Pre-launch and on-orbit spectral calibration of MethaneSAT

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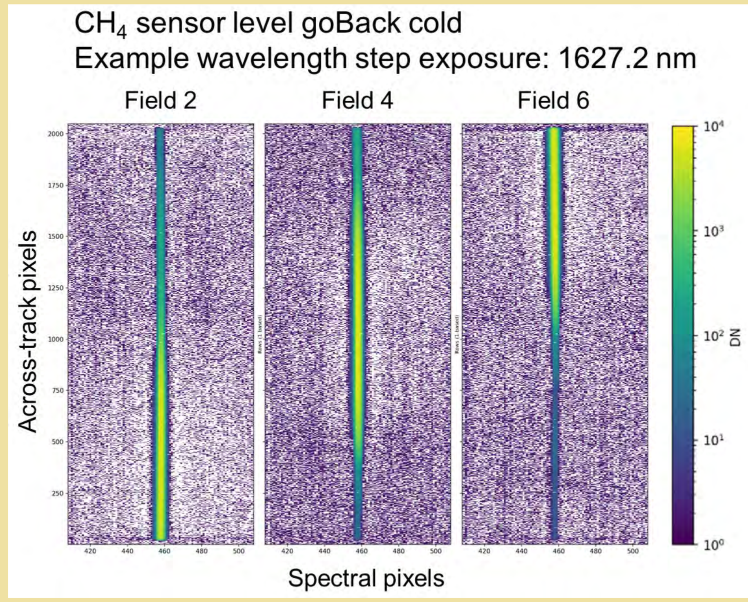
I. Introduction

- MethaneSAT is a push-broom, area-mapping satellite launched into sun-synchronous orbit on March 4, 2024
- The MethaneSAT mission aims to catalyze methane (CH_4) emission reductions by mapping, quantifying, and tracking oil and gas CH_4 discrete and dispersed sources
- We present novel methods for pre-launch instrument spectral response function (ISRF) estimation, evaluate on-orbit spectral calibration, and investigate thermal defocusing impacts on ISRFs and retrievals

Specification	CH_4, CO_2 Spectrometer	O_2, H_2O Spectrometer
Passband (nm)	1598 to 1683	1249 to 1305
L2 retrieval bands (nm)	1598 to 1618 (CO_2) 1629 to 1654 (CH_4)	1249 to 1288 (O_2) 1290 to 1295 (H_2O)
Dispersion (nm / pixel)	0.08	0.06
Median spectral FWHM (nm)	0.25 (CO_2) 0.23 (CH_4)	0.16
Calibration window spectral pixel range	720 to 2030	720 to 2030
Science window spectral pixel range	880 to 1967	816 to 1807
Usable across-track pixel range	35 to 2013	32 to 2018
Point spread function FWHM (spatial pixels)	1.8	1.5

II. Methods

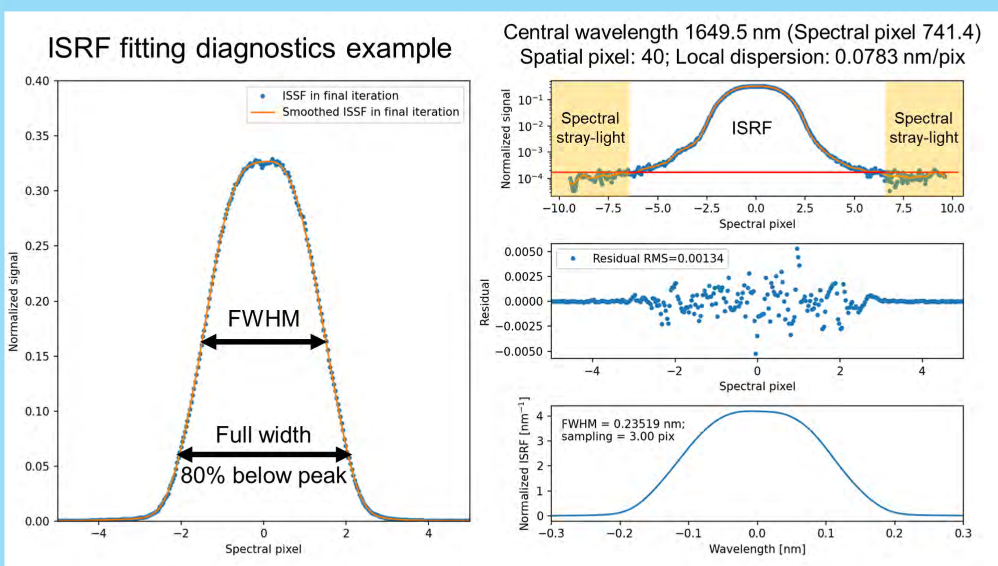
- ISRF estimation algorithms for MethaneAIR (Staebell et al., 2021) were refined for MethaneSAT
- In-band straylight correction via iterative deconvolution with far-field kernel followed by ghost kernel (Tol et al., 2018) was applied to exposures within usable across-track pixel area
- Instrument line shapes at 17 (CH_4) and 13 (O_2) central wavelengths were smoothed across moving spatial pixel windows to mitigate laser speckle noise
- Subsampling of micro-wavelength steps ensured consistency between data sets
- ISRFs were fit using an iterative, third order Savitzky–Golay filter with n=31 window length
- ISRFs at overlapping spatial pixels for 3 illumination fields were merged via exponential signal-weighted median, reducing flight system level FOV edge artifacts
- Outlier ISRF positions were masked and gap-filled using median ISRF of 30 nearest spatial pixels

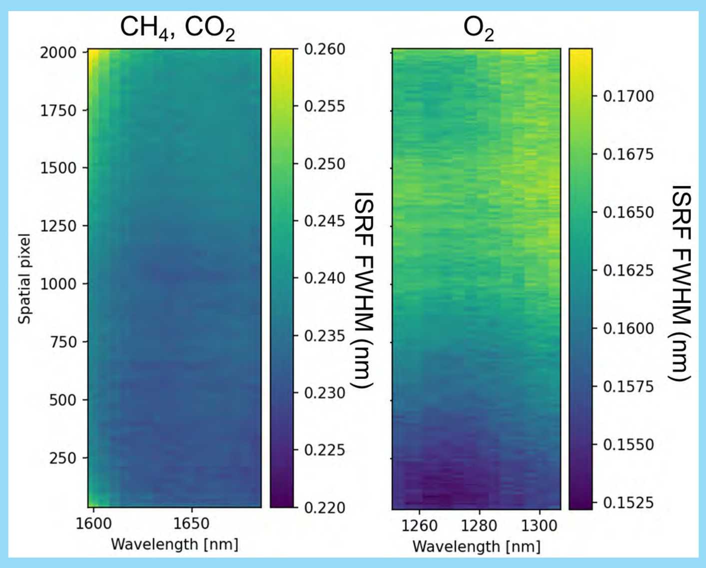


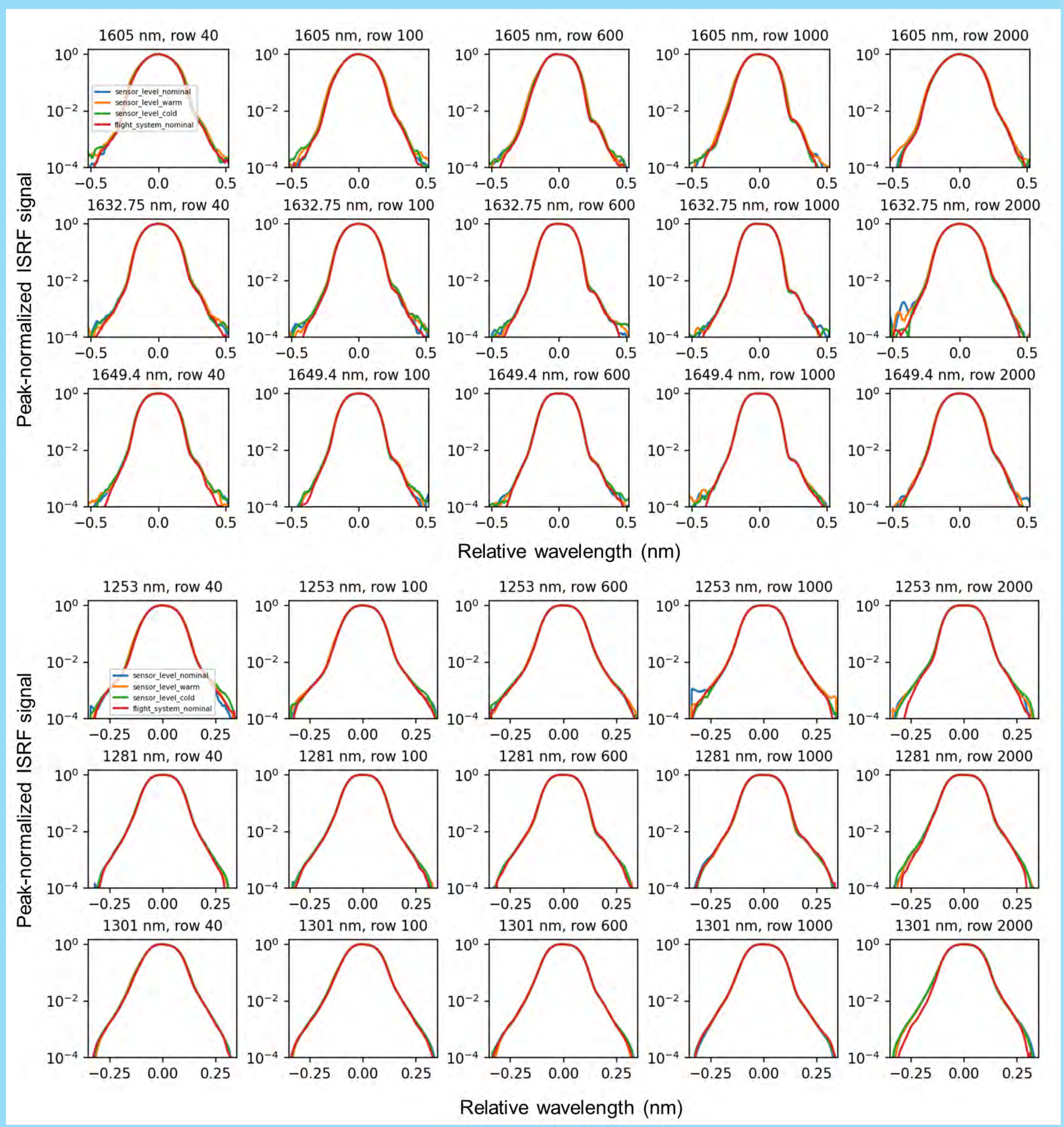
Experiment	Micro-wavelength step size (nm)	Micro-wavelength step range (nm)	Exposure level smoothing window (spatial pixels)
CH_4 sensor level goBack	0.010	0.16	20
CH_4 flight system level	0.010	0.16	30
O_2 sensor level goBack	0.008	0.10	10
O_2 flight system Level	0.008	0.10	10

III. ISRF Fitting

- We compare ISRFs from individual spectrometers (sensor level) at three temperatures, and integrated flight system
- We highlight sensor level cold (CH_4) and flight system level (O_2) ISRFs representative of on-orbit performance

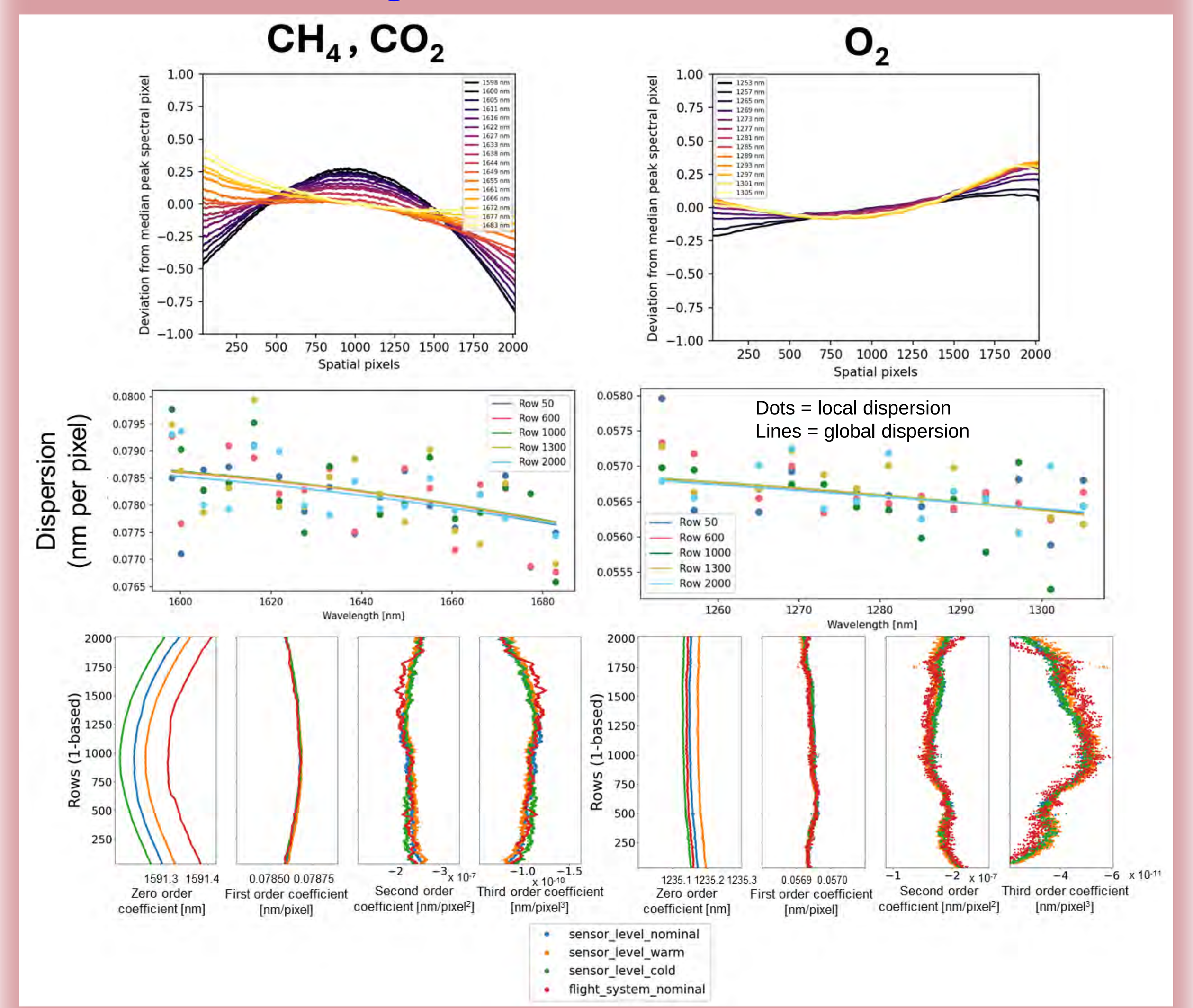






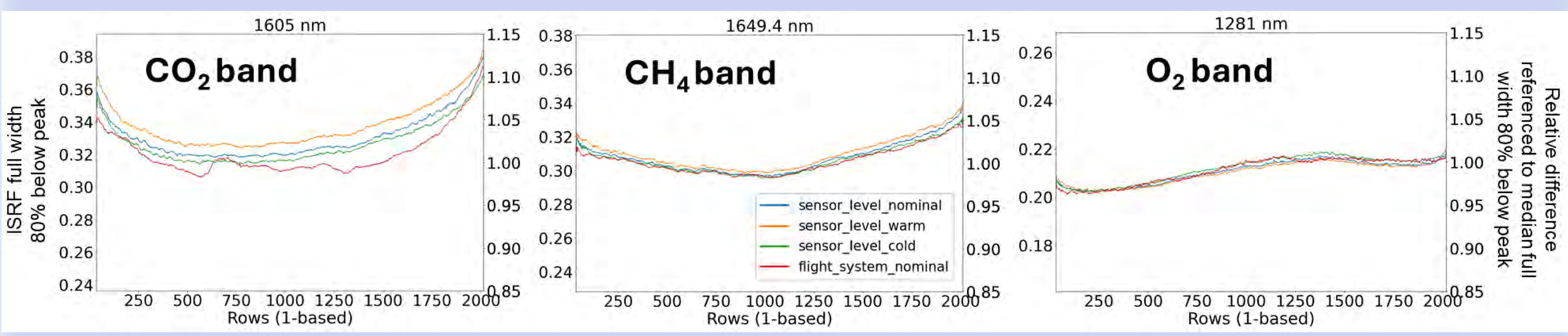
- Peak-normalized ISRF shapes are consistent across data sets, including spatial/spectral edges
- ISRF wings have relatively small speckle noise features minimized by exposure level spatial pixel smoothing

IV. Wavelength calibration



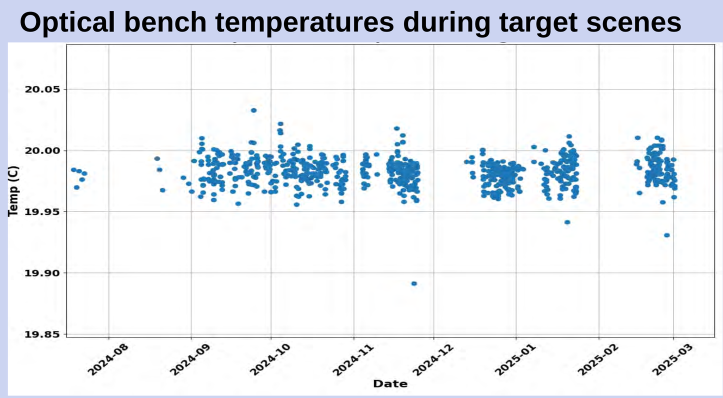
- Spectral distortion of illuminated slit is < ± 0.75 spectral pixel (CH_4, CO_2) and < ± 0.25 spectral pixel (O_2)
- Dispersion decreases with increasing wavelength
- Wavelength calibration curve is derived with 3rd order polynomial fitting, where spatial pixel ensemble of Akaike and Bayesian information criteria are minimized
- Wavelength calibration coefficients are generally insensitive to temperature, except for <0.1 nm wavelength offset that is fit within L2

V. Thermal ISRF variation effects

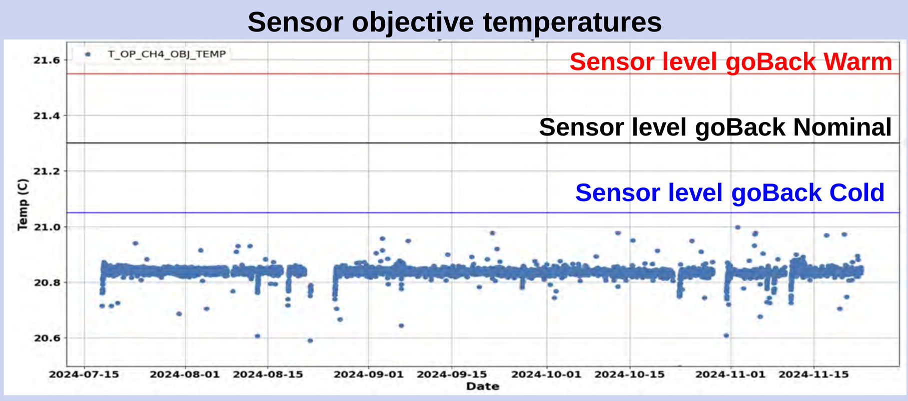


- ISRF widths in four different temperature experiments generally show <1% width temperature sensitives relative to ~5% across-track gradient, except for ~5% width temperature sensitivity and ~10% across-track gradient in the CO_2 band

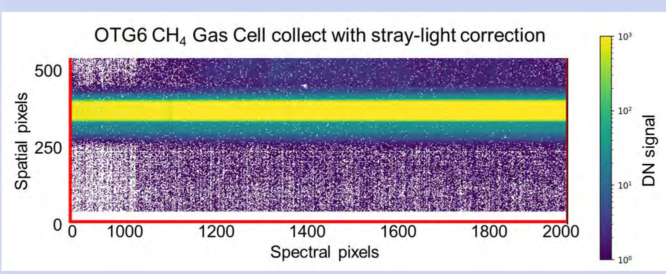
Optical bench temperatures during target scenes



Sensor objective temperatures



- During on-orbit collects, the optical bench was thermally stable across three seasons
- On-orbit CH_4 sensor objective temperatures are cooler than target sensor level temperatures, closest to the cold temperature sensor goBack experiment



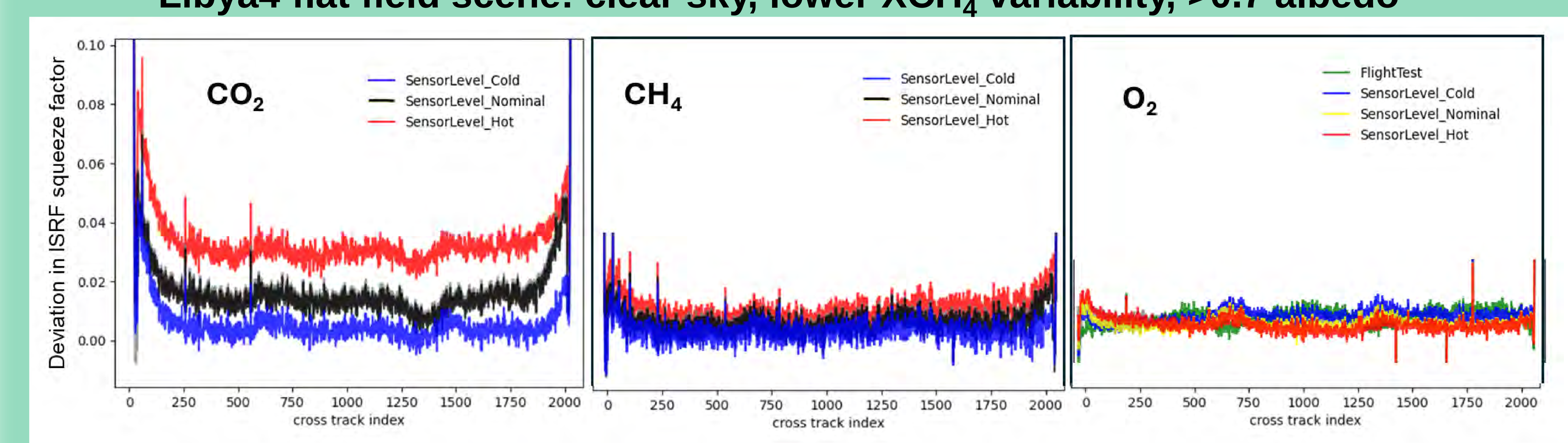
ISRF lookup table	Fitted VCD (molecules CH_4 cm^{-2})	VCD standard error (relative error)	Residual RMS	Fitted VCD bias relative to flight system level
Flight system level	6.905×10^{19}	2.066×10^{17} (0.3%)	0.00181	NA
Sensor level cold	6.916×10^{19}	2.080×10^{17} (0.3%)	0.00182	+0.16%
Sensor level nominal	6.922×10^{19}	2.097×10^{17} (0.3%)	0.00183	+0.25%
Sensor level warm	6.951×10^{19}	2.193×10^{17} (0.3%)	0.00189	+0.67%

- ISRFs from thermal variation experiments result in <0.7 % change in fitted vertical column density based on single spatial pixel retrievals using pure CH_4 gas calibration cell illuminated exposures

VI. On-orbit ISRF stability

- We evaluated four distinct ISRF data sets for on-orbit calibration by examining scaling the tabulated ISRF wavelength grid by a fitted squeeze factor at L2
- Positive deviations in squeeze factors indicate on-orbit ISRFs narrower than pre-launch

Libya4 flat field scene: clear sky, lower XCH_4 variability, >0.7 albedo



- Cold temperature ISRFs are narrowest and closer to on-orbit CH_4 and CO_2 bands, whereas warmer temperature case is closet to on-orbit O_2 ISRF
- CO_2 band squeeze factors exhibit relatively higher temperature sensitivity
- Fitted XCH_4, VCDs, and fit residuals across-track variations are not correlated with the narrower on-orbit across-track edge ISRFs compared with those during pre-launch

VII. Key Points

- ISRF methods were refined to account for MethaneSAT's larger field of view
- ISRFs measured at temperatures closest to on-orbit have optimal ISRF squeeze factors
- On-orbit thermal stability across multiple seasons suggest ISRFs are stable

References

Staebell, C., et al.: Spectral calibration of the MethaneAIR instrument, Atmos. Meas. Tech., 14, 3737–3753, https://doi.org/10.5194/amt-14-3737-2021.

Tol, P.J.J., et al.: Characterization and correction of stray light in TROPOMI-SWIR, Atmos. Meas. Tech., 11, 4493–4507, https://doi.org/10.5194/amt-11-4493-2018.