Comparison of the TIR spectral radiance between GHG satellite-based multi-sensors (GOSAT, GOSAT-2, AIRS, IASI, and CrIS) and aircraft-based S-HIS

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Introduction

Background of this study

- For GOSAT/GOSAT-2, the combination of SWIR and TIR radiance spectra provides a partial column density of GHG between lower and upper troposphere. It is necessary for obtaining accurate partial column density to perform a TIR spectral validation.
- Comparison between satellite-based sensors and high-quality reference data from aircraft provide an accurate spectral validation.

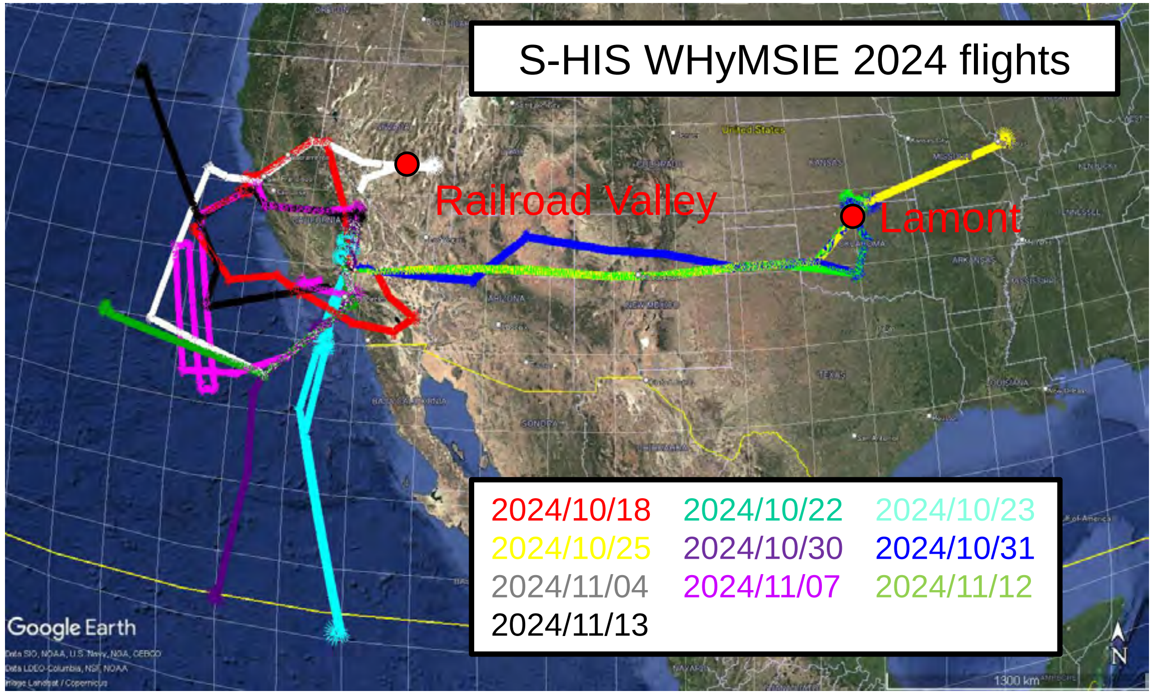
Comparison with Scanning High-Resolution Interferometer Sounder (S-HIS)

Instrument pointing	Cross-track scanning
Swath width	40 km (at 20 km altitude)
Horizontal resolution	2 km (at 20 km altitude)
Wavelengths	3.3 - 18 µm
Maximum optical path depth (Spectral resolution)	±1.037 cm (0.48 cm^{-1})
Radiometric uncertainty	< 0.2 K (3σ) for all bands for scene brightness temperatures greater than 220 K (Joseph K. Taylor et al. 2023)

- S-HIS data is high-quality reference TIR data due to frequently maintenance and calibration.
- Comparison of S-HIS with satellite-sensor in the literature
  - AIRS: Tobin et al. (2006)
  - GOSAT/FTS: Kataoka et al. (2014)

Introduction

Westcoast & Heartland Hyperspectral Microwave Sensor Intensive Experiment (WHyMSIE) 2024 of S-HIS flights



- 10 flights of S-HIS WHyMSIE 2024 (2024/10~2024/11)
- Lamont (north-central Oklahoma) observation
  - Atmospheric profiling (radiosonde) and surface radiation measurements collected by the Atmospheric Radiation Measurement (ARM) facility are available.
  - Satellite-based sensors including GOSAT-2/ FTS-2 observe.
- Railroad Valley (vicarious calibration site for GOSAT and GOSAT-2), ocean etc.

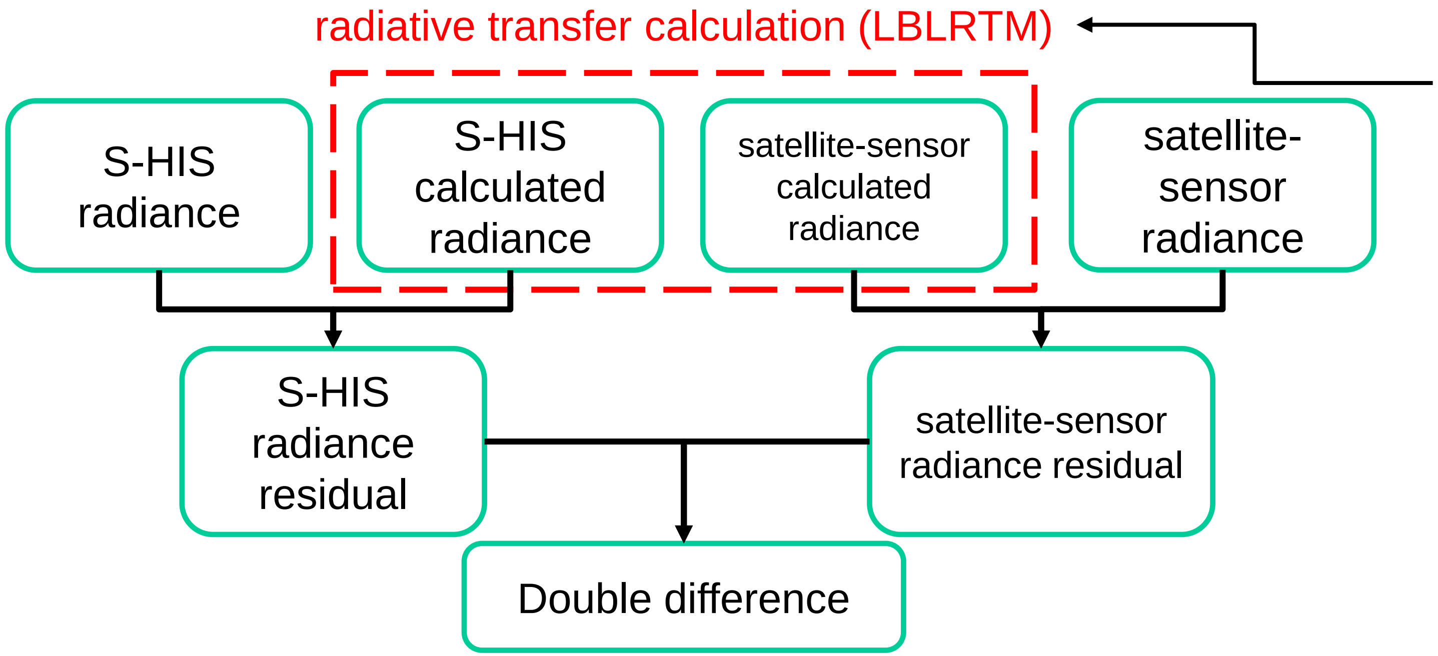
Many coincidences between satellite-based sensors and S-HIS

Objective of this study

For the TIR spectral validation, we demonstrate the comparison between GHG satellite-based TIR sensors including GOSAT-2/FTS-2 and S-HIS WHyMSIE 2024 spectral data.

Method

TIR double difference method (Tobin et al. 2006; Kataoka et al. 2014)



- This method enables to evaluate the bias of satellite-sensor toward S-HIS with reducing the effect of difference in observation geometry and errors of calculation parameters.
- This method is independent of sensor type including interferometer and diffraction grating.
- Spectral resolution was matched to the common spectral resolution by the convolution of instrument line shape function of each sensor.

Input parameters for land coincidence

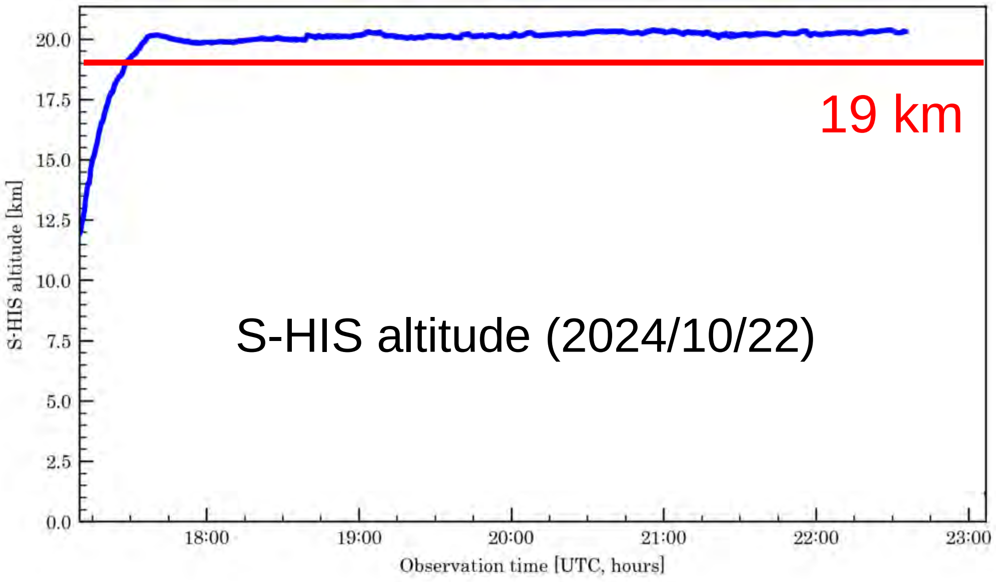
Parameter	Source
Land surface temperature (LST)	MODIS/Aqua Land Surface Temperature/3-Band Emissivity Daily L3 Global 1 km SIN Grid Day
Emissivity	Combined ASTER and MODIS Emissivity database over Land (CAMEL) Emissivity Monthly Global 0.05Deg
Temperature and relative humidity profile	• Radiosonde from the Atmospheric Radiation Measurement (ARM) Facility • LBLRTM U.S. standard model
O_3 profile	• ERA5 reanalysis (> 1 hPa) • LBLRTM U.S. standard model (< 1 hPa)
CO_2 profile	• CarbonTracker CO_2 2022 North America (> 1 hPa) • LBLRTM U.S. standard model (< 1 hPa)
CH_4 profile	• CarbonTracker CH_4 2023 (> 1 hPa) • LBLRTM U.S. standard model (< 1 hPa)
Other trace gas profile	LBLRTM U.S. standard model

Coincidences between satellite-based sensors and S-HIS WHyMSIE 2024

Coincidence conditions

1. The observation points of S-HIS WHyMSIE 2024 are distributed within the footprint of FTS, FTS-2, AIRS, CrIS, or IASI, and within ±30 minutes of the observation time difference with FTS, FTS-2, AIRS, CrIS, or IASI.
2. The altitude of S-HIS WHyMSIE 2024 flight is higher than 19 km.

→ Most altitudes of S-HIS WHyMSIE 2024 flight are around 20 km.

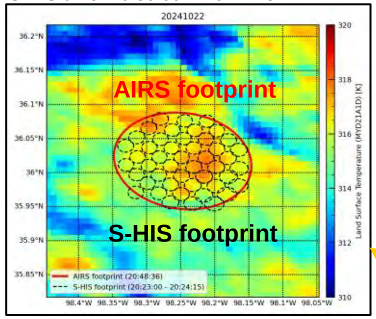


Coincidences with S-HIS WHyMSIE 2024

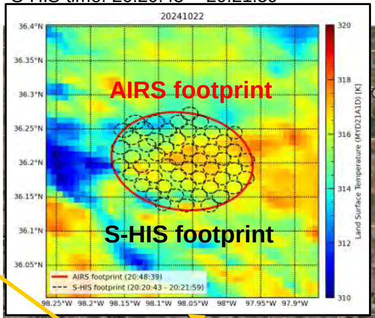
Date	Sensors matched with S-HIS	Coincidence area
2024/10/22	FTS-2, AIRS	near Lamont
2024/10/31	CrIS, AIRS	near Lamont
2024/11/04	FTS, AIRS	Railroad valley
2024/11/07	CrIS, AIRS	Ocean
2024/11/12	CrIS, IASI	Ocean
2024/11/13	CrIS, AIRS	Ocean

Coincidences between FTS-2 – S-HIS and AIRS – S-HIS (Lamont, 10/22/2024)

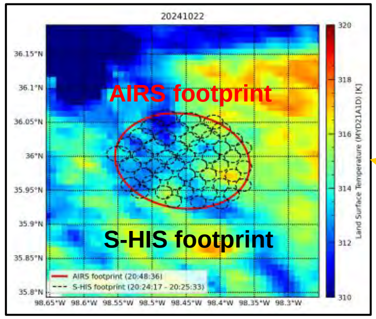
AIRS scan angle: 35.23 [deg]
AIRS time: 20:48:36
S-HIS time: 20:30:00 ~ 20:24:15



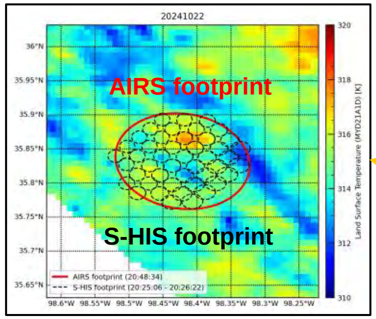
AIRS scan angle: 36.50 [deg]
AIRS time: 20:48:39
S-HIS time: 20:20:43 ~ 20:21:59

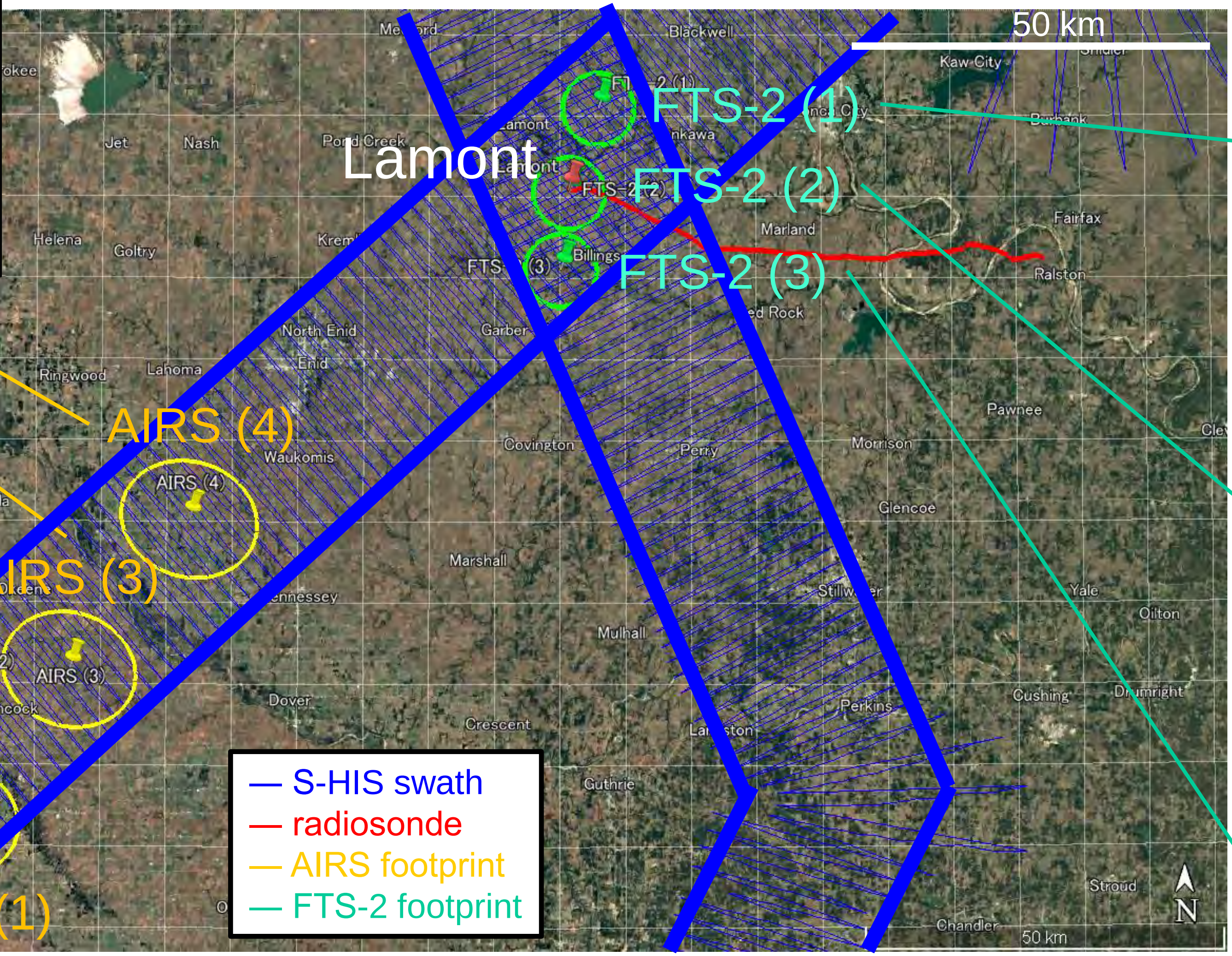


AIRS scan angle: 33.97 [deg]
AIRS time: 20:48:36
S-HIS time: 20:24:17 ~ 20:25:33

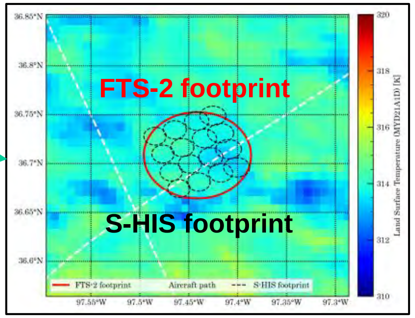


AIRS scan angle: 33.95 [deg]
AIRS time: 20:48:34
S-HIS time: 20:25:06 ~ 20:26:22

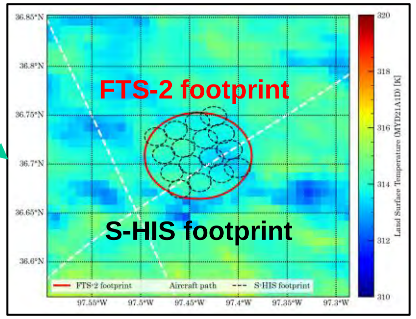




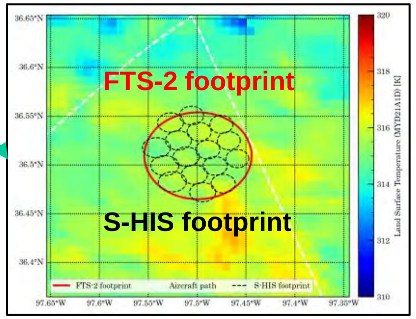
FTS-2 viewAT/CT: -0.89 / 0.21 [deg]
FTS-2 time: 19:50:55
S-HIS time: 19:54:46 ~ 19:55:19



FTS-2 viewAT/CT: -2.76 / 0.33 [deg]
FTS-2 time: 19:50:59
S-HIS time: 19:53:51 ~ 19:54:34



FTS-2 viewAT/CT: -4.78 / 0.22 [deg]
FTS-2 time: 19:51:04
S-HIS time: 19:53:07 ~ 19:53:50



Color: MODIS LST (MYD21A1D)

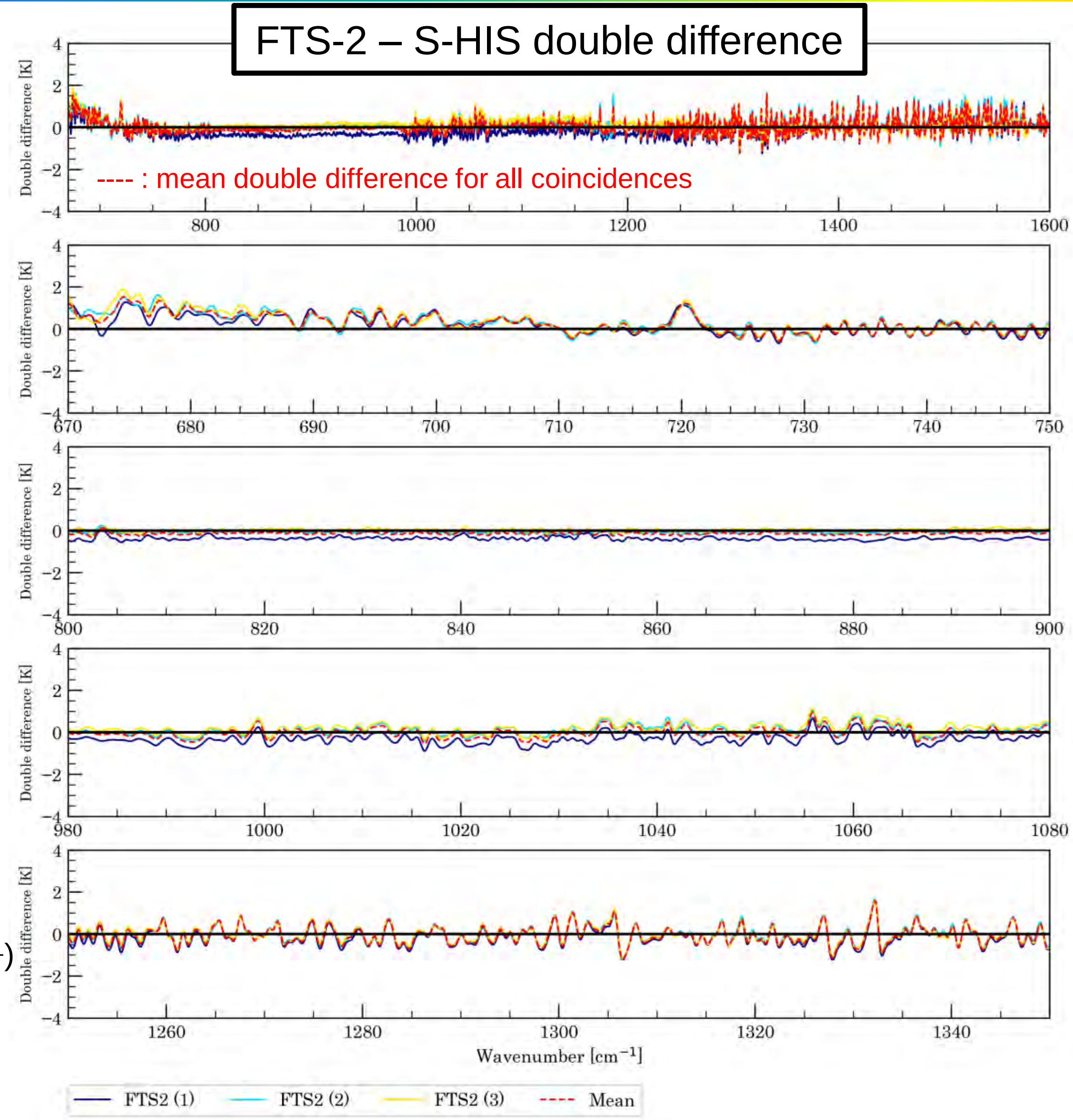
Results: Double Difference

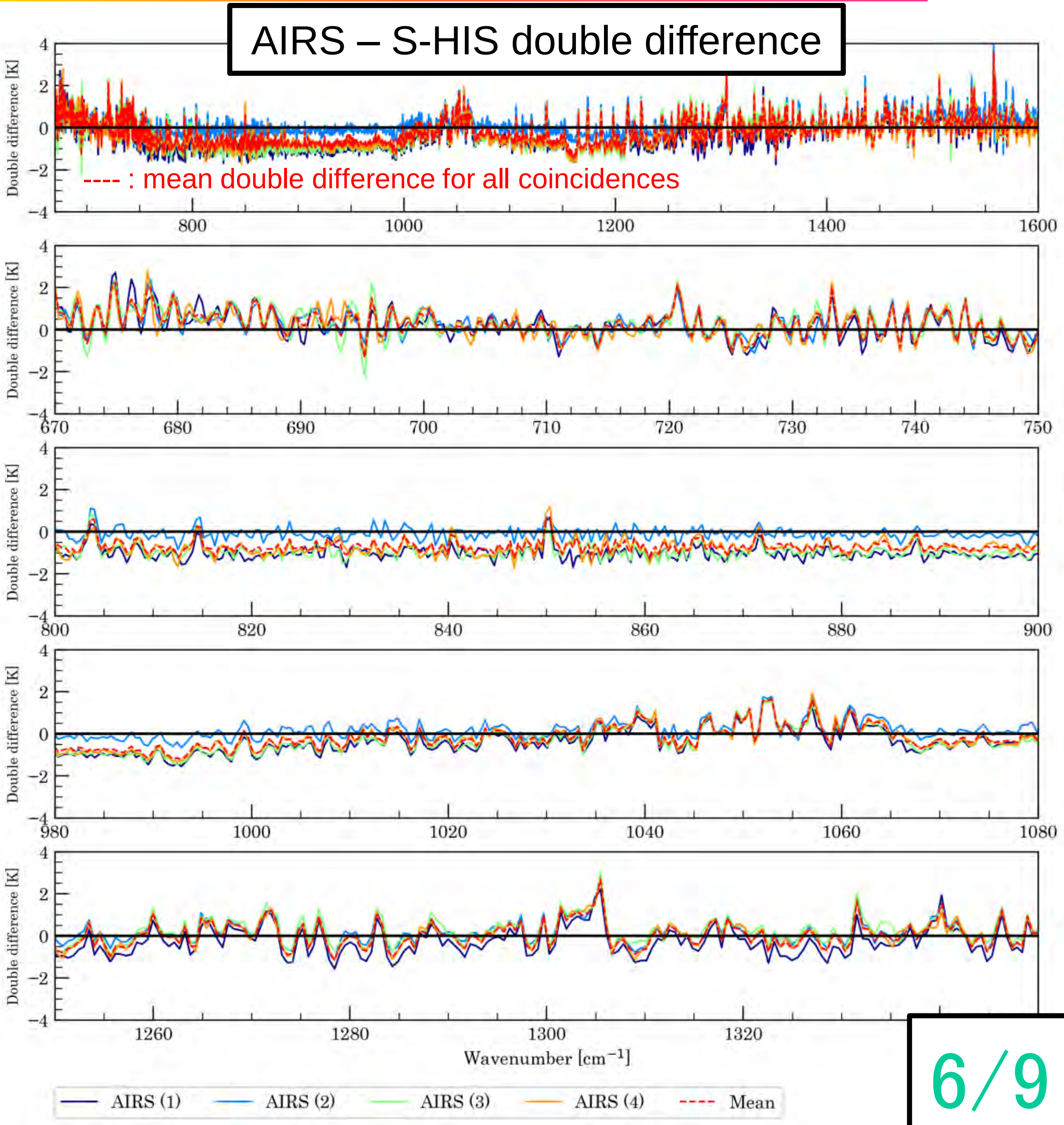
CO_2 channel
(670 ~ 750 cm^{-1})

Atmospheric window channel
(800 ~ 900 cm^{-1})

O_3 channel
(980 ~ 1080 cm^{-1})

CH_4 channel
(1250 ~ 1350 cm^{-1})





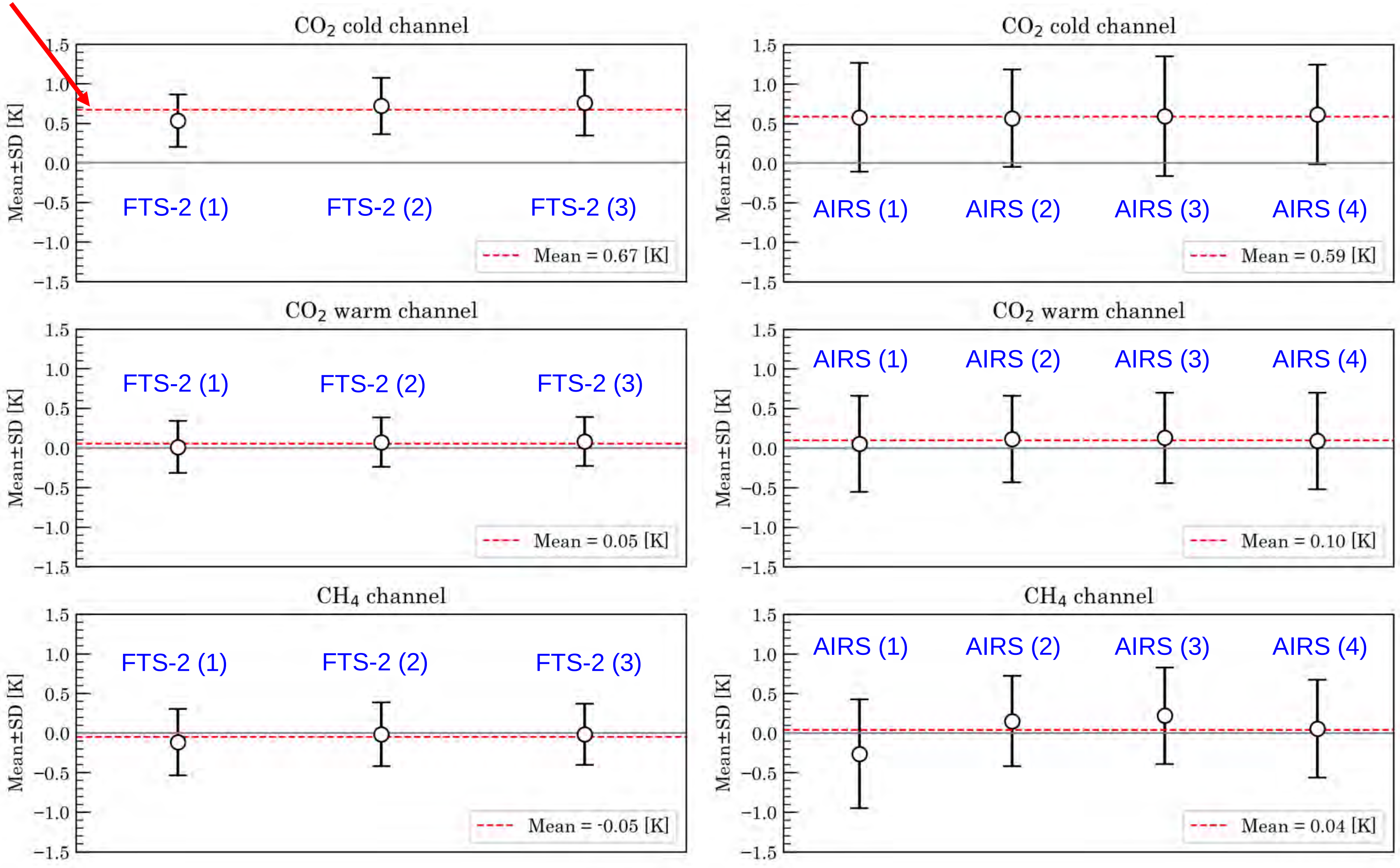
Results: Spectral Mean and Standard Deviation of Double Difference

Spectral mean of mean double difference for all coincidences

CO_2 cold channel
(670 ~ 700 cm^{-1})

CO_2 warm channel
(700 ~ 750 cm^{-1})

CH_4 channel
(1250 ~ 1350 cm^{-1})



Discussion: Comparison of TIR inter-comparison

TIR double difference with S-HIS WHyMSIE 2024

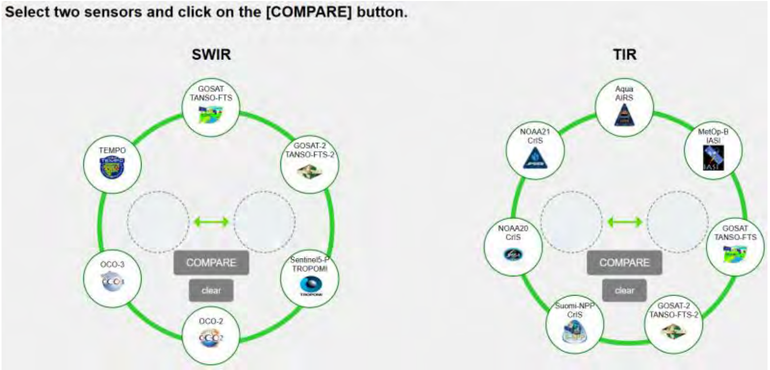
	Spectral mean ± standard deviation of mean double difference for all coincidences [K]		
	CO_2 cold channel (670 ~ 700 cm^{-1})	CO_2 warm channel (700 ~ 750 cm^{-1})	CH_4 channel (1250 ~ 1350 cm^{-1})
FTS-2 – S-HIS	0.67 ± 0.34	0.05 ± 0.31	-0.05 ± 0.40
AIRS – S-HIS	0.59 ± 0.60	0.10 ± 0.55	0.04 ± 0.61

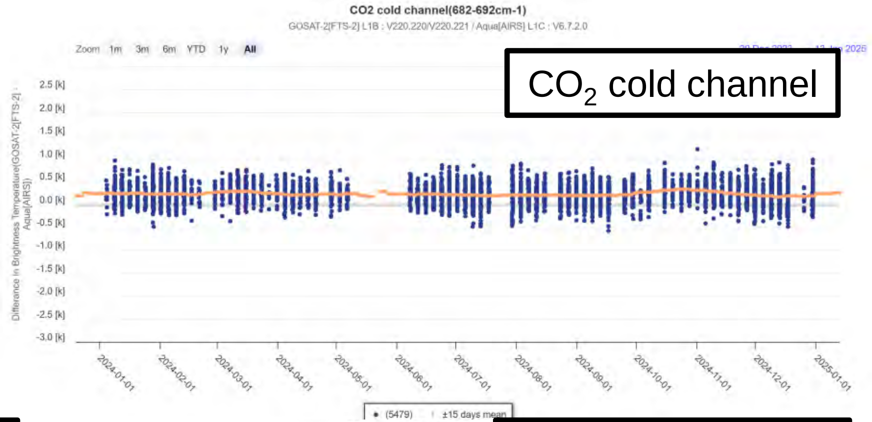
FTS-2 – AIRS TIR inter-comparison in 2024 from match up viewer

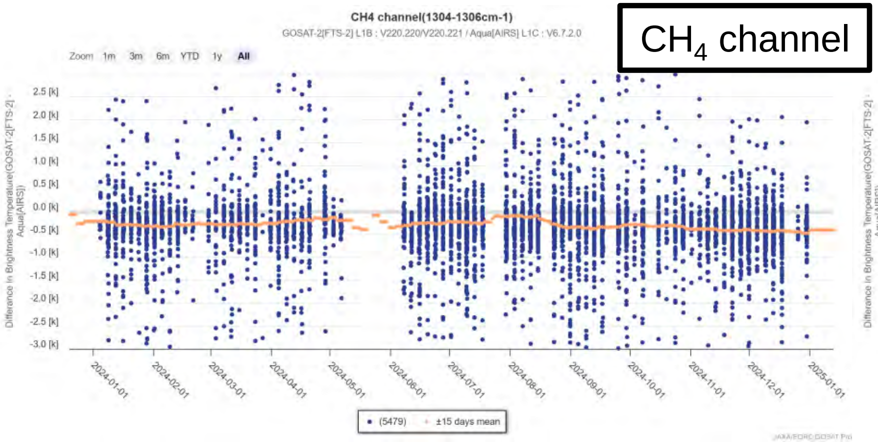
(difference in brightness temperature)

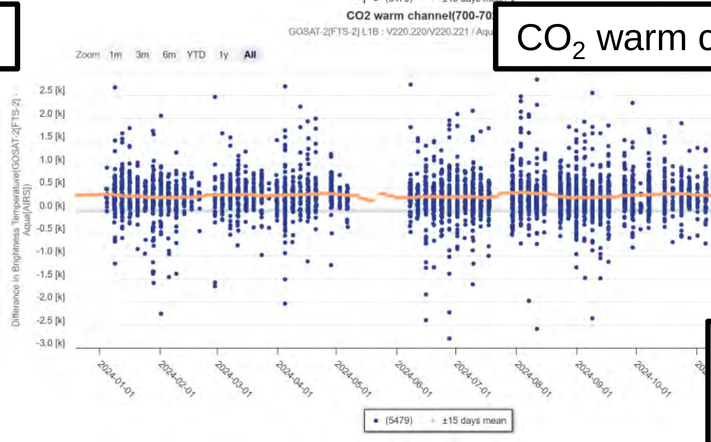
https://www.eorc.jaxa.jp/GOSAT/Matchup_forCal/top_matchup_viewer.html

FTS-2 – AIRS difference in brightness temperature	Mean±STD [K] (1) 2024/01~2024/12 (2) S-HIS flight month (2024/10 ~ 2024/11)
CO_2 cold channel 682 ~ 692 cm^{-1}	(1) 0.22 ± 0.21 (2) 0.26 ± 0.22
CO_2 warm channel 700 ~ 702 cm^{-1}	(1) 0.30 ± 0.45 (2) 0.31 ± 0.34
CH_4 channel 1304 ~ 1306 cm^{-1}	(1) -0.30 ± 1.13 (2) -0.38 ± 0.77









Conclusion

- For GOSAT/GOSAT-2, the combination of SWIR and TIR radiance spectra provides a partial column density of GHG between lower and upper troposphere. It is necessary for obtaining accurate partial column density to perform a TIR spectral validation.
- For the TIR spectral validation, we demonstrated the comparison between GHG satellite-based TIR sensors including GOSAT-2/FTS-2 and WHyMSIE 2024 data of S-HIS, which is high-quality reference airborne data due to frequently maintenance and calibration, with TIR double difference method.
- Based on the double difference near Lamont on October 22, 2024, biases of FTS-2 and AIRS toward S-HIS are similar.

CO_2 cold & warm channel: positive bias (< 1 K) / CH_4 channel: ~ 0 K

→ Similar result with TIR inter-comparison between FTS-2 and AIRS. This implies that similar bias between FTS-2 and AIRS with that estimated from S-HIS double difference can be obtained in other month without S-HIS flights.