MethaneAIR: A High-Resolution IR Imaging Spectrometer for Airborne Measurements of CH_4 & CO_2

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- Measures total-column dry air mole fraction of CH_4 and CO_2 over a 23.7° swath at high spatial resolution
- Precursor to MethaneSAT, which will revolutionize measurements and modeling of CH_4 emissions across the globe
- Observations facilitate advances in spectroscopy and retrievals needed for precise emissions measurements from MethaneSAT
- By itself represents a major advance in the state of the art of airborne remote sensing of CH_4 and CO_2

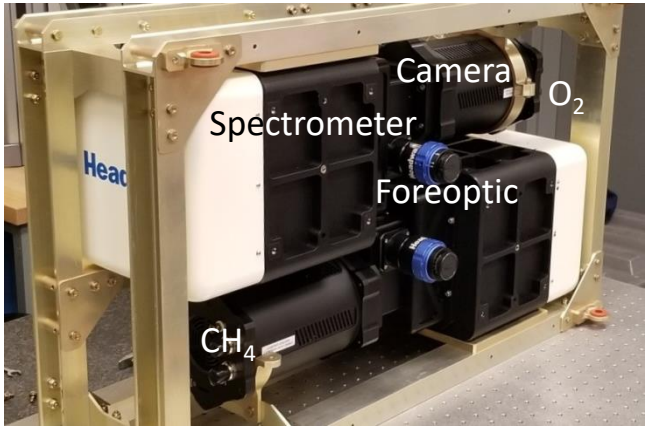

Figure 1: *The two MethaneAIR spectrometers mounted in their instrument rack.*

Figure 2: *MethaneAIR installed in the NSF/ NCAR Gulfstream V under its thermal enclosure.*

Design and Performance

Like MethaneSAT, MethaneAIR consists of a pair of pushbroom grating spectrometers. One measures CH_4 and CO_2 in the 1.6 µm absorption band, and the other measures O_2 in the 1.27 µm singlet-delta band. Each instrument is an Offner-style spectrometer (Headwall Photonics) that images a slit onto a chilled InGaAs detector (Princeton IR Technologies).

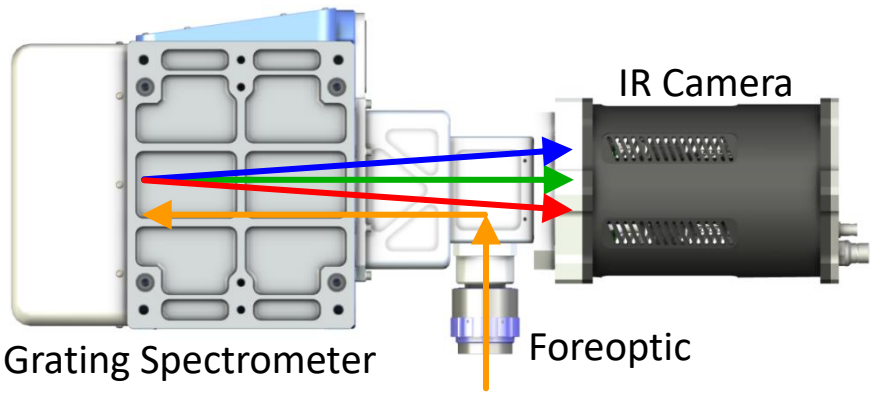

Figure 3: *Light path through one of the spectrometers.*

MethaneAIR Specifications	
O_2 passband (nm)	1236–1319
O_2 dispersion (nm per pixel)	0.08
O_2 spectral FWHM (nm)	0.22
CH_4 passband (nm)	1592–1680
CH_4 dispersion (nm per pixel)	0.1
CH_4 spectral FWHM (nm)	0.3
Plate scale (° per pixel)	0.0275
Field of view (°)	23.7
Swath width (km) at 12 km altitude	5.05
Cross-track pixel (m) at 12 km altitude	5.76
Along-track pixel (m)	≈ 25

MethaneAIR provides high sensitivity, high spectral resolution, and very low spectral distortion in a small, low-cost package. The optical design provides sub-pixel spectral smile and keystone distortion and relatively uniform focus across wavelength and field angle. Anti-reflection coatings and high grating efficiency provide an optical transmittance of 37 – 39 % in the CH_4 channel and 45 – 47 % in the O_2 channel. The CH_4 and O_2 channels have polarization sensitivities of 5 – 10 % and 20 – 25 %, respectively.

Implementation

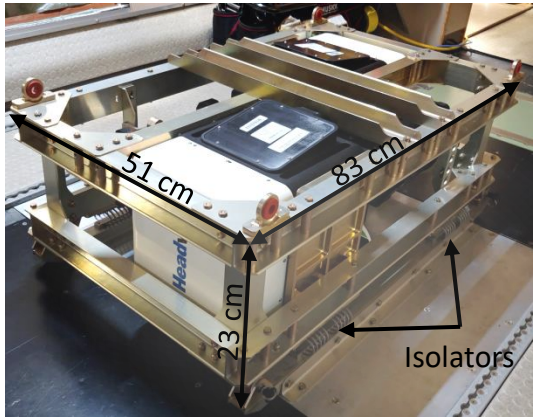

Figure 4: *The two MethaneAIR spectrometers are mounted side by side in a single instrument rack, which is isolated from aircraft vibration by wire isolators.*

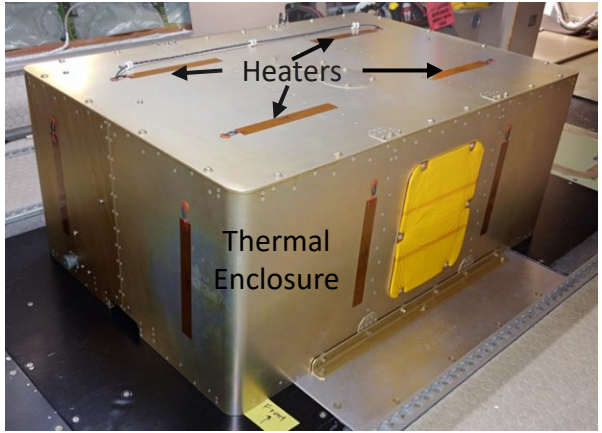

Figure 5: *A heated thermal enclosure regulates the instrument temperature to maintain a consistent spectral response function.*

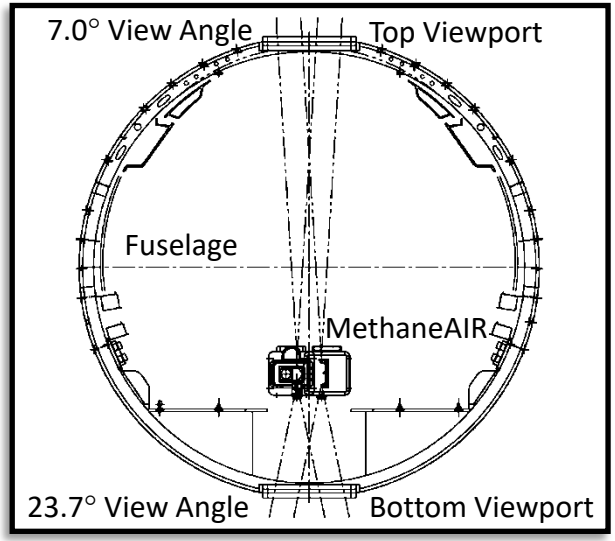

Figure 6: *For CH_4 and CO_2 measurements, the spectrometers observe out of a 46 cm (18 in.) viewport on the bottom of the GV, using a 25 mm wide angle lens (23.7° field of view). A 180° rotation of the instrument rack allows the O_2 spectrometer to observe out of the overhead viewport in order to image the airglow, using an 85 mm lens that provides a 7° field of view.*

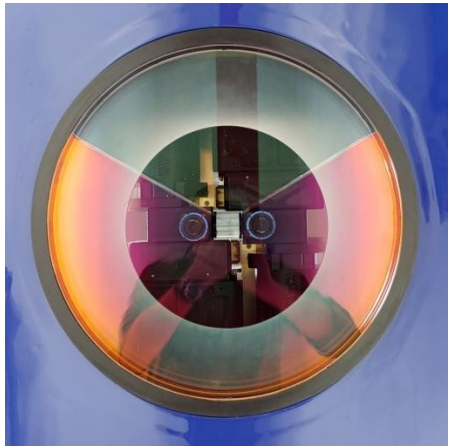

Figure 7: *The viewport consists of two panes of glass anti-reflection coated for an overall transmission above 98%.*

Alignment & Calibration

Staebell et al., Atmos. Meas. Tech., 14, 3737–3753, 2021 https://doi.org/10.5194/amt-14-3737-2021

Each spectrometer was internally aligned from foreoptic to focal plane by Headwall, and the two spectrometers were co-boresighted to within 1° when they were mounted in the rack. Lab calibration was performed with the instruments in their down-looking flight configuration and at the flight temp. Radiometric, instrument spectral response function (ISRF), and stray light calibrations were performed.

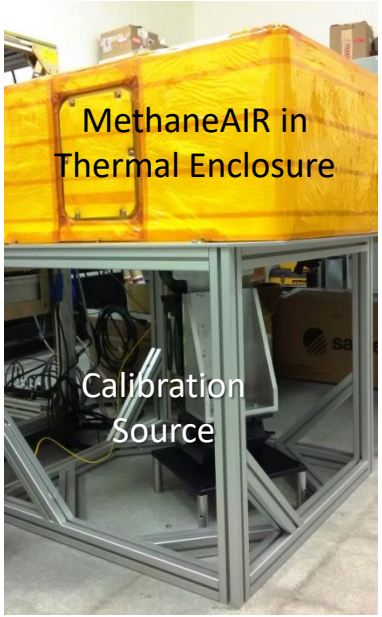

Figure 8: *Laboratory calibration station.*

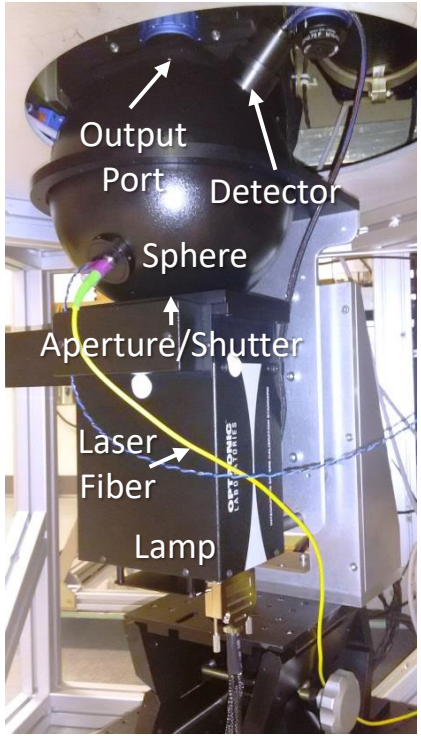

Figure 9: *An integrating sphere is used in the radiometric and ISRF calibrations. During the radiometric calibration, the sphere is fed by a broadband calibrated lamp behind a variable aperture. The ISRF measurements are provided by an IR laser, which is fiber-coupled to the integrating sphere.*

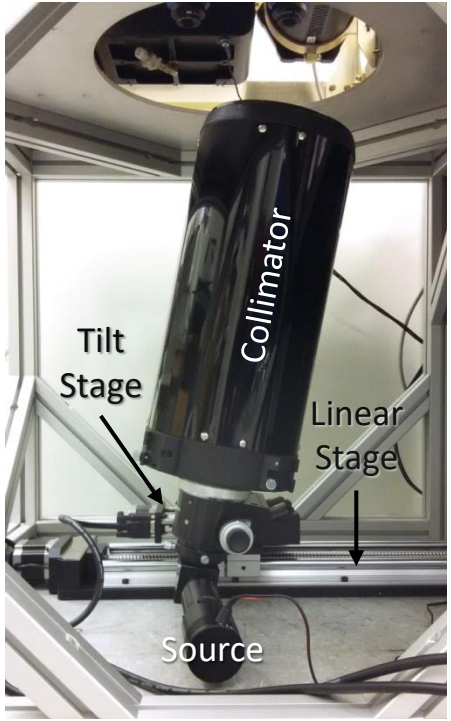

Figure 10: *A collimated laser source is used to measure stray light.*

Flight Campaigns

Platform: NSF/NCAR Gulfstream V (Broomfield, CO)
Typical altitude and airspeed: 12 km, 490 knots

Engineering flights, November 2019

- Initial in-flight instrument check
- Explore sensitivity to pressure, temperature, polarization, albedo
- Provide limited data set for algorithm development
- Electrical issues grounded NCAR GV after only 2 successful flights

Science flights, July/August 2021

- Explore sensitivity to aerosols (e.g., seek out plume from Denver)
- Image emission plumes from a large feed lot and a monitored power plant
- Map out portion of Delaware Basin (part of Permian Basin) in collaboration with ongoing EDF study. Aim for 3 revisits to region – different winds
- Measure spatial variation in airglow
  - Focus on region downwind of front range mountains

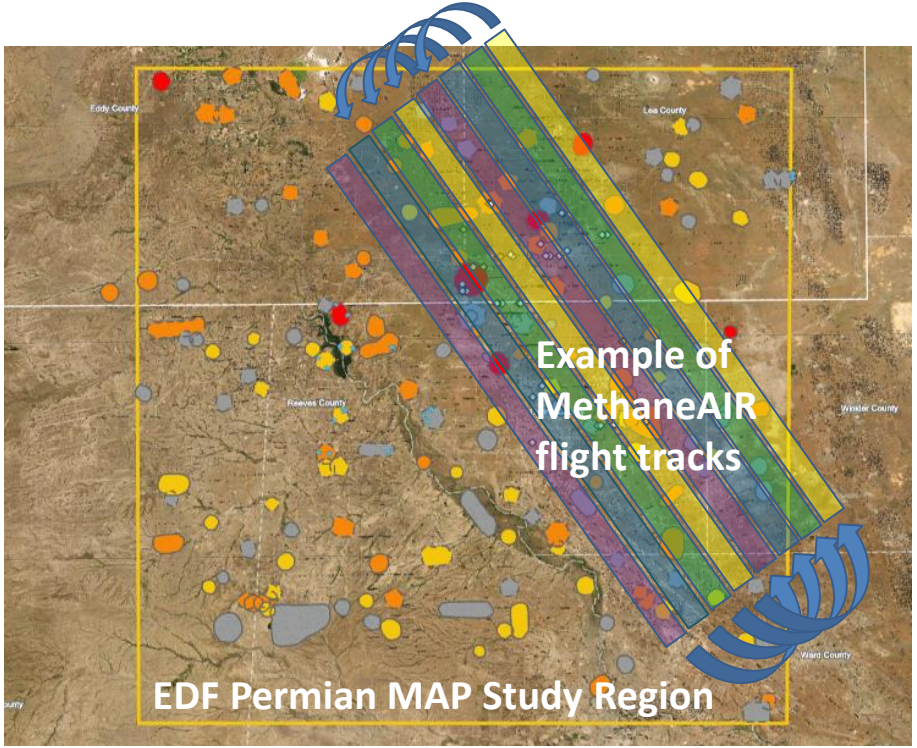

Figure 11: *In July 2021, MethaneAIR will transit from CO to the Permian region and map critical areas, "mowing the lawn" parallel to the wind direction. The yellow box represents the primary focus area of the EDF's* Permian Methane Analysis Project (PermianMAP, *https://www.permianmap.org*) *and the colored markers indicate different methane emission rates.*

Flight Spectra

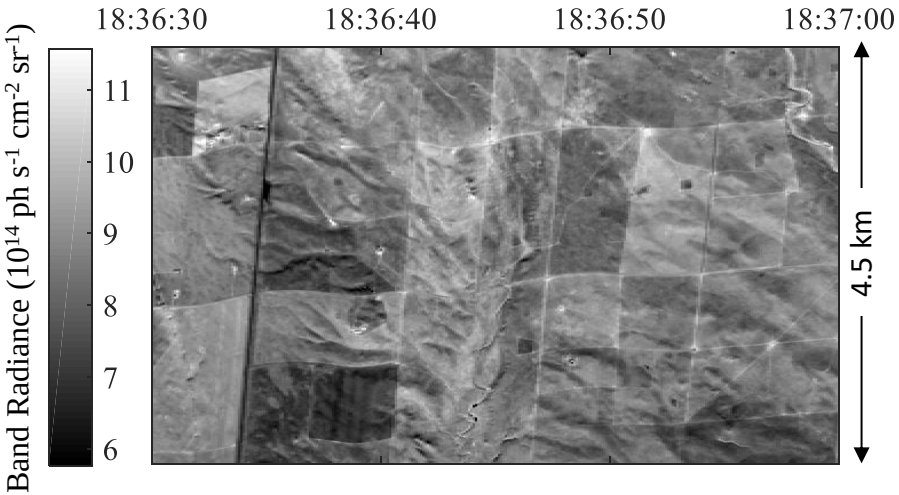

Figure 12: *Integrated radiance in the O_2 band (1236 – 1319 nm). At 12 km MSL, MethaneAIR observed a 4.5 × 7.5 km region in 30 seconds.*

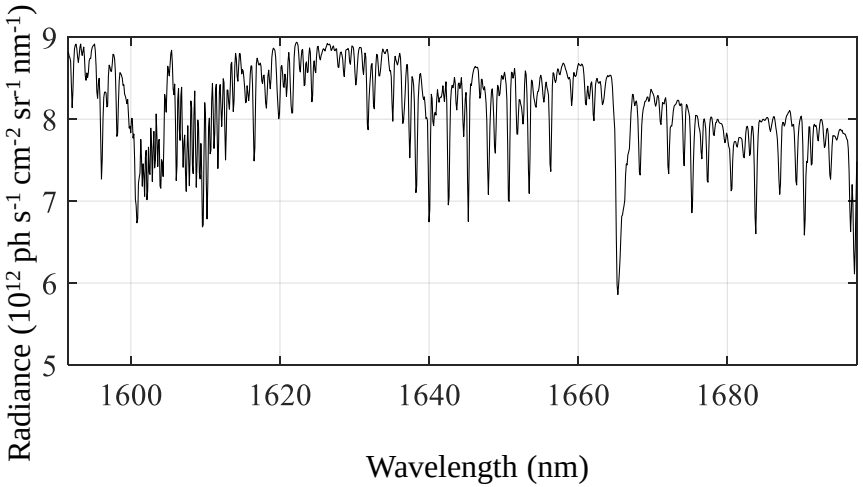

Figure 13: *Mean spectral radiance in the CH_4 band over the region shown in Figure 12.*

For more information on MethaneAIR and MethaneSAT, see the following presentations:

Mon. 6/14 9:45 AM	*MethaneSAT: Towards detecting agricultural emissions from space*
Mon. 6/14 9:45 AM	*A Rapid and Automatic Orthorectification of MethaneAIR/MethaneSAT Imagery thorough the A-KAZE Algorithm*
Mon. 6/14 12:00 PM	*Development of the L0--L1B processor for MethaneAIR and MethaneSAT*
Mon. 6/14 12:00 PM	*XCH4 retrieval from MethaneAIR: An airborne precursor to the MethaneSAT mission*
Mon. 6/14 12:30 PM	*MethaneSAT: A new approach to quantifying area and point source methane emissions*
Tue. 6/15 9:45 AM	*The O2 airglow retrievals: implications to mesospheric temperature and greenhouse gas remote sensing from space*