

Radiative Closure Study in the Thermal and Far-Infrared Using Airborne FIRR-2 Measurements During the ECALOT Campaign

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Introduction

- The EarthCARE Commissioning Cal/Val Campaign in Ottawa (ECALOT) was conducted between October 2024 and March 2025 to support the validation of EarthCARE Level-1 and Level-2 products.
- Coordinated airborne and ground-based observations were performed over eastern Canada using the National Research Council Canada's (NRC) Convair-580 and surface sites in Ottawa and Montreal.
- During the last 2 flights, the Far-Infrared Radiometer version 2 (FIRR-2), owned by ECC, was deployed onboard the Convair-580 (Fig. 1).
- This study presents a first radiative closure assessment using FIRR-2 observations and some EarthCARE products.

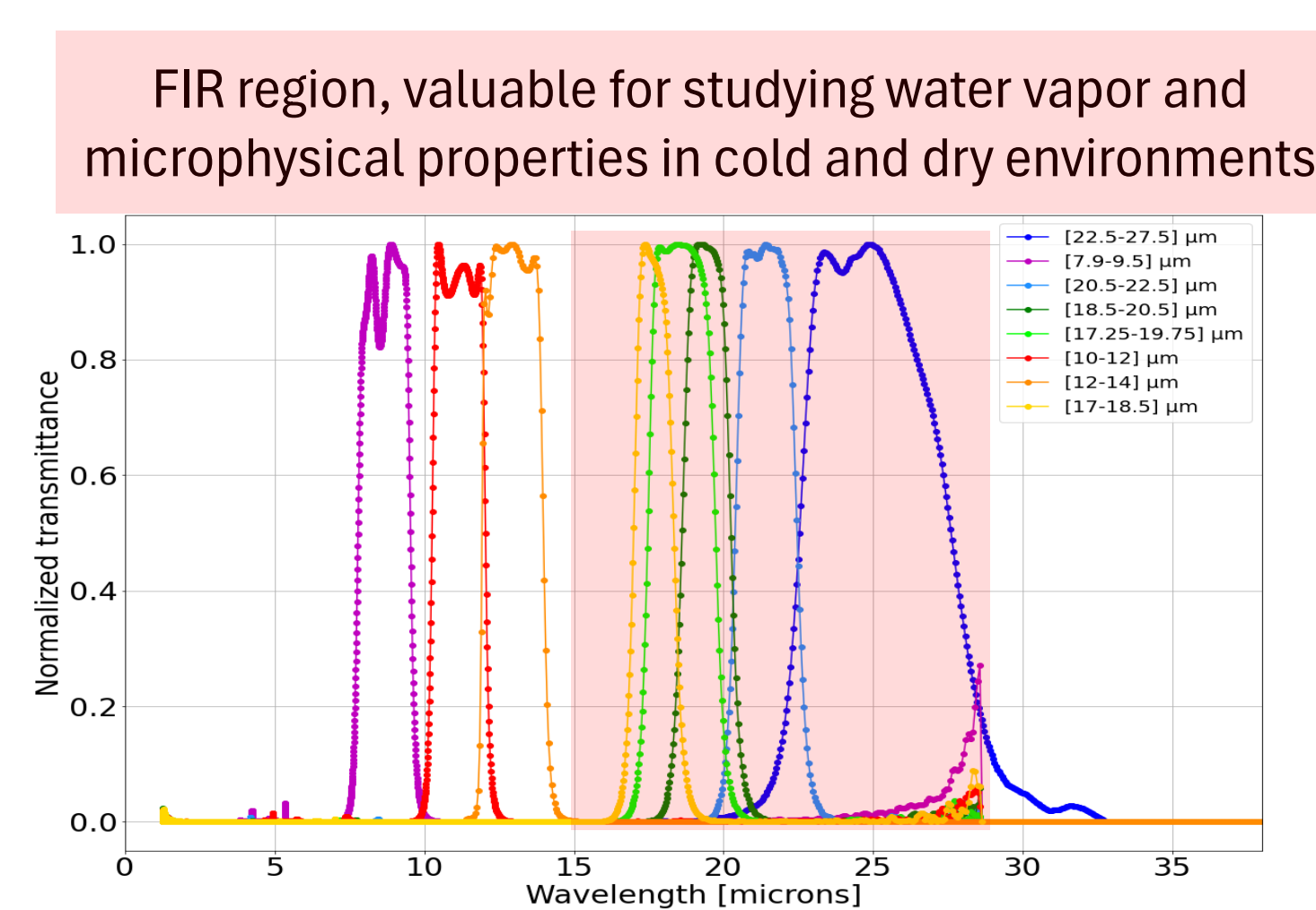
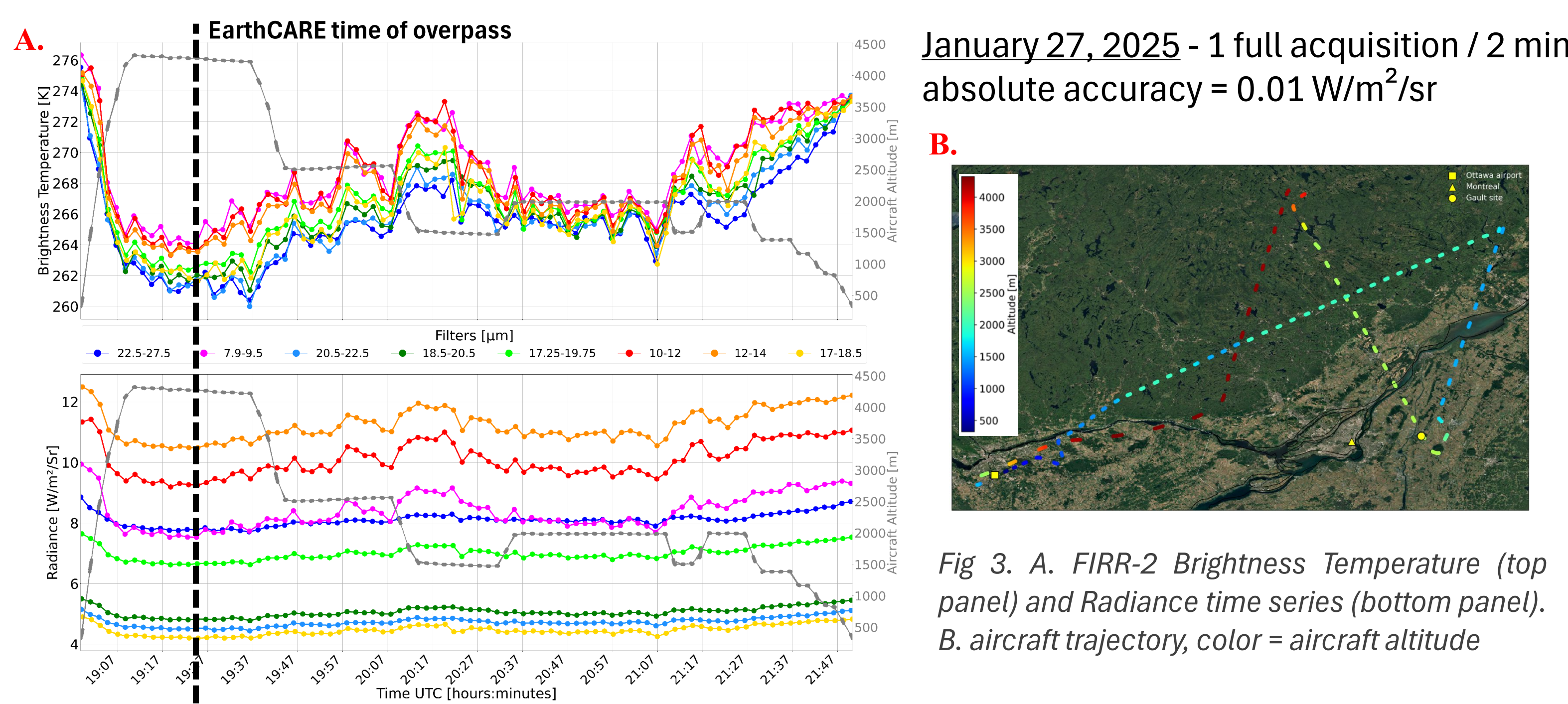


Fig 1. FIRR-2 in the Convair's belly pod, aiming at the nadir

Fig 2. FIRR-2, 8 filters' normalized transmittance

FIRR-2 and EarthCARE data

- FIRR-2, the technological precursor of the Thin Ice Clouds and Far-Infrared Emissions (TICFIRE) instrument (HAWC space mission project, planned for launch in 2032), provides radiometrically calibrated radiance in 8 spectral bands between 7.9 μm and 27.5 μm (Fig. 2).



January 27, 2025 - 1 full acquisition / 2 min absolute accuracy = 0.01 W/m²/sr

Fig 3. A. FIRR-2 Brightness Temperature (top panel) and Radiance time series (bottom panel). B. aircraft trajectory, color = aircraft altitude

- Fig. A shows the temporal variation in FIRR-2 observations along the flight path (Fig. B). By combining these observations with co-located measurements from onboard lidar, radar, and microphysical probes, we can better understand the effects of temperature, humidity, surface properties, and cloud microphysics on the measured radiances and brightness temperatures.

To carry out the radiative closure study, we used EarthCARE's products to constrain the radiative transfer code MODTRAN.

- Humidity and Temperature profiles obtained from the EarthCARE X-MET product, which is based on ECMWF model runs.
- Liquid/Ice Water Content profiles and Ice effective diameter obtained from the EarthCARE L2 synergy product (Baseline BA version 11.4).
- Ice crystal optical properties from the Baum *et al.*, 2014 Look-Up Table.

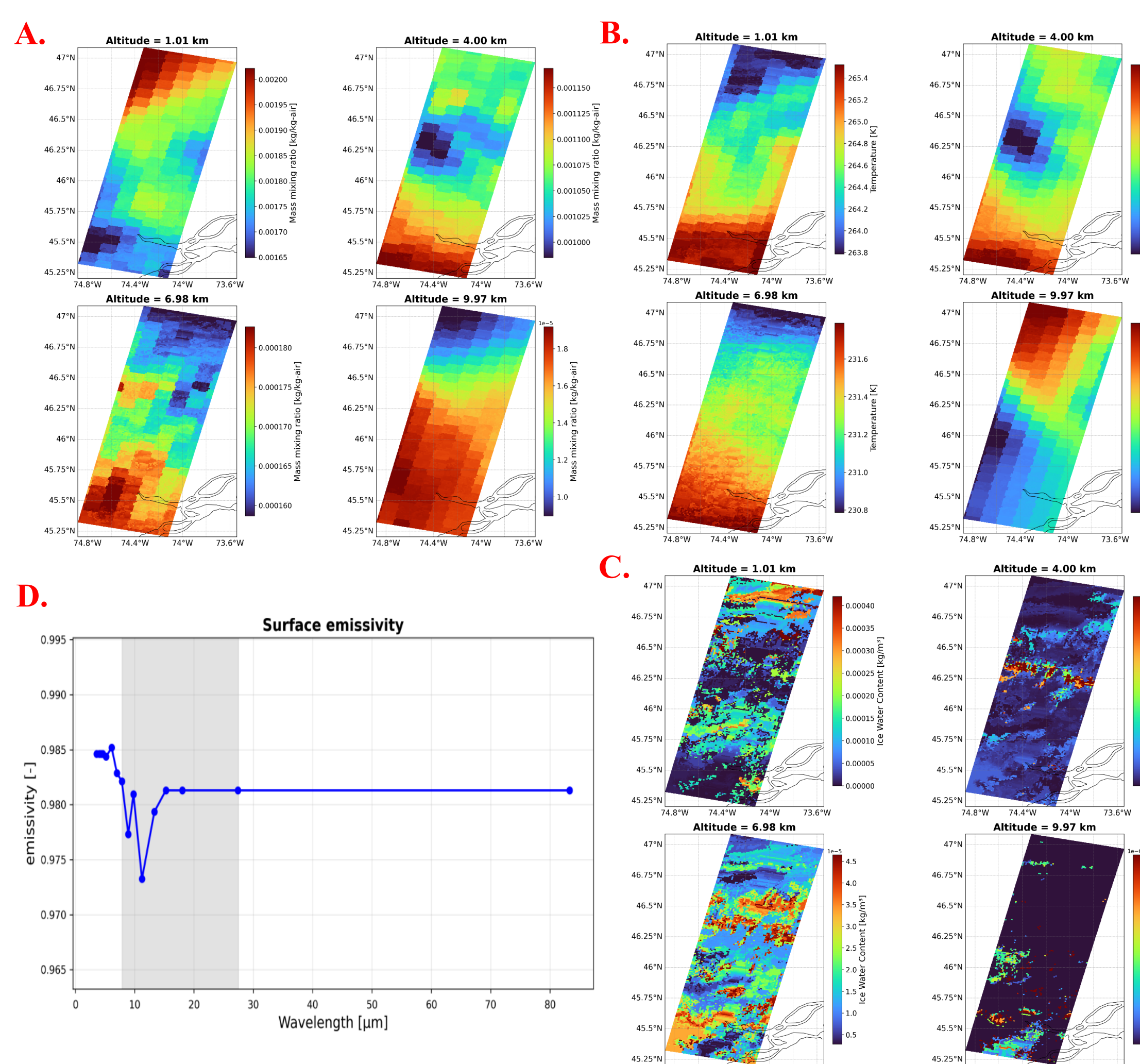


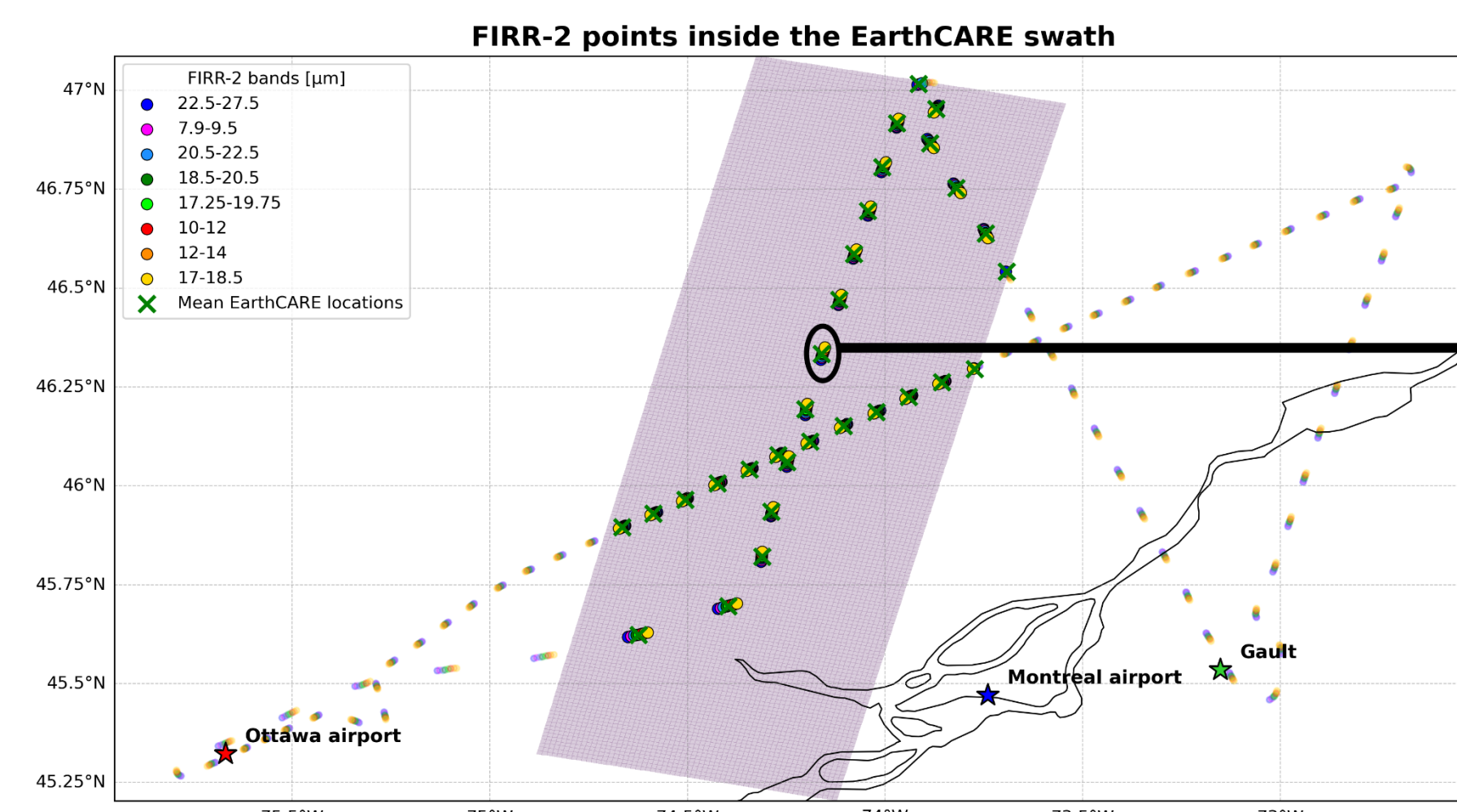
Fig 4. Humidity (A.), Temperature (B.), and Ice Water Content (C.), at 4 altitudes: 1 km, 4 km, 7 km, and 10 km. Surface emissivity (D.), the grey rectangle represents the FIRR-2 spectral range

- Fig. 4 shows the 3D atmospheric structure from X-MET and EarthCARE L2 synergy products.
- Q, T, and IWC exhibit significant variability with both altitude and horizontal position. These variations are expected to contribute to the radiance variability observed by FIRR-2.
- These variables are used as inputs in MODTRAN.

RT closure: Preliminary results

Methodology

- Identify the FIRR-2 points included in the EarthCARE swath and look for the EarthCARE points closest to the FIRR-2 observations (see Fig. 5, grey rectangle).
- From the points included in the EarthCARE swath, identify the one that most closely coincides with the satellite's overpass time (see Fig. 5, black circle).
- Creation of input files (in JSON format) for the radiative transfer code: MODTRAN



EarthCARE time of overpass: 2025-01-27 19:24:48 UTC

Fig 5. FIRR-2 acquisitions (coloured dots), EarthCARE swath (grey rectangle), average of the EarthCARE points closest to the FIRR-2 8-band points (green cross)

FIRR-2	22.5-27.5 μm	7.9-9.5 μm	20.5-22.5 μm	18.5-20.5 μm	17.25-19.75 μm	10-12 μm	12-14 μm	17-18.5 μm
RAD [W m ⁻² sr ⁻¹]	7.773316	7.527028	4.525072	4.825126	6.654059	9.244387	10.48274	4.195169
BT [K]	261.27	264.07	261.78	262.03	262.63	263.66	263.54	261.65
Aircraft alt. [m]	4269.68	4267.6	4265.97	4264.12	4263.41	4262.55	4261.92	4261.74

Tab 1. FIRR-2 acquisition used for the rad. closure study – closest temporal match to the EarthCARE overpass at 19:24:48 UTC

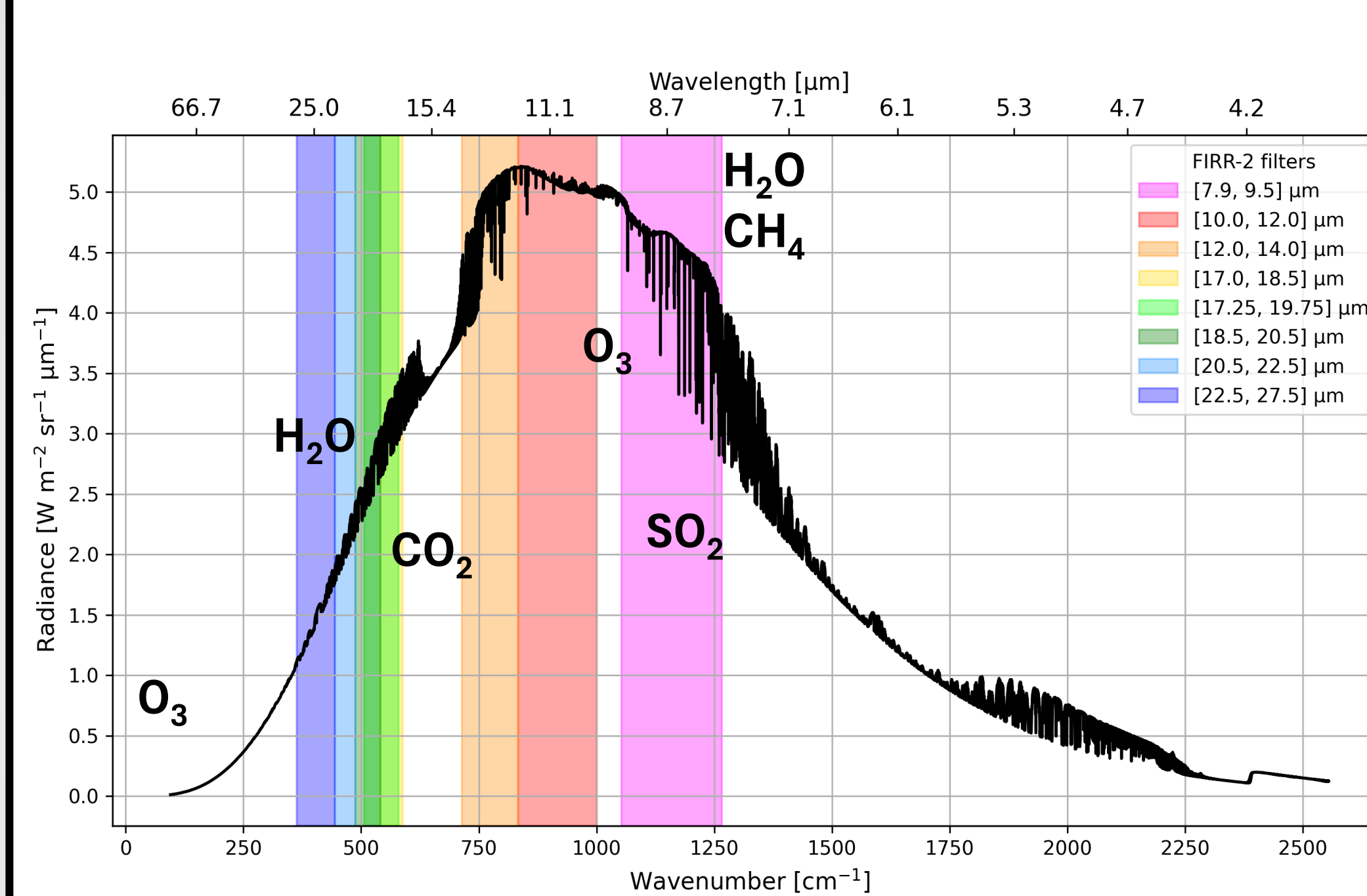


Fig 6. Radiance spectrum obtained using MODTRAN (black curve) and EarthCARE data as input parameters for the RT code. The rectangles define the 8 FIRR-2 filters

MODTRAN configuration

- Include default heavy molecules profiles + default CO₂, O₂, NO, SO₂, NO₂, NH₃ and HNO₃ profiles.
- DISORT with 8 streams and 0.1 cm⁻¹ spectral resolution.
- LWC, IWC profiles from synergy product and Q, T profiles from X-MET, from 600 m to 67 km (below 600 m, presence of NaN values).
- Effective diameter = Reff x 2 (spherical approximation), then compute the mean value. Ice habit: Aggregate-Solid-Columns.
- No tropospheric aerosols, but the presence of background stratospheric aerosols.
- Nadir-viewing geometry with observer altitude fixed at the mean aircraft altitude (4.265 km).
- Multiple scattering enabled.

To compare with FIRR-2, the spectrum (Fig. 6) must be spectrally integrated for each band (see Tab 2.).

MODTRAN	22.5-27.5 μm	7.9-9.5 μm	20.5-22.5 μm	18.5-20.5 μm	17.25-19.75 μm	10-12 μm	12-14 μm	17-18.5 μm
RAD [W m ⁻² sr ⁻¹]	4.579607	6.717877	3.551509	3.735748	5.715597	7.484388	8.754610	3.419349
Abs. Diff. [W m ⁻² sr ⁻¹]	3.193710	0.809151	0.973563	1.089378	0.938462	1.759999	1.72813	0.775820
Rel. Diff. (%)	41.09	10.75	21.51	22.58	14.10	19.04	16.49	18.49

Tab 2. Integrated radiance obtained from the MODTRAN simulation. Absolute difference FIRR-2 - MODTRAN, expressed in W/m²/sr. Relative difference = (Absolute difference / FIRR-2) * 100, expressed as a percentage

The largest FIRR-2/MODTRAN discrepancy is observed in the 22.5–27.5 μm band, which is highly sensitive to water vapor. This difference may be partly explained by the absence of atmospheric layers below 600 m in the atmospheric input profiles, leading to an underestimation of thermal emission from the most humid part of the atmosphere.

In addition, the contribution of the diamond window installed beneath FIRR-2 to maintain acceptable temperature and pressure conditions inside the aircraft has not yet been removed from the FIRR-2 measurements. The last experiment indicates a transmittance of ~70%, a reflectance of ~25%, and an emittance of ~5%. Future work will include a correction for the window contribution. Accounting for the window effect is expected to reduce the amplitude of the observed radiance and brightness temperature variations, leading to a more robust radiative closure assessment.

Perspectives

This study provides an initial assessment of EarthCARE products using observations from the airborne Far-Infrared Radiometer version 2 (FIRR-2). Future work will expand the analysis to include the second flight during which FIRR-2 was operated. Additional EarthCARE retrieval products will also be evaluated and compared. While the current analysis relies on the synergy retrieval product dataset, future investigations will assess the impact of different composite retrieval configurations, including versions 11.30, 11.40, and 11.40 without empirical adiabatic profile correction. The influence of these retrieval products on simulated radiances and cloud property characterization will be examined to identify the most appropriate configuration for far-infrared radiative transfer studies. The outcomes of this ongoing work will contribute to a future peer-reviewed publication.

Acknowledgement

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