

Analysis of the synergy between FORUM-like instruments and IASI through complete data fusion and synergistic retrieval.



Cecilia Tirelli ⁽¹⁾, Marco Ridolfi ⁽²⁾, Simone Ceccherini ⁽¹⁾, Samuele Del Bianco ⁽¹⁾, Luca Palchetti ⁽²⁾, Ugo Cortesi ⁽¹⁾



(1) Istituto di Fisica Applicata "Nello Carrara" - Consiglio Nazionale delle Ricerche, Sesto Fiorentino (Firenze), Italy
(2) Istituto Nazionale di Ottica - Consiglio Nazionale delle Ricerche, Sesto Fiorentino (Firenze), Italy



INTRODUCTION

In the framework of the FIT-FORUM project, we present the results obtained from the Complete Data Fusion (CDF) algorithm when applied to selected matching measurements acquired in a stratospheric balloon campaign from Teresina, Brazil, on 30 June 2005. The measurements are those collected by the REFIR-PAD spectroradiometer, a FORUM-like instrument, and IASI-B, a balloon version of IASI. We analyse the performances of the fused products as compared to those of the inversion of the individual measurements and to those of the synergistic retrieval.

THE CDF METHOD

The **Complete Data Fusion (CDF)** [1] is an a-posteriori algorithm to combine independent measurements of the same profile from different instruments into a single estimate for a comprehensive and concise description of the atmospheric state. The CDF solution $\mathbf{x}_f$ for the considered profiles $\hat{\mathbf{x}}_i$ ($i=1,2,...,N$) is given by:

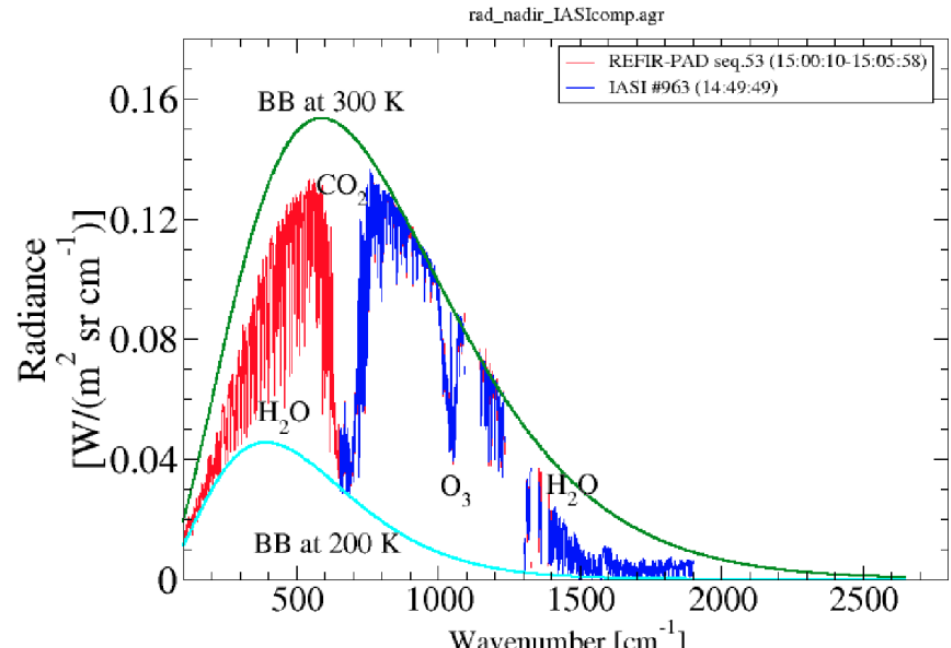
$$\mathbf{x}_f = \left(\sum_{i=1}^N \mathbf{S}_i^{-1} \mathbf{A}_i + \mathbf{S}_a^{-1} \right)^{-1} \left(\sum_{i=1}^N \mathbf{S}_i^{-1} \mathbf{a}_i + \mathbf{S}_a^{-1} \mathbf{x}_a \right) \quad \mathbf{a}_i \equiv \hat{\mathbf{x}}_i - (\mathbf{I} - \mathbf{A}_i) \mathbf{x}_{ai},$$

$\mathbf{x}_{ai}$: a priori profiles
 $\mathbf{S}_i$: covariance matrices (CMs)
 $\mathbf{A}_i$: averaging kernel matrices (AKMs);

with the corresponding total error CM and AKM:

$$\mathbf{S}_f = \left(\sum_{i=1}^N \mathbf{S}_i^{-1} \mathbf{A}_i + \mathbf{S}_a^{-1} \right)^{-1} \quad \mathbf{A}_f = \left(\sum_{i=1}^N \mathbf{S}_i^{-1} \mathbf{A}_i + \mathbf{S}_a^{-1} \right)^{-1} \sum_{i=1}^N \mathbf{S}_i^{-1} \mathbf{A}_i$$

$\mathbf{x}_a$: a priori profile
 $\mathbf{S}_a$: CM a priori for data fusion.

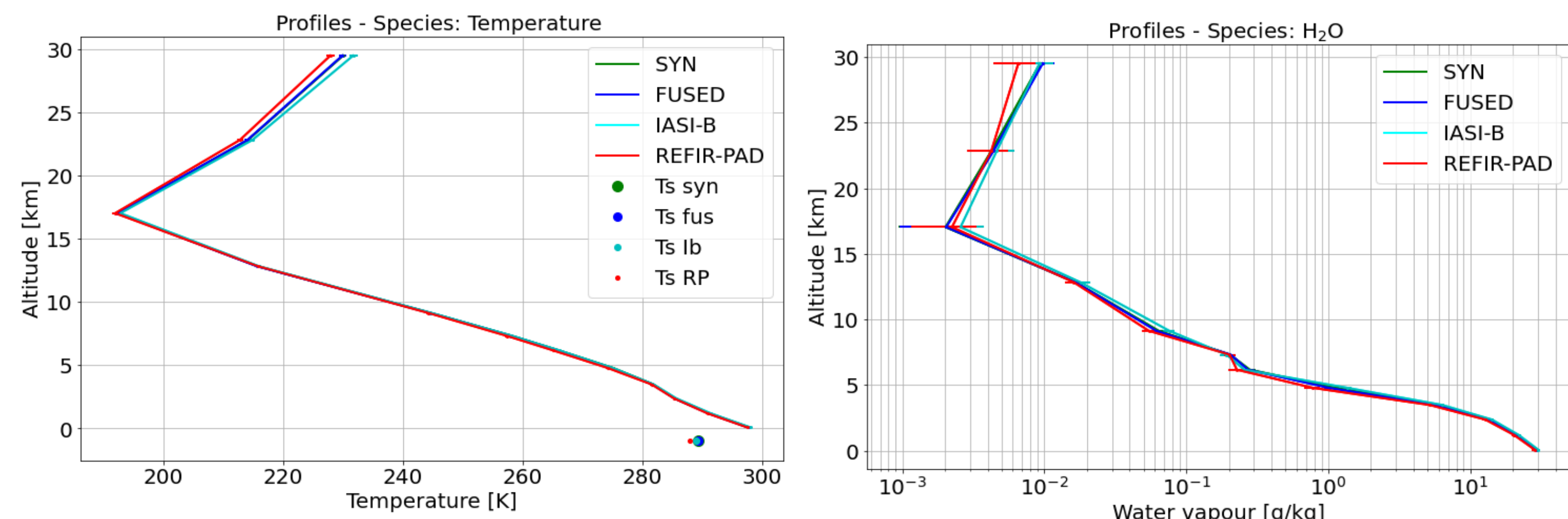


During the Teresina campaign REFIR-PAD and IASI-B operated simultaneously on CNES stratospheric balloon. REFIR-PAD is a compact Fourier Transform Spectrometer designed for applications and developments, it can be operated either from ground or from stratospheric balloons. IASI-B is the balloon-borne version of the IASI instrument, mainly used for satellite validation. Both instruments observed in the nadir geometry with co-aligned Lines of Sight, in a configuration similar to that expected from FORUM and IASI-NG. The two instruments measured for 8 hours. Here, we present the results from the analysis of two clear-sky spectra and their combination.

Instruments

Instrument	REFIR-PAD Radiation Explorer in the Far Infrared – Prototype for Applications and Development	IASI-B Infrared Atmospheric Sounding Interferometer – Balloon
Type	Fourier Transform Spectrometer (FTS)	
Spectral range	~100 – 1500 cm ⁻¹	~700 – 1400 cm ⁻¹ (Teresina campaign)
Spectral resolution	0.4 cm ⁻¹	0.05 cm ⁻¹
Altitude of operation	Stratospheric balloon (~34 km floating altitude)	
Measured quantities	T, surface temperature, H ₂ O, O ₃ , surface emissivity	T, surface temperature, H ₂ O, O ₃ , surface emissivity

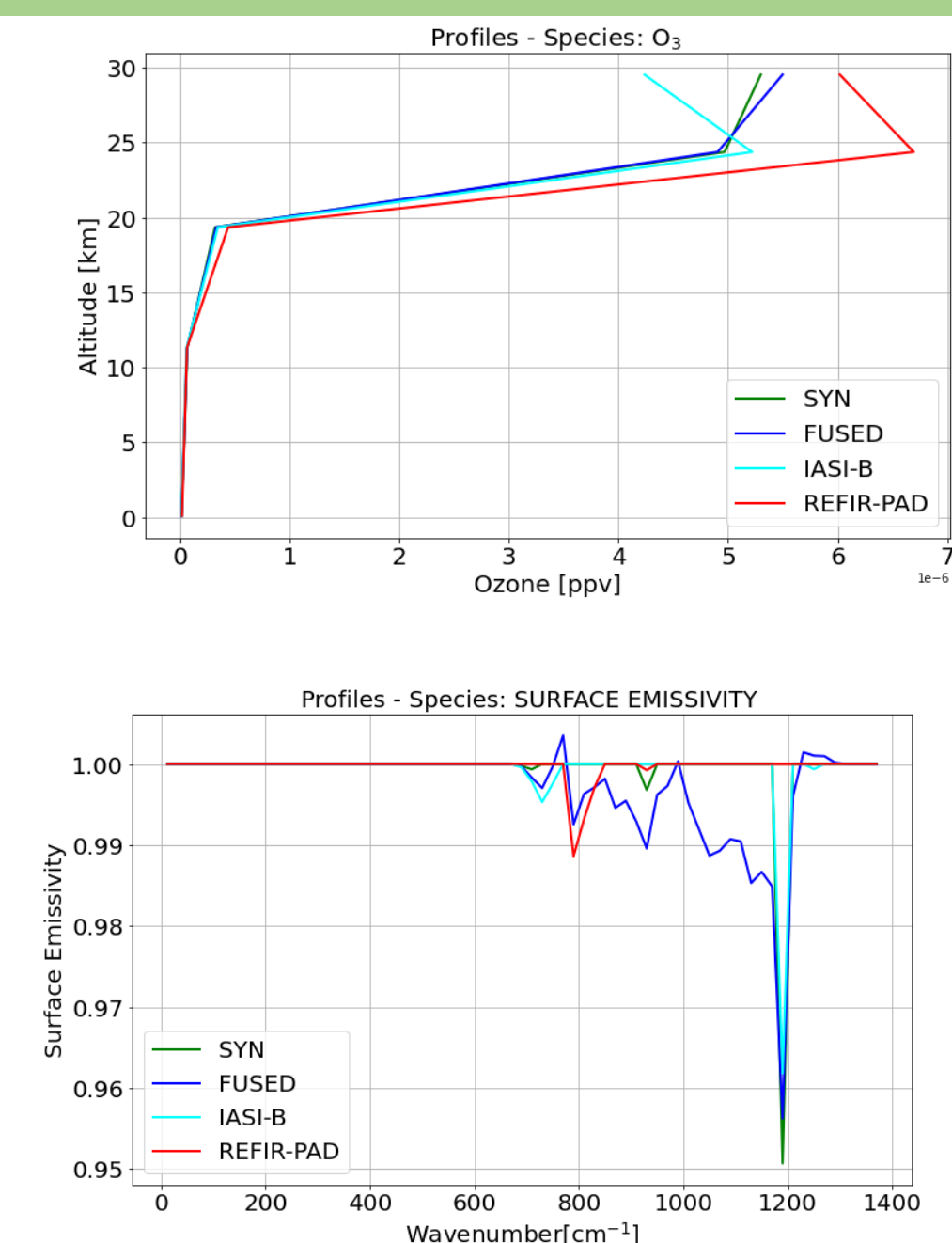
Results of retrievals and CDF



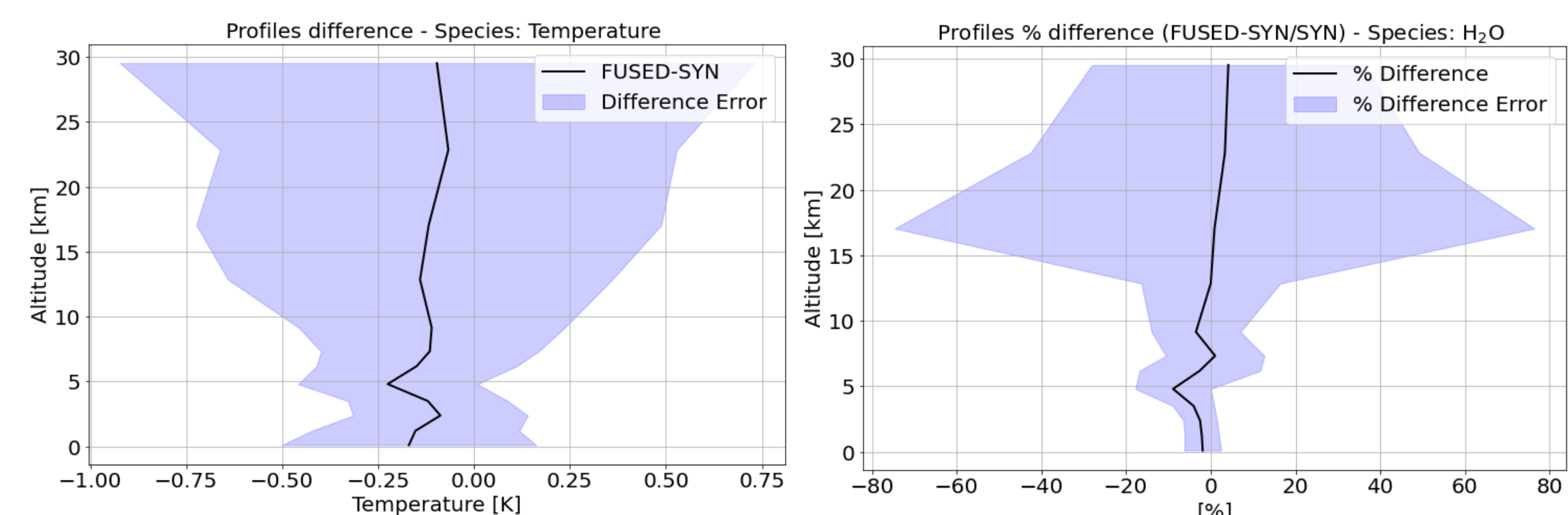
Vertical profiles (0-30 km) of temperature (left; surface temperature is also shown) and water vapour (right) for the individual products (IASI-B and REFIR-PAD), the synergistic retrieval (SYN) and the fused product (FUSED).

Vertical profiles (0-30 km) of temperature, water vapour and ozone, surface temperature and surface spectral emissivity were retrieved from the selected clear-sky spectra of IASI-B and REFIR-PAD, for both instruments separately and from a synergistic retrieval carried out using the FARM code. IASI-B and REFIR-PAD retrieved state vectors were combined a posteriori with the CDF algorithm.

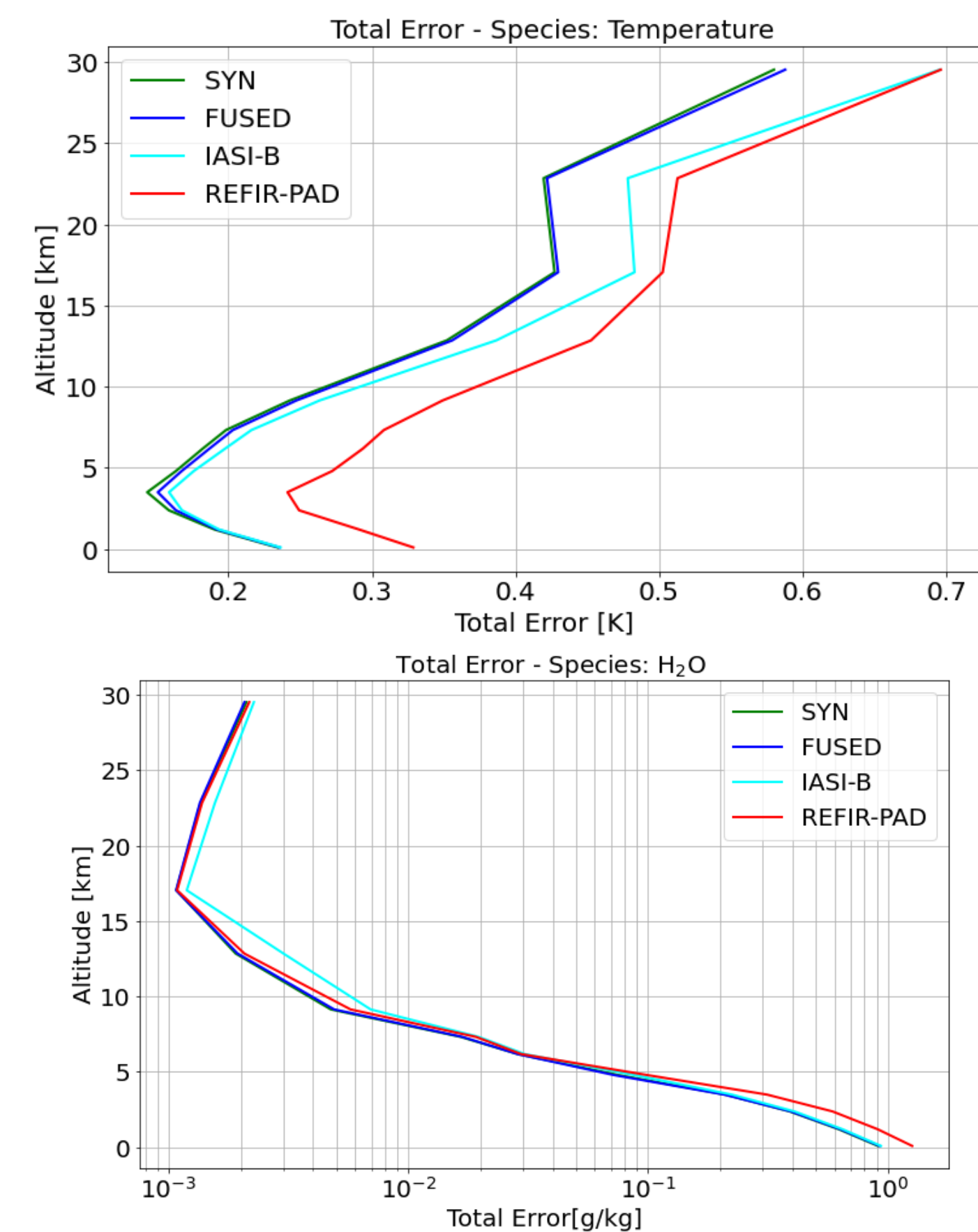
The results are shown in the figures, for the individual products (IASI-B and REFIR-PAD), the synergistic retrieval (SYN) and the fused product (FUSED).



Vertical profile (0-30 km) of ozone (top) and surface spectral emissivity (bottom).



Profile differences between the fused and synergistic retrievals for temperature (left) and water vapour (percentage difference; right), compared with the errors on the differences



Total error profiles for temperature (top) and water vapour (bottom).

H ₂ O	
Product	DOFs
FUSED	4.98
SYNERGISTIC	4.98
IASI-B	4.16
REFIR-PAD	4.33

Temperature	
Product	DOFs
FUSED	3.91
SYNERGISTIC	3.98
IASI-B	3.58
REFIR-PAD	2.75

SR vs CDF

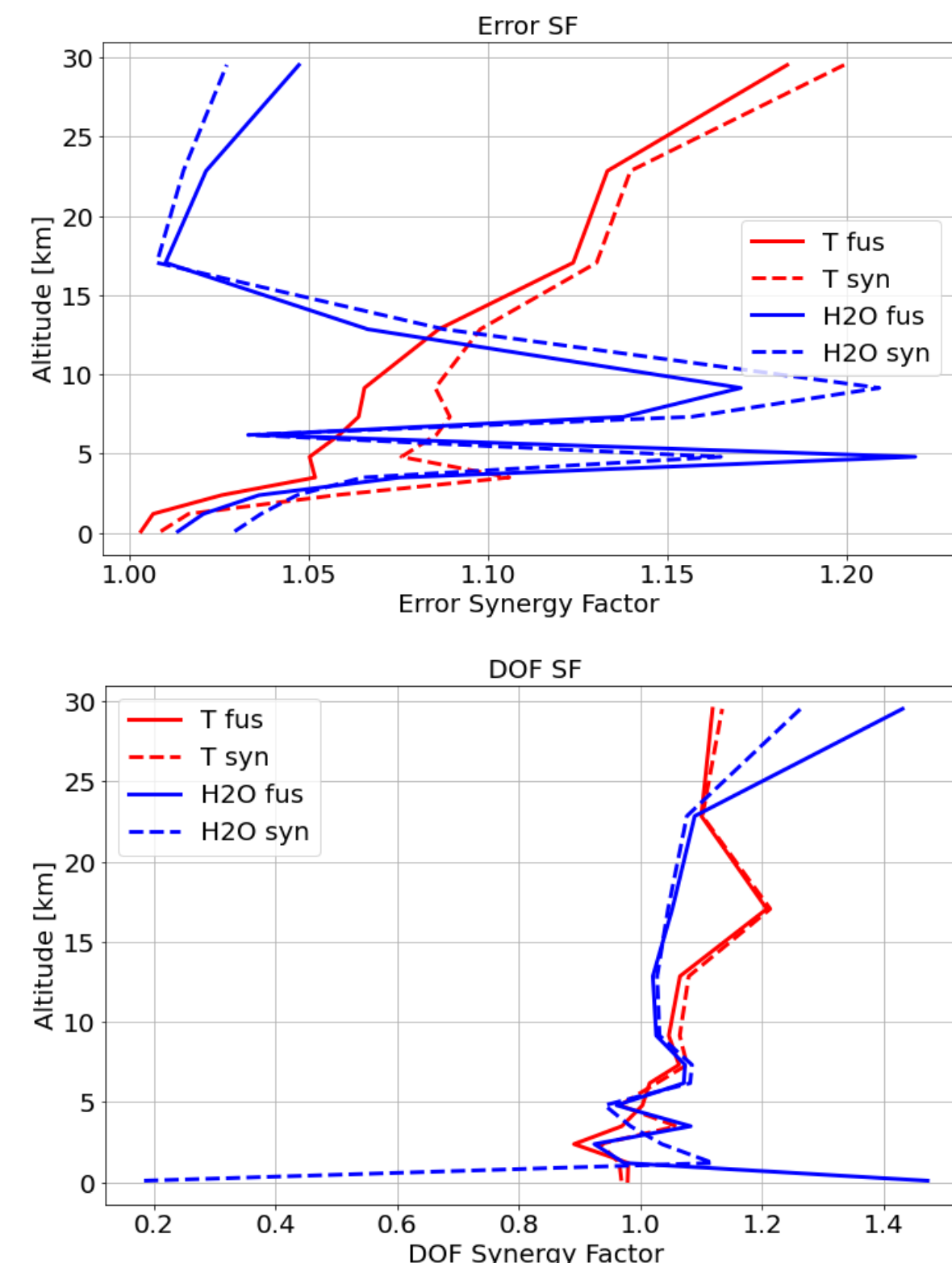
We analyzed the results considering:

- The difference between the fused products and the synergistic ones (here shown for temperature and water vapour), considering the respective errors
- The total error profiles of the combined products and of the individual ones.
- The degrees of freedom (DOFs) for the individual and combined products (in the Tables).
- The DOF and Error Synergy Factors (SF_{DOF} and SF_{err})

$$SF_{err}^{(j)} = \frac{\min_{i=1,2,...,N} \sigma_{tot,i}^{(j)}}{\sigma_{tot,f}^{(j)}}$$

$$SF_{DOF}^{(j)} = \frac{\text{diag} A_f^{(j)}}{\max_{i=1,2,...,N} \text{diag} A_i^{(j)}}$$

The SFs are equal to 1 when the combined measurements are complementary and greater than 1 when a synergy between the two individual data sets really exists.



Conclusions

The **differences between the synergistic and fused profiles** for temperature and water vapour (% difference) remain within the difference (and % difference) error at all altitudes, indicating good consistency between the two approaches, as expected.

- From the analysis of the **total error profiles**, we can infer that, for temperature, REFIR-PAD exhibits the largest errors at all altitudes, while IASI-B performs better below 15 km. The synergistic and fused retrievals significantly reduce the errors. For water vapour, REFIR-PAD shows higher errors below 5 km, while the synergistic retrieval and IASI-B yield comparable performance. Overall, the synergistic and fused retrievals achieve the lowest errors across the entire vertical extent.
- The **SF profiles** show that the synergy between the datasets is fully exploited across the whole altitude range for both the synergistic and fused products.
- The **DOF values** reported in the tables indicate that the fused and synergistic products provide the highest number of degrees of freedom for both temperature and water vapour.

ACKNOWLEDGMENTS

The results presented in this poster arise from research activities conducted in the framework of the FIT-FORUM (Forward and Inverse Tool for FORUM) project, a research project developed within an Implementation Agreement (n. 2023-23-HH.0) between ASI and the University of Bologna

REFERENCES

[1] Ceccherini, S., Zoppetti, N., and Carli, B.: An improved formula for the complete data fusion, Atmospheric Measurement Techniques, 15, 7039–7048, <https://doi.org/10.5194/amt-15-7039-2022>, 2022.

Oct 15 to Oct 17, 2025

Joint FORUM-HAWC Workshop

McGill University, Montreal, Canada