Files and Data Formats for the Benchmark Dataset for Methane and Carbon Dioxide Plumes

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This benchmark dataset includes ten AVIRIS-NG scenes, with seven scenes containing methane (CH_4) plumes and four scenes containing carbon dioxide (CO_2) plumes. Dates of the AVIRIS-NG scenes span 2015 to 2019. Basic scene names, metadata, and plume locations can be found on the dataset webpage. The dataset provides radiance, reflectance, water vapor, metadata, and methane or carbon dioxide retrieval images for each scene. Each image includes a binary file and an associated ENVI-format header text file with the metadata pertaining to the image. Image headers have file names that are identical to the binary file name, plus an ".hdr" extension. All binary files are least-significant byte first (little-endian), but are a mixture of band interleave by line (BIL), band interleave by pixel (BIP) and band sequential (BSQ). Note that the data processing workflow changed starting with the 2016 flight season, so the one 2015 scene included in the dataset contains some differences in naming and data format. These differences are described below.

The base name of each file in the dataset starts with "ang" (for AVIRIS-NG) followed by date and time codes. "t" separates the time code from the date code.

angYYYYMMDDtHHmmss

All dates and times below refer to the start of scene acquisition:

YYYY: Year

MM: Month

DD: Day

HH: Hour

mm: Minute

ss: Second

The date and time codes are followed by a product name. In some cases, the product name will be followed by a three- or four-character version number indicating code and calibration versions used for processing by JPL.

1. Calibrated radiance data, no orthocorrection applied

This data file provides the calibrated radiance spectrum measured for each pixel. No orthocorrection has been included, so pixels in the same column were measured by the same detectors (AVIRIS-NG is a pushbroom instrument). All non-orthocorrected images are 598 columns wide, corresponding to the width of the instrument's detector array.

Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_clip

File name example: ang20191023t151141_rdn_v2x1_clip

File type: Binary, 32-bit floating point, BIL

Orthocorrected: No

Units: $\mu Wcm^{-2}nm^{-1}sr^{-1}$ (microWatts per centimeter squared per nm per steradian)

2. Calibrated radiance data, orthocorrection applied

This data file provides the calibrated radiance spectrum measured for each pixel, with orthocorrection applied to remove the effects of aircraft motion and topography and to provide geospatial referencing for the image. The image background, outside the area of orthocorrected data, is indicated by a negative

data value. This value is -9999 for all orthocorrected radiance files except for the scene acquired in 2015. For this scene, the background value is -50.
Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_img
File name example: ang20191023t151141_rdn_v2x1_img
File type: Binary, 32-bit floating point, BIL
Orthocorrected: Yes
Units: $\mu Wcm^{-2}nm^{-1}sr^{-1}$ (microWatts per centimeter squared per nm per steradian)

3. Geometric lookup table
This data file is the lookup table used to convert product 1 to product 2. This image is orthocorrected, but the pixel values indicate the (x,y) coordinates of that pixel in the original non-orthocorrected image (product 1). Pixel (x,y) coordinates are referenced from (1,1), and the background value in each band is 0. Since nearest-neighbor resampling is used for orthocorrection, a pixel from the original image may be repeated multiple times in the orthocorrected image. Pixel coordinates are sign-coded. Positive coordinates indicate a "real" pixel, with the center of the nearest-neighbor pixel from the non-orthocorrected image falling within the orthocorrected pixel. Negative coordinates indicate an infilled pixel, with the center of the nearest-neighbor pixel from the non-orthocorrected image falling outside the orthocorrected pixel.
Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_glt *(_ort_glt for 2015 scene)*
File name example: ang20191023t151141_rdn_v2x1_glt
File type: Binary, long integer, BIP *(integer, BIL for 2015 scene)*
Orthocorrected: Yes
Bands (units):
1: Pixel x-coordinate from non-orthocorrected image (none)
2: Pixel y-coordinate from non-orthocorrected image (none)

4. Input geometry file
This data file provides the UTM coordinates (x,y,z) for the center of each pixel in the non-orthocorrected radiance file (product 1 above).
Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_igm *(_ort_igm for 2015 scene)*
File name example: ang20191023t151141_rdn_v2x1_igm
File type: Binary, 64-bit double precision floating point, BIP *(BIL for 2015 scene)*
Orthocorrected: No
Bands (units):
1: Pixel center easting, WGS-84, zone indicated in header file (meters)
2: Pixel center northing, WGS84, zone indicated in header file (meters)
3: Pixel center estimated surface elevation (meters)

5. Pixel locations, no orthocorrection applied
This data file provides the geographic location (x,y,z) of the center of each pixel in the non-orthocorrected radiance file (product 1 above).
Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_loc *(not produced for 2015 scene)*
File name example: ang20191023t151141_rdn_v2x1_loc
File type: Binary, 64-bit double precision floating point, BIP

Orthocorrected: No
Bands (units):
1: Pixel center longitude, WGS-84, (degrees)
2: Pixel center latitude, WGS84, (degrees)
3: Pixel center estimated surface elevation (meters)

6. Pixel locations, orthocorrection applied
This data file provides the geographic location (x,y,z) of the center of each pixel in the orthocorrected radiance file (product 2 above).
Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_loc_ort *(not produced for 2015 scene)*
File name example: ang20191023t151141_rdn_v2x1_loc_ort
File type: Binary, 64-bit double precision floating point, BIP
Orthocorrected: Yes
Bands (units):
1: Pixel center longitude, WGS-84, (degrees)
2: Pixel center latitude, WGS84, (degrees)
3: Pixel center estimated surface elevation (meters)

7. Observation parameters, no orthocorrection applied
This data file contains a wide variety of geometric parameters for each pixel within the non-orthocorrected image.
Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_obs *(not produced for 2015 scene)*
File name example: ang20191023t151141_rdn_v2x1_obs
File type: Binary, 64-bit double precision floating point, BIP
Orthocorrected: No
Bands (units):
1: Path length from surface to sensor (meters)
2: To-sensor azimuth (degrees, measured clockwise from north)
3: To-sensor zenith (degrees)
4: To-sun azimuth (degrees, measured clockwise from north)
5: To-sun zenith (degrees)
6: Solar phase between to-sensor and to-sun vectors in principal plane (degrees)
7: Surface slope (degrees)
8: Surface aspect (degrees, measured clockwise from north)
9: Cosine i, the apparent local illumination factor based on slope/aspect and to-sun vector (none, range is -1 to 1)
10: UTC Time (decimal hours)
11: Earth-sun distance (astronomical units)

8. Observation parameter file, orthocorrection applied
This data file is the orthocorrected version of product 7, and contains a wide variety of geometric parameters for each pixel within the orthocorrected image.
Naming convention: angYYYYMMDDtHHmmss_rdn_vnxn_obs_ort *(_obs_ort for 2015 scene)*
File name example: ang20191023t151141_rdn_v2x1_obs_ort

File type: Binary, 64-bit double precision floating point, BIP *(32-bit floating point, BIP for 2015 scene)*
Orthocorrected: Yes
Bands (units):
1: Path length from surface to sensor (meters)
2: To-sensor azimuth (degrees, measured clockwise from north)
3: To-sensor zenith (degrees)
4: To-sun azimuth (degrees, measured clockwise from north)
5: To-sun zenith (degrees)
6: Solar phase between to-sensor and to-sun vectors in principal plane (degrees)
7: Surface slope (degrees)
8: Surface aspect (degrees, measured clockwise from north)
9: Cosine i, the apparent local illumination factor based on slope/aspect and to-sun vector (none, range is -1 to 1)
10: UTC Time (decimal hours)
11: Earth-sun distance (astronomical units)

9. Apparent surface reflectance
This data file contains orthocorrected apparent surface reflectance retrieved by JPL. The background value is -9999, except for the 2015 scene where the -50 background value in the original radiance image was carried through reflectance processing, resulting in negative reflectance values. See Thompson et al. (2015) for more details on reflectance retrieval.
Naming convention: angYYYYMMDDtHHmmss_corr_vnxn_img
File name example: ang20191023t151141_corr_v2x1_img
File type: Binary, 32-bit floating point, BIL
Orthocorrected: Yes
Units: reflectance

10. Water absorption
This data file contains column water vapor, optical absorption path length for liquid water, and optical absorption path length for ice. See Thompson et al. (2015) for more details on three-phase water retrievals.
Naming convention: angYYYYMMDDtHHmmss_h2o_vnxn_img *(_h2o_v1h for 2015 scene)*
File name example: ang20191023t151141_h2o_v2x1_img
File type: Binary, 32-bit floating point, BIL
Orthocorrected: Yes
Bands (units):
1: Retrieved column water vapor (centimeters)
2: Liquid water absorption path length (centimeters)
3: Ice absorption path length (centimeters)

11. Methane and carbon dioxide retrieved concentration-path length, no orthocorrection applied
This data file contains the output from L1-sparse albedo-corrected methane or carbon dioxide retrieval, as described by Foote et al. (2020). Non-orthocorrected radiance was used as the input for retrieval, with groups of five adjacent detector columns used for background covariance estimation. Outputs

include red, green, and blue radiance values for visualization purposes, retrieved concentration-path length, and the albedo factor used for albedo correction. See Foote et al. (2020) for an in-depth description of this algorithm.
Naming convention: angYYYYMMDDtHHmmss_ch4 (for CH_4) or angYYYYMMDDtHHmmss_co2 (for CO_2)
File name example: ang20191023t151141_ch4
File type: Binary, 32-bit floating point, BSQ
Orthocorrected: No
Bands (units):
1: Radiance of red band closest to 640 nm ($\mu Wcm^{-2}nm^{-1}sr^{-1}$)
2. Radiance of green band closest to 550 nm ($\mu Wcm^{-2}nm^{-1}sr^{-1}$)
3. Radiance of blue band closest to 460 nm ($\mu Wcm^{-2}nm^{-1}sr^{-1}$)
4. Matched filter retrieval of CH_4 or CO_2 concentration-path length (ppm-m)
5. Albedo factor (none)

12. Methane and carbon dioxide retrieved concentration-path length, orthocorrection applied
This data file applies orthocorrection to product 11. The background value is -9999.
Naming convention: angYYYYMMDDtHHmmss_ch4_geo (for CH_4) or angYYYYMMDDtHHmmss_co2_geo (for CO_2)
File name example: ang20191023t151141_ch4_geo
File type: Binary, 32-bit floating point, BSQ
Orthocorrected: Yes
Bands (units):
1: Radiance of red band closest to 640 nm ($\mu Wcm^{-2}nm^{-1}sr^{-1}$)
2. Radiance of green band closest to 550 nm ($\mu Wcm^{-2}nm^{-1}sr^{-1}$)
3. Radiance of blue band closest to 460 nm ($\mu Wcm^{-2}nm^{-1}sr^{-1}$)
4. Matched filter retrieval of CH_4 or CO_2 concentration-path length (ppm-m)
5. Albedo factor (none)

13. Methane and carbon dioxide unit enhancement spectra
Each unit enhancement spectrum (a.k.a. unit absorption spectrum) corresponds to the natural log of the change in radiance with a 1 ppm-m change in methane or carbon dioxide, and serves as the matched filter target spectrum (Foote et al., 2020; Foote et al., 2021). Unit enhancement spectra are dependent on solar zenith angle, ground elevation, sensor altitude, and column water vapor. All unit enhancement spectra were modeled using MODTRAN, assuming methane or carbon dioxide enhancements within a uniform 500 m layer at the surface (Foote et al., 2021). A range of enhancements was modeled, and then linear regression was used to determine the slope of ln(Δradiance)/ Δppm-m. Only SWIR bands were modeled in MODTRAN, and shorter wavelength absorption coefficients can be assumed to be zero. Values in each file have been multiplied by 1E5, in keeping with expected scaling in matched filter code used by JPL and by Foote et al. (2020).
Naming convention: angYYYYMMDDtHHmmss_ch4_uas (for CH_4) or angYYYYMMDDtHHmmss_co2_uas (for CO_2)
File name example: ang20191023t151141_ch4_uas
File type: ASCII text file
Orthocorrected: N/A

References

Foote, M. D., Dennison, P. E., Thorpe, A. K., Thompson, D. R., Jongaramrungruang, S., Frankenberg, C., & Joshi, S. C. (2020). Fast and Accurate Retrieval of Methane Concentration From Imaging Spectrometer Data Using Sparsity Prior. *IEEE Transactions on Geoscience and Remote Sensing*, 58, 6480-6492. https://doi.org/10.1109/TGRS.2020.2976888

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Thompson, D. R., Gao, B. C., Green, R. O., Roberts, D. A., Dennison, P. E., & Lundeen, S. R. (2015). Atmospheric correction for global mapping spectroscopy: ATREM advances for the HyspIRI preparatory campaign. *Remote Sensing of Environment*, *167*, 64-77. https://doi.org/10.1016/j.rse.2015.02.010