Far-IR spectral measurements performed by FIRMOS-B during the Timmins stratospheric balloon flight: characterization of the measurements and retrieval studies

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CNR-INO ISTITUTO NAZIONALE DI OTTICA CONSIGLIO NAZIONALE DELLE RICERCHE

IFAC

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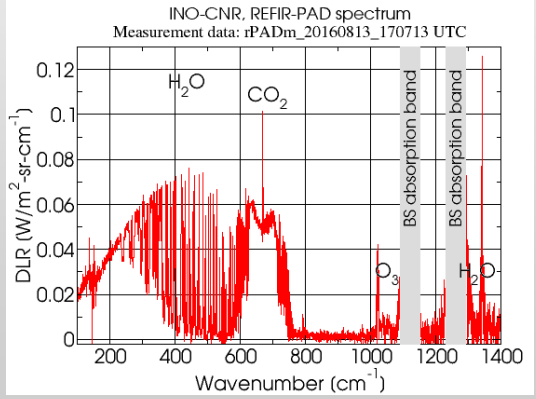
CNR-INO support to FORUM mission preparation: field campaigns

FIR FTS spectral measurments from ground and stratospheric balloons

REFIR-PAD (CNR-INO, ASI) from 2005 to date
From stratospheric balloon (30-35 km) and high-altitude sites (>3km)

FIRMOS (ESA – CNR-INO – ASI)
From high-altitude sites

FIRMOS-B (ESA – CNR-INO – ASI)
From stratospheric balloons

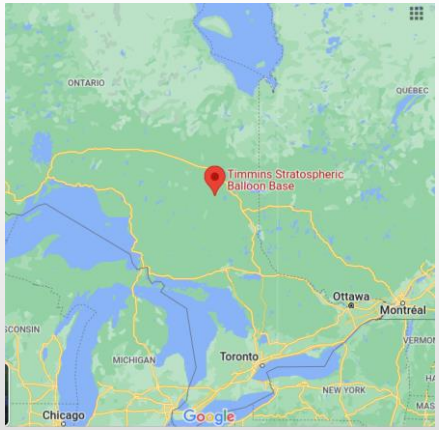


HEMERA-3 flight from Timmins (CA, 48°34’N, 81°23’W)

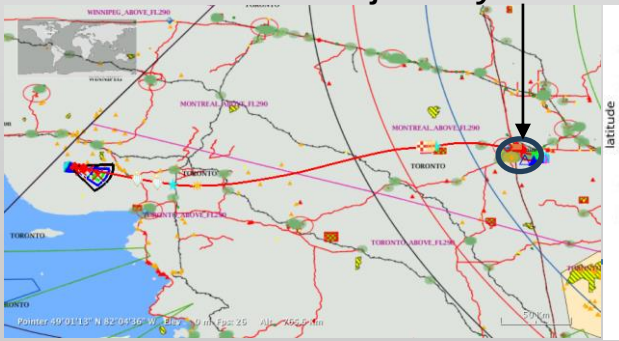
The HEMERA-3 flight was the fourth and last launch of the Strato-Sciences 2022 balloon campaign carried out with the CNES CARMEN gondola in August 2022 from the ASC/CSA stratospheric balloon base in Timmins (CA, 48°34’N, 81°23’W).

The flight had a few problems:

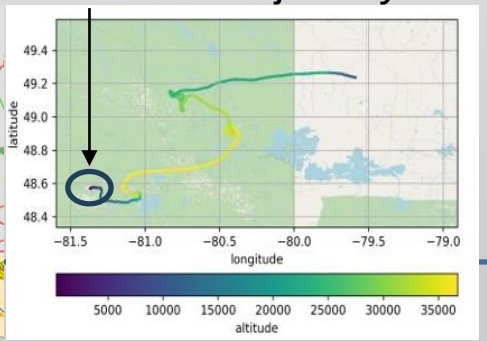
- After the initial phase, the balloon started to lose height, probably because of a He leak.
- As a result, the flight path was different from planned.



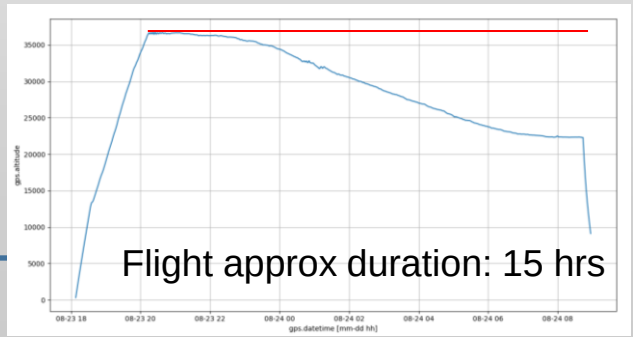
Planned trajectory



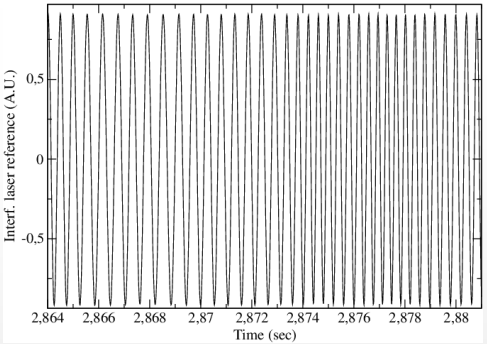
Real trajectory

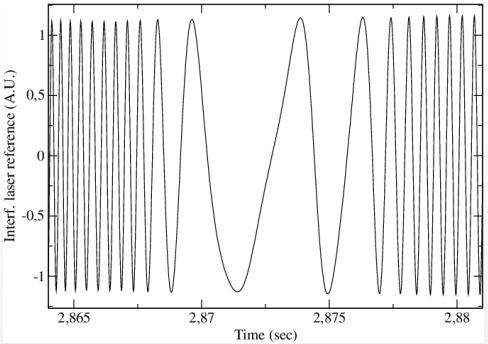


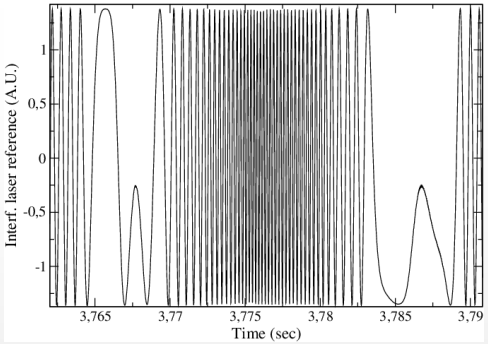
Balloon Altitude



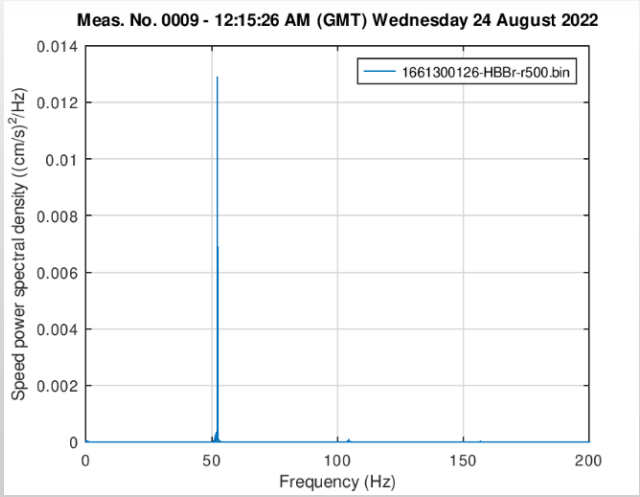
FIRMOS measurements affected by slide speed variations due to mechanical resonance with GLORIA compressor







- The interferometric slide should move at a constant speed. The OPD is measured by counting the fringes of a co-aligned reference laser beam ($\lambda = 785$ nm).
- Disturbance on the slide speed due to vibrations produced by the GLORIA-B++ compressor
- The disturbance was discovered only a few hours before the planned launch date during the end-to-end test.

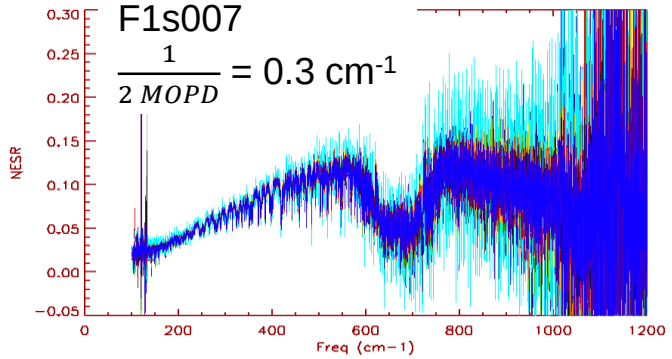


FIRMOS measurements recovered (approx 12 %)

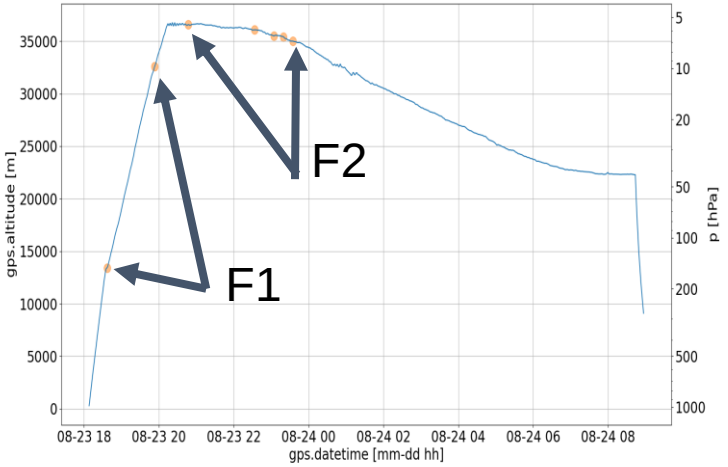
Despite these inconveniences, we were able to recover 7 measurement sequences:

- 2 in the ascending part of the flight (F1 – both in clear sky)
- 5 in the first part of the flight (F2 – with clouds in FIRMOS FOV) when the floating altitude was above 35 km.

Each sequence consists in more than 30 individual spectra that are processed individually.



Flight part	Seq.	N spectra	Start time UTC	End time UTC	start epoch	end epoch	Altitude km
F1	002	33	18:36:55	18:46:08	166 12 79508	166 12 80368	13.43--15.52
F1	007	32	19:53:07	20:02:20	166 12 84080	166 12 84940	32.57--34.34
F2	002	34	20:46:55	20:56:08	166 12 87308	166 12 88168	36.57--36.62
F2	009	34	22:33:36	22:42:49	166 12 93709	166 12 94569	36.08--35.99
F2	011	34	23:04:05	23:13:18	166 12 95538	166 12 96398	35.50--35.52
F2	012	34	23:19:19	23:28:32	166 12 96452	166 12 97312	35.42--35.10
F2	013	34	23:34:34	23:43:47	166 12 97367	166 12 98227	34.99--34.86



Retrieval codes used (1/3) - KLIMA

- **KLIMA**: full physics code developed at CNR-IFAC for accurate clear-sky retrievals
  - optical depths computed line by line based on input spectroscopic data
  - atmospheric layering and retrieval grids are user defined
  - optimal estimation inversion
  - can retrieve simultaneously atmospheric profiles (T, H2O, + ..) and surface properties (surface temperature and emissivity at a user defined grid)
  - no scattering model (code used only to process clear-sky measurements)
  - References:

Del Bianco, S.; Carli, B.; Gai, M.; Laurenza, L.M.; Cortesi, U. XCO2 retrieved from IASI using KLIMA algorithm. Ann. Geophys., 56. https://doi.org/10.4401/ag-6331, 2014.

Dinelli, B.M.; Del Bianco, S.; Castelli, E.; Di Roma, A.; Lorenzi, G.; Premuda, M.; Barbara, F.; Gai, M.; Raspollini, P.; Di Natale, G. GBB-Nadir and KLIMA: Two Full Physics Codes for the Computation of the Infrared Spectrum of the Planetary Radiation Escaping to Space. *Remote Sens.*, *15*, 2532. https://doi.org/10.3390/rs15102532, 2023.

Retrieval codes used (2/3) - SACR

- **SACR (Simultaneous Atmosphere and Cloud Retrieval)** developed at CNR-INO:
  - gas ODs computed by LBLRTM
  - multiple scattering modelled with a two-streams δ-Eddington approximation
  - optimal estimation inversion
  - can retrieve simultaneously atmospheric profiles (T, H2O, + ..), cloud properties: Di, Dw, γ, OD, CTH, surface temperature.
  - References:

G. Di Natale, L. Palchetti, G. Bianchini, M. Ridolfi, The two-stream δ-Eddington approximation to simulate the far infrared Earth spectrum for the simultaneous atmospheric and cloud retrieval, Journal of Quantitative Spectroscopy and Radiative Transfer, 246 https://doi.org/10.1016/j.jqsrt.2020.106927, 2020.

Di Natale, G., Ridolfi, M., and Palchetti, L.: A new approach to crystal habit retrieval from far-infrared spectral radiance measurements, Atmos. Meas. Tech., 17, 3171–3186, https://doi.org/10.5194/amt-17-3171-2024, 2024.

Retrieval codes used (3/3) - FARM

- **FARM (Fast Retrieval Model)** developed at CNR-INO, extended at CNR-ISAC:
  - Uses the σ-F2N fast forward model exploiting gas ODs parametrized vs T, pseudo-monochromatic wavenumber grid, Chou + Tang emulation of multiple scattering. Computes analytical Jacobians. Masiello et al. 2024 and Refs therein.
  - Fixed atmospheric layering, profiles can be retrieved at all or a subset of layers.
  - Synergistic optimal estimation inversion (Ridolfi et al. 2022)
  - Can retrieve simultaneously atmospheric profiles (T, H2O, + max 11 gases), surface properties (Temperature and emissivity at a user defined grid), cloud ice and water mass mixing ratio and effective dimension profiles.
  - Code developed within ASI projects (FORUM-SCIENZA and FIT-FORUM).

Masiello G., Serio C., Maestri T., Martinazzo M., Masin F., Liuzzi G., Venafra S., The new σ-IASI code for all sky radiative transfer calculations in the spectral range 10 to 2760 cm-1: σ-IASI/F2N, Journal of Quant. Spect. and Radiative Transfer, 312, 108814, ISSN 0022-4073, https://doi.org/10.1016/j.jqsrt.2023.108814, 2024.

Ridolfi, M., Tirelli, C., Ceccherini, S., Belotti, C., Cortesi, U., and Palchetti, L.: Synergistic retrieval and complete data fusion methods applied to simulated FORUM and IASI-NG measurements, Atmos. Meas. Tech., 15, 6723–6737, https://doi.org/10.5194/amt-15-6723-2022, 2022.

Instrument Spectral Response Function (ISRF)

All retrieval codes were adapted to simulate spectral radiance measurements acquired with the following instrument spectral response function:

$$\mathrm{ISRF}(\sigma - \sigma_0) = \alpha * \mathrm{sinc}(2\pi(\sigma - \delta\sigma_0)L) + (1-\alpha) * \mathrm{sinc}^2(2\pi(\sigma - \delta\sigma_0)L)$$

with:

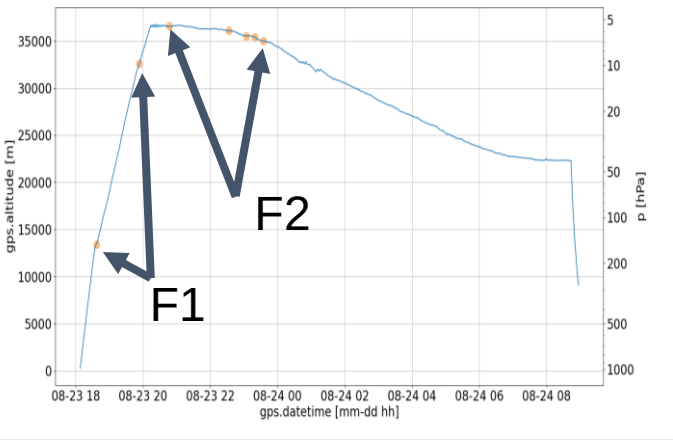
$L = MOPD = 1.67$ cm or 1 / (2 MOPD) = 0.3 cm^{-1}

σ = wavenumber (cm^{-1})

$\alpha = \Omega\,(\sigma - \delta\sigma_0)L/2$ Ω = instrument solid angle aperture (sr), retrieval parameter

$\delta = (1 + \epsilon * 10^{-6})$ where ϵ (ppm) is a wavenumber-stretching retrieval parameter

FIRMOS Field of View (22.4 mrad) is considered homogeneous



F1 s002

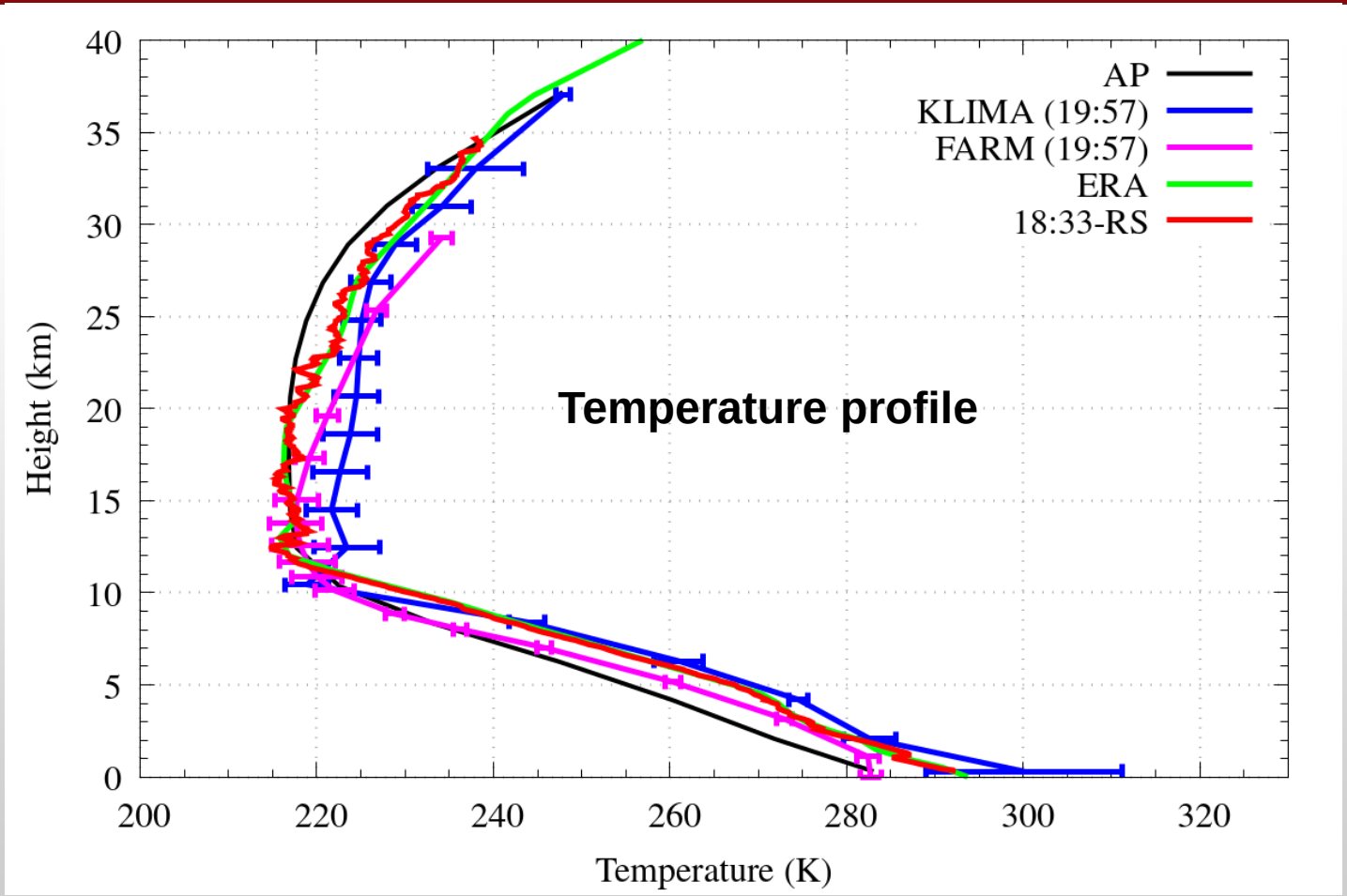
F1 s007

F2 s002

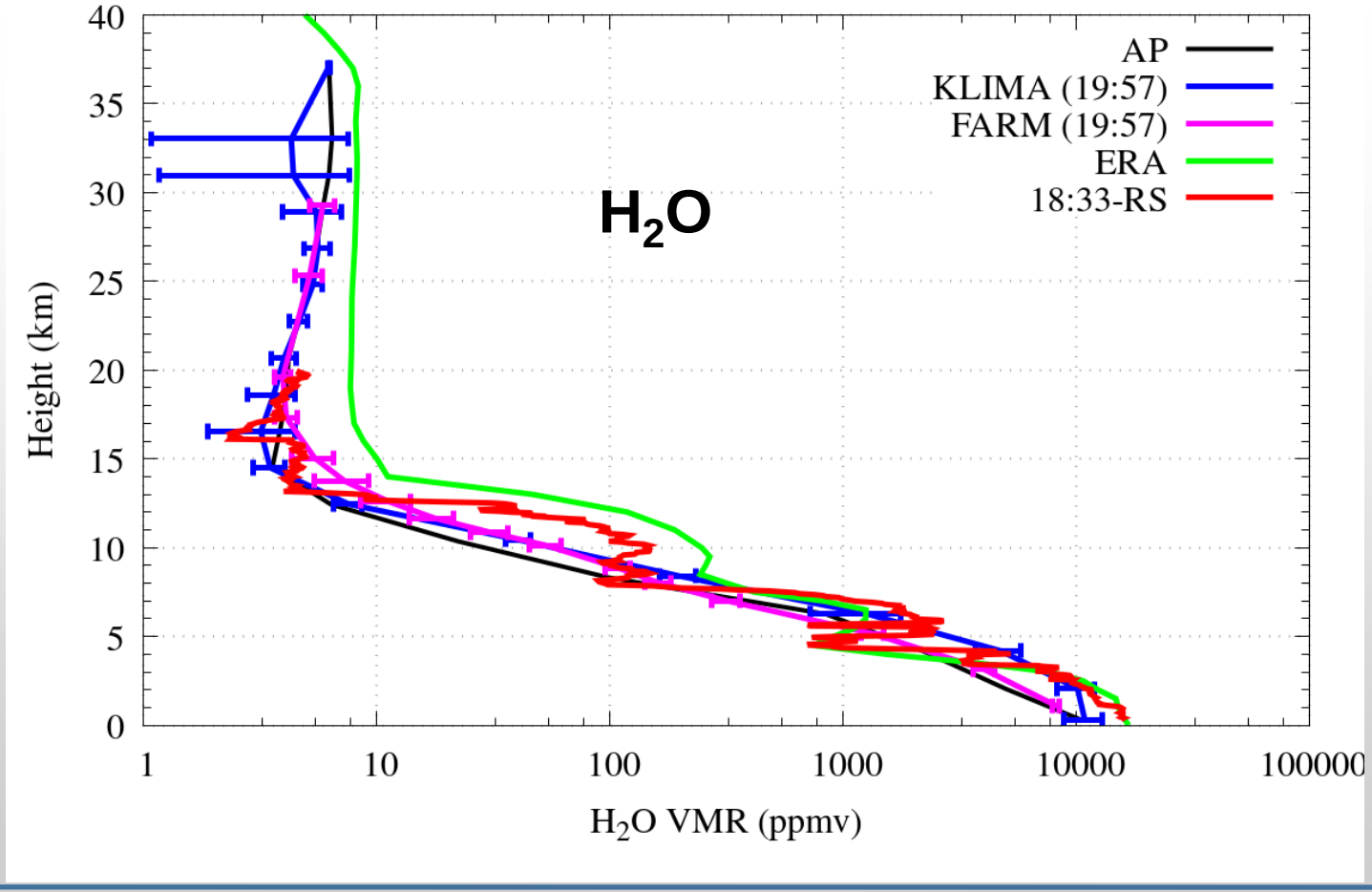
F2 s009

F2 s013

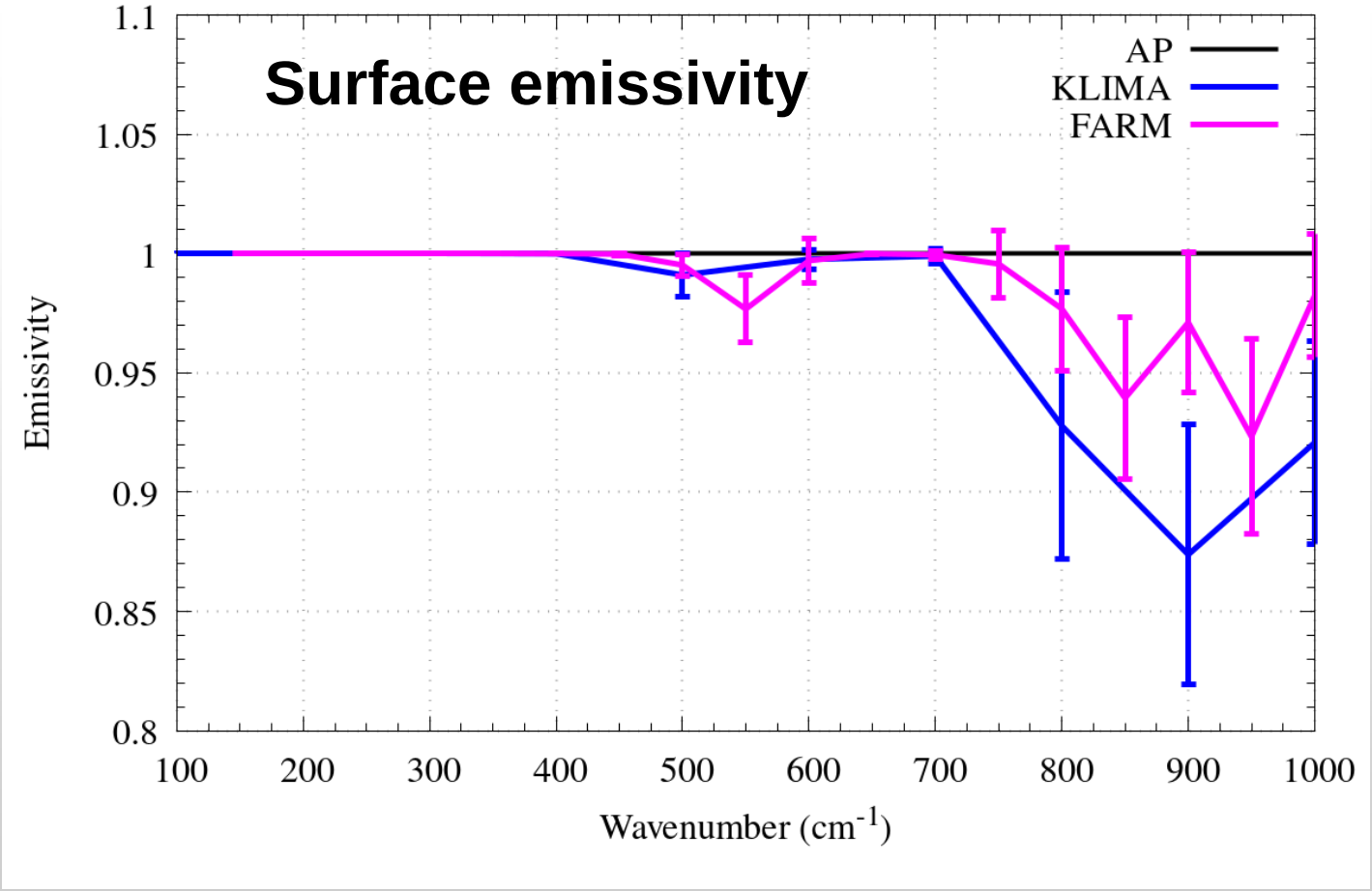
Results for clear scene F1 s007: KLIMA and FARM



Results for clear scene F1 s007: KLIMA and FARM

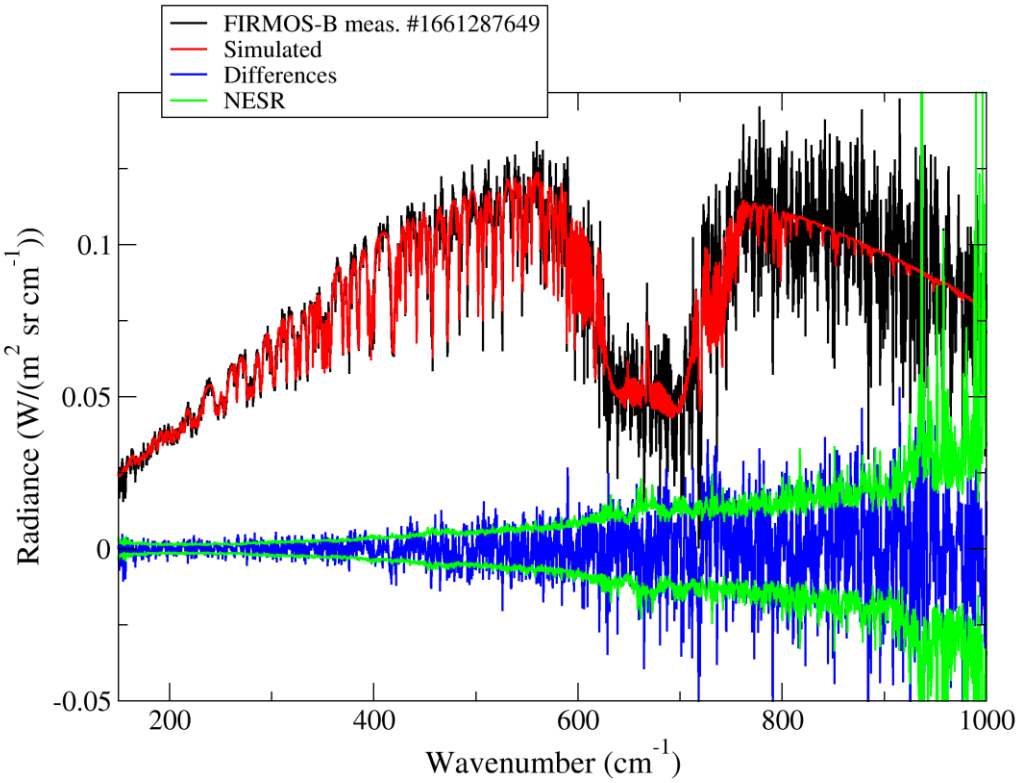


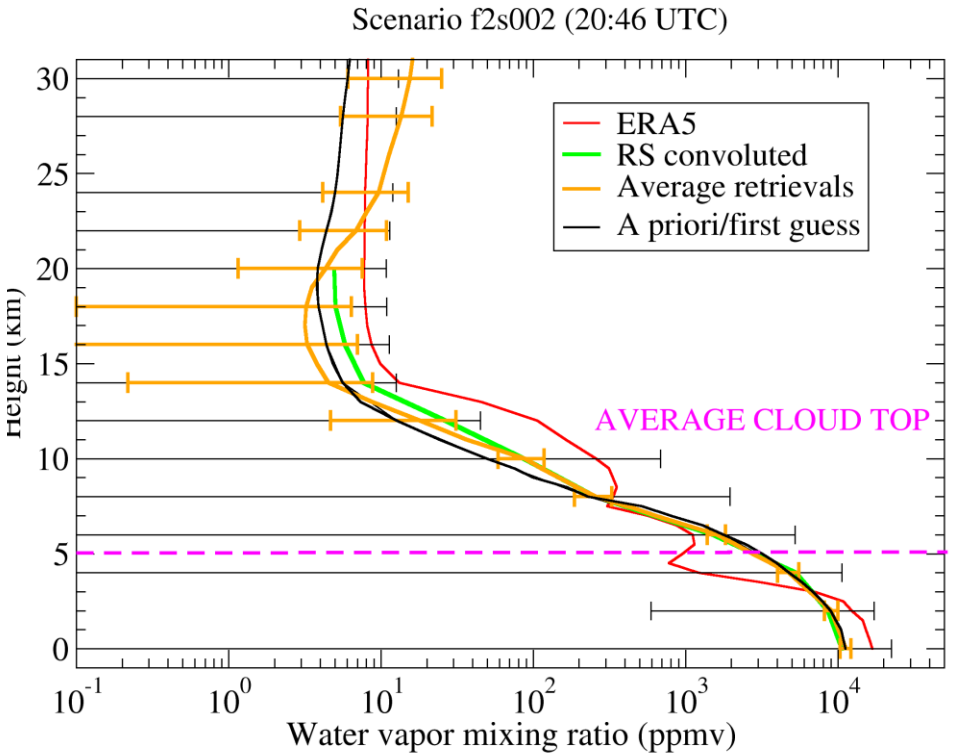
Results for clear scene F1 s007: KLIMA and FARM



Results for cloudy scenes F2 s002: SACR

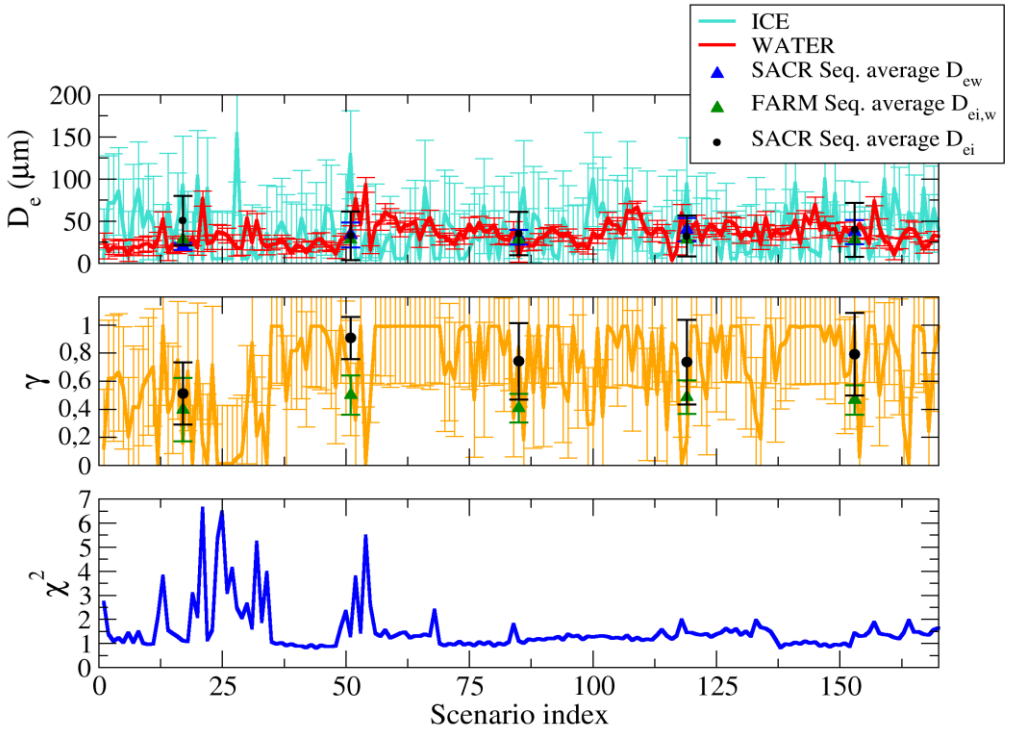
Average residuals of the fit and retreived water vapour profile for F2 s002

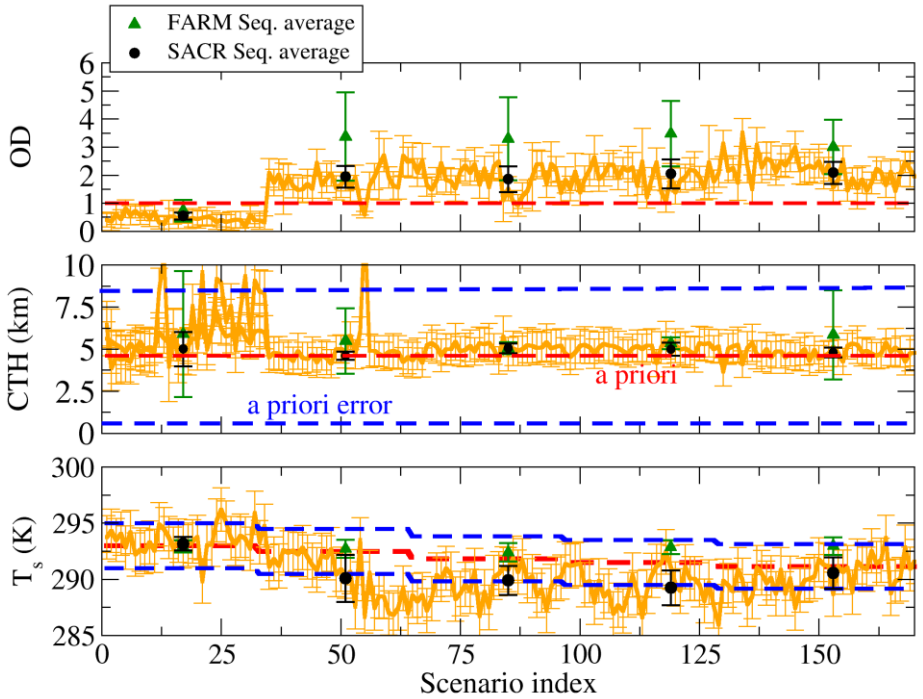




Results for cloudy scenes F2 s00*: SACR and FARM

Cloud parameters, Ts and normalized CHI2





Conclusion and future perspectives

- T and H2O profiles retrieved from FIRMOS clear-sky measurements generally agree well with local radiosoundings.
- The retrieved emissivity is quite variable from a measurement to measurement, even within the same sequence of spectra. Spectral features of the surface emissivity, however, are visible.
- The Chou-Tang scattering emulation scheme implemented in σ-F2N within FARM reproduces quite well the cloud-parameters retrieved with SACR that is based on the 2-streams d-Eddington approximation

for the near future …

- The cloud LWC, IWC profiles retrieved by FARM are quite «nervous», thus it would be desirable to better constrain the retrieval by reducing the number of cloud-parameters retrieved.
- Synergystic (joint) retrievals from FIRMOS & GLORIA-B++ that was operated at nadir on the same balloon flight from Timmins. This would be a check of the possibility to expliot the future synergy of FORUM and IASI-NG measurements.