXIS[\"geodetic latitude (Lat)\",north, ORDER[1], ANGLEUNIT[\"degree\",0.0174532925199433]], AXIS[\"geodetic longitude
(Lon)\",east, ORDER[2], ANGLEUNIT[\"degree\",0.0174532925199433]], USAGE[ SCOPE[\"Horizontal component of 3D system.\",
AREA[\"World.\", BBOX[-90,-180,90,180]], ID[\"EPSG\",4326]]" ;
        double lat(lat) ;
            lat:long_name = "latitude" ;
            lat:units = "degrees_north" ;
            lat:standard_name = "latitude" ;
            lat:actual_range = 39.6700462962963, 40.4299537037037 ;
        double lon(lon) ;
            lon:long_name = "longitude" ;
            lon:units = "degrees_east" ;
            lon:standard_name = "longitude" ;
            lon:actual_range = -105.069953703704, -104.650046296296 ;
        float num_samples(lat, lon) ;
            num_samples:_FillValue = 0.f ;
            num_samples:grid_mapping = "crs" ;
        float total_sample_weight(lat, lon) ;
            total_sample_weight:_FillValue = 0.f ;
            total_sample_weight:grid_mapping = "crs" ;
        double time(lat, lon) ;
            time:_FillValue = 0. ;
            time:grid_mapping = "crs" ;
            time:units = "seconds since 1970-1-1 0:0:0, in UTC" ;
        float xch4(lat, lon) ;
            xch4:_FillValue = 1.e+36f ;
            xch4:grid_mapping = "crs" ;
            xch4:long_name = "retrieved column-averaged dry-air CH4 mole fraction" ;
            xch4:standard_name = "dry_atmosphere_mole_fraction_of_methane" ;
            xch4:units = "1e-9" ;

// global attributes:
    string :product_type = "segment" ;
    string :geospatial_lat_min = "39.67" ;
    string :geospatial_lat_max = "40.43" ;
    string :geospatial_lon_min = "-105.07" ;
    string :geospatial_lon_max = "-104.65" ;
    string :geospatial_lat_resolution = "1/3 arcseconds" ;
    string :geospatial_lon_resolution = "1/3 arcseconds" ;
    string :time_coverage_start = "2024-07-18T20:14:18Z" ;
    string :time_coverage_end = "2024-07-18T20:21:02Z" ;

group: Provenance {

// group attributes:
    :__auto__ = "Version not found" ;
    :Python = "3.9.5" ;

```

```

:msat-netcdf = "0.4.3" ;
:_schema_ = "1.2.3" ;
:msat_level3 = "1.2.3" ;
:click = "8.1.7" ;
:GitPython = "3.1.43" ;
:netCDF4 = "1.7.1.post1" ;
:popy = "0.2.2" ;
:mypy = "Version not found" ;
:strenum = "0.4.15" ;
:msat-common = "0.12.1" ;
:black = "Version not found" ;
:flake8 = "Version not found" ;
:numpy = "1.26.4" ;
:scipy = "1.13.1" ;
:mashumaro = "3.13.1" ;
:pytest = "8.2.2" ;
:google-cloud-storage = "2.17.0" ;
:coverage = "Version not found" ;
:opencv-python = "4.5.5.64" ;
:pytest-mock = "3.14.0" ;
:types-PyYAML = "Version not found" ;
:flytekit = "1.13.0" ;
:shapely = "2.0.5" ;
:time-machine = "Version not found" ;
} // group Provenance

group: apriori_data {
  variables:
    float xco2(lat, lon) ;
      xco2:_FillValue = 1.e+36f ;
      xco2:long_name = "a priori column-averaged dry-air CO2 mole fraction" ;
      xco2:standard_name = "dry_atmosphere_mole_fraction_of_carbon_dioxide" ;
      xco2:units = "1e-6" ;
    float xch4(lat, lon) ;
      xch4:_FillValue = 1.e+36f ;
      xch4:long_name = "a priori column-averaged dry-air CH4 mole fraction" ;
      xch4:standard_name = "dry_atmosphere_mole_fraction_of_methane" ;
      xch4:units = "1e-9" ;
    float co2_vcd(lat, lon) ;
      co2_vcd:_FillValue = 1.e+36f ;
      co2_vcd:grid_mapping = "crs" ;
      co2_vcd:long_name = "a priori CO2 vertical column density (TCCON GGG2020)" ;
      co2_vcd:proposed_standard_name = "atmosphere_mole_content_of_carbon_dioxide" ;
      co2_vcd:units = "molecules/cm2" ;
    float ch4_vcd(lat, lon) ;
      ch4_vcd:_FillValue = 1.e+36f ;
      ch4_vcd:grid_mapping = "crs" ;
      ch4_vcd:long_name = "a priori CH4 vertical column density (TCCON GGG2020)" ;
      ch4_vcd:standard_name = "atmosphere_mole_content_of_methane" ;
      ch4_vcd:units = "molecules/cm2" ;
    float h2o_vcd(lat, lon) ;
      h2o_vcd:_FillValue = 1.e+36f ;
      h2o_vcd:grid_mapping = "crs" ;
      h2o_vcd:long_name = "a priori H2O vertical column density (GEOS-FP)" ;
      h2o_vcd:standard_name = "atmosphere_mole_content_of_water_vapor" ;
      h2o_vcd:units = "molecules/cm2" ;
    float air_vcd(lat, lon) ;
      air_vcd:_FillValue = 1.e+36f ;
      air_vcd:grid_mapping = "crs" ;
      air_vcd:long_name = "sum of a priori N2, O2, Ar, CO2, CH4, and H2O vertical column densities" ;
      air_vcd:units = "molecules/cm2" ;
    float albedo_ch4band(lat, lon) ;

```

```

        albedo_ch4band:_FillValue = 1.e+36f ;
        albedo_ch4band:grid_mapping = "crs" ;
        albedo_ch4band:long_name = "clear-sky surface albedo derived from 1622nm radiance" ;
        albedo_ch4band:standard_name = "surface_albedo" ;
        albedo_ch4band:units = "1" ;
        albedo_ch4band:valid_range = 0.f, 1.f ;
float surface_pressure(lat, lon) ;
    surface_pressure:_FillValue = 1.e+36f ;
    surface_pressure:grid_mapping = "crs" ;
    surface_pressure:long_name = "a priori surface pressure" ;
    surface_pressure:standard_name = "surface_air_pressure" ;
    surface_pressure:units = "hPa" ;
float zonal_wind(lat, lon) ;
    zonal_wind:_FillValue = 1.e+36f ;
    zonal_wind:grid_mapping = "crs" ;
    zonal_wind:standard_name = "eastward_wind" ;
    zonal_wind:long_name = "eastward wind component at 10 m, from GEOS-5" ;
    zonal_wind:units = "m/s" ;
float meridional_wind(lat, lon) ;
    meridional_wind:_FillValue = 1.e+36f ;
    meridional_wind:grid_mapping = "crs" ;
    meridional_wind:standard_name = "northward_wind" ;
    meridional_wind:long_name = "northward wind component at 10 m, from GEOS-5" ;
    meridional_wind:units = "m/s" ;
} // group apriori_data

group: geolocation {
    variables:
        float terrain_height(lat, lon) ;
            terrain_height:_FillValue = 1.e+36f ;
            terrain_height:standard_name = "surface_height_above_geopotential_datum" ;
            terrain_height:comment = "the vertical distance above either the EGM96 (MethaneAIR) or EGM2008 (MethaneSAT)
geoid, though having been interpolated by L1b and regridded by L3; this exists for diagnostic purposes only" ;
            terrain_height:units = "km" ;
        float sza(lat, lon) ;
            sza:_FillValue = 1.e+36f ;
            sza:grid_mapping = "crs" ;
            sza:standard_name = "solar_zenith_angle" ;
            sza:units = "degrees" ;
            sza:valid_range = 0.f, 90.f ;
        float vza(lat, lon) ;
            vza:_FillValue = 1.e+36f ;
            vza:grid_mapping = "crs" ;
            vza:standard_name = "sensor_zenith_angle" ;
            vza:units = "degrees" ;
            vza:valid_range = 0.f, 90.f ;
        float saa(lat, lon) ;
            saa:_FillValue = 1.e+36f ;
            saa:grid_mapping = "crs" ;
            saa:standard_name = "solar_azimuth_angle" ;
            saa:units = "degrees" ;
            saa:valid_range = 0.f, 360.f ;
        float vaa(lat, lon) ;
            vaa:_FillValue = 1.e+36f ;
            vaa:grid_mapping = "crs" ;
            vaa:standard_name = "sensor_azimuth_angle" ;
            vaa:units = "degrees" ;
            vaa:valid_range = 0.f, 360.f ;
} // group geolocation

group: co2proxy_fit_diagnostics {
    variables:

```

```

float bias_corrected_co2_vcd(lat, lon) ;
    bias_corrected_co2_vcd:_FillValue = 1.e+36f ;
    bias_corrected_co2_vcd:grid_mapping = "crs" ;
    bias_corrected_co2_vcd:long_name = "retrieved CO2 vertical column density with across-track bias correction" ;
    bias_corrected_co2_vcd:proposed_standard_name = "atmosphere_mole_content_of_carbon_dioxide" ;
    bias_corrected_co2_vcd:units = "molecules/cm2" ;
float bias_corrected_ch4_vcd(lat, lon) ;
    bias_corrected_ch4_vcd:_FillValue = 1.e+36f ;
    bias_corrected_ch4_vcd:grid_mapping = "crs" ;
    bias_corrected_ch4_vcd:long_name = "retrieved CH4 vertical column density with across-track bias correction" ;
    bias_corrected_ch4_vcd:standard_name = "atmosphere_mole_content_of_methane" ;
    bias_corrected_ch4_vcd:units = "molecules/cm2" ;
} // group co2proxy_fit_diagnostics

group: o2dp_fit_diagnostics {
variables:
    float bias_corrected_o2_vcd(lat, lon) ;
        bias_corrected_o2_vcd:_FillValue = 1.e+36f ;
        bias_corrected_o2_vcd:grid_mapping = "crs" ;
        bias_corrected_o2_vcd:long_name = "retrieved O2 vertical column density with across-track bias correction" ;
        bias_corrected_o2_vcd:proposed_standard_name = "atmosphere_mole_content_of_oxygen" ;
        bias_corrected_o2_vcd:units = "molecules/cm2" ;
    float bias_corrected_delta_pressure(lat, lon) ;
        bias_corrected_delta_pressure:_FillValue = 1.e+36f ;
        bias_corrected_delta_pressure:grid_mapping = "crs" ;
        bias_corrected_delta_pressure:long_name = "retrieved minus a priori surface pressure with across-track bias correction"
;
        bias_corrected_delta_pressure:units = "hPa" ;
} // group o2dp_fit_diagnostics

group: h2o_w1_fit_diagnostics {
variables:
    float bias_corrected_h2o_vcd(lat, lon) ;
        bias_corrected_h2o_vcd:_FillValue = 1.e+36f ;
        bias_corrected_h2o_vcd:grid_mapping = "crs" ;
        bias_corrected_h2o_vcd:long_name = "retrieved H2O vertical column density with across-track bias correction" ;
        bias_corrected_h2o_vcd:standard_name = "atmosphere_mole_content_of_water_vapor" ;
        bias_corrected_h2o_vcd:units = "molecules/cm2" ;
} // group h2o_w1_fit_diagnostics

group: h2o_w2_fit_diagnostics {
variables:
    float bias_corrected_h2o_vcd(lat, lon) ;
        bias_corrected_h2o_vcd:_FillValue = 1.e+36f ;
        bias_corrected_h2o_vcd:grid_mapping = "crs" ;
        bias_corrected_h2o_vcd:long_name = "retrieved H2O vertical column density with across-track bias correction" ;
        bias_corrected_h2o_vcd:standard_name = "atmosphere_mole_content_of_water_vapor" ;
        bias_corrected_h2o_vcd:units = "molecules/cm2" ;
} // group h2o_w2_fit_diagnostics
}

```

5.0 Data Remarks

Future release will remove along-track oscillations in XCH₄

6.0 References

Instrumentation and algorithms

Chan Miller, Christopher, Sebastien Roche, Jonas S. Wilzewski, Xiong Liu, Kelly Chance, Amir H. Souri, Eamon Conway, Bingkun Luo, Jenna Samra, Jacob Hawthorne, Kang Sun, Carly Staebell, Apisada Chulakadabba, Maryann Sargent, Joshua S. Benmergui, Jonathan E. Franklin, Bruce C. Daube, Yang Li, Joshua L. Laughner, Bianca C. Baier, Ritesh Gautam, Mark Omara, and Steven C. Wofsy, Methane retrieval from MethaneAIR using the CO₂ Proxy Approach: A demonstration for the upcoming MethaneSAT mission, *Atmos. Meas. Tech.*, 17, 5429–5454, 2024 <https://doi.org/10.5194/amt-17-5429-2024>.

Conway, EK, Souri, AH, Benmergui, J, Sun, K, Liu, X, Staebell, C, Chan Miller, C, Franklin, J, Samra, J, Wilzewski, J, Roche, S, Luo, BK, Chulakadabba, A, Sargent, M, Hohl, J, Daube, B, Gordon, I, Chance, K, Wofsy, S, Level0 to Level1B processor for MethaneAIR, *ATMOSPHERIC MEASUREMENT TECHNIQUES* 17, 1347-1362, DOI: 10.5194/amt-17-1347-2024, 2024.

Staebell, C, Sun, K, Samra, J, Franklin, J, Miller, CC, Liu, X, Conway, E, Chance, K, Milligan, S, Wofsy, S., Spectral calibration of the MethaneAIR instrument, *Atmospheric Measurement Techniques* 14, 3737-3753, do: 10.5194/amt-14-3737-2021, 2021.

Controlled releases

Chulakadabba, A, Sargent, M, Lauvaux, T, Benmergui, JS, Franklin, JE, Chan Miller, C, Wilzewski, JS, Roche, S, Conway, E, Souri, AH, Sun, K, Luo, BK, Hawthorne, J, Samra, J, Daube, BC, Liu, X, Chance, K, Li, Y, Gautam, R, Omara, M, Rutherford, JS, Sherwin, ED, Brandt, A, Wofsy, SC, Methane point source quantification using MethaneAIR: a new airborne imaging spectrometer, *ATMOSPHERIC MEASUREMENT TECHNIQUES* 16, 5771-5785, DOI: 10.5194/amt-16-5771-2023, 2023.

7.0 Appendix

None