Inversion of atmospheric far-IR spectral radiances acquired by FTS instruments deployed in ground and stratospheric balloon campaigns

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UNIVERSITÀ DEGLI STUDI DELLA BASILICATA

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Oct 15 - 17, 2025
Joint FORUM-HAWC Workshop
McGill University, Montreal, Canada

Experimental activities at CNR-INO in support to FORUM mission preparation

Development of FIR FTS and deployment from ground and from stratospheric balloons

REFIR-PAD (CNR-INO, ASI) from 2005 to 2025
stratospheric balloon (~30 km) and high-altitude sites (DOME-C > 3km)

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

FORUM – BALLOON (ASI – CNR-INO)
New instrument for both ground and stratospheric balloons

Inversion of the measured spectral radiances in two selected case studies

In view of future application to FORUM & IASI-NG measurements, the focus here is on the so called “synergistic retrieval” ...

2962 m a.s.l.

	FIRMOS	E-AERI
Range (cm^{-1})	100-1000	400-1600
Resolution (cm^{-1})	0.3	0.5
FOV (mrad)	22	46
LOS	zenith	zenith

	R-PAD	IASI-B
Range (cm^{-1})	100-950	700-1400
Resolution (cm^{-1})	0.5	0.05
FOV (mrad)	115	16
LOS	nadir	nadir

FARM: Fast Retrieval Model

Bayesian inversion algorithm, using a priori and Tikhonov constraints.
The cost function can include up to two radiances $\mathbf{y}_i$ sounding the same air-masses:

$$\zeta^2(\mathbf{x}) = (\mathbf{y}_1 - \mathbf{F}_1(\mathbf{x}))^T \mathbf{S}_{y1}^{-1} (\mathbf{y}_1 - \mathbf{F}_1(\mathbf{x})) + (\mathbf{y}_2 - \mathbf{F}_2(\mathbf{x}))^T \mathbf{S}_{y2}^{-1} (\mathbf{y}_2 - \mathbf{F}_2(\mathbf{x})) + (\mathbf{x}_a - \mathbf{x})^T (\mathbf{S}_a^{-1} + \mathbf{L}^T\mathbf{L}) (\mathbf{x}_a - \mathbf{x})$$

The minimum of the cost is found with the iterative Levemberg-Marquardt approach and a stopping criterion.

The state vector x

$\mathbf{x}$ = ($\mathbf{T}$(p), Ts, $\mathbf{VMR}_{i=1,\ldots,N}$, $\mathbf{e}$(v), **CLD**)
CLD = (**WC**(p), **D**e(p))$_{i/w}$ or
(CTH, CBH, WC, De)$_{i/w}$

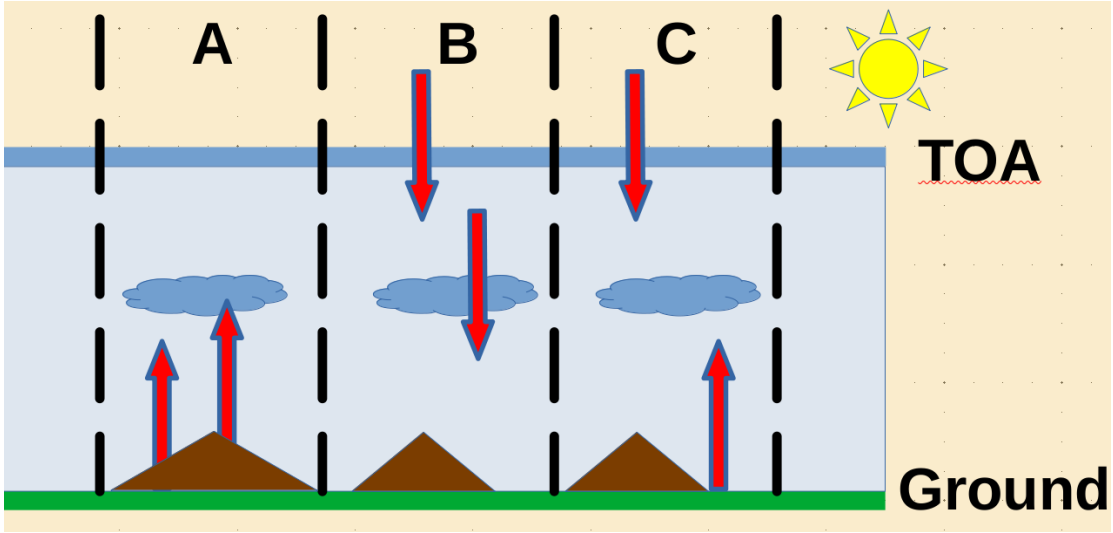
The forward model F(x)

σ-IASI/F2N, a fast quasi-monochromatic RTM developed at UNIBAS and UNIBO (see Masiello et al 2024). Uses fixed layering and parametrized gas optical depths, Chou / Tang scaling to simulate clouds, analytical Jacobians.

Masiello G. et al., The new σ-IASI code for all sky radiative transfer calculations in the spectral range 10 to 2760 cm^{-1}: σ-IASI/F2N, JQSRT, 312, 108814, 2024. https://doi.org/10.1016/j.jqsrt.2023.108814

FARM: Fast Retrieval Model

Measurement configurations handled



Supported synergistic measurement configurations:

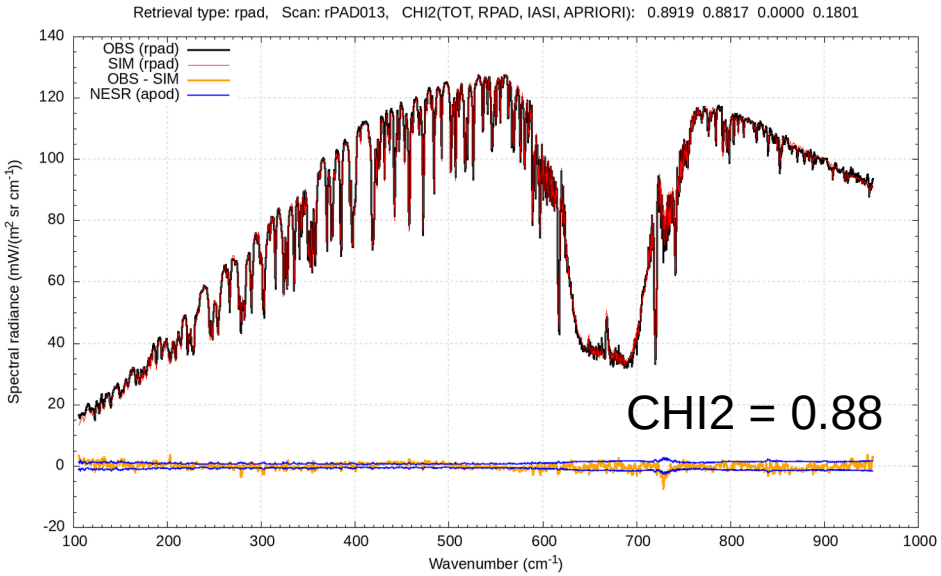
A) Zenith – Zenith
B) Nadir – Nadir
C) Nadir – Zenith

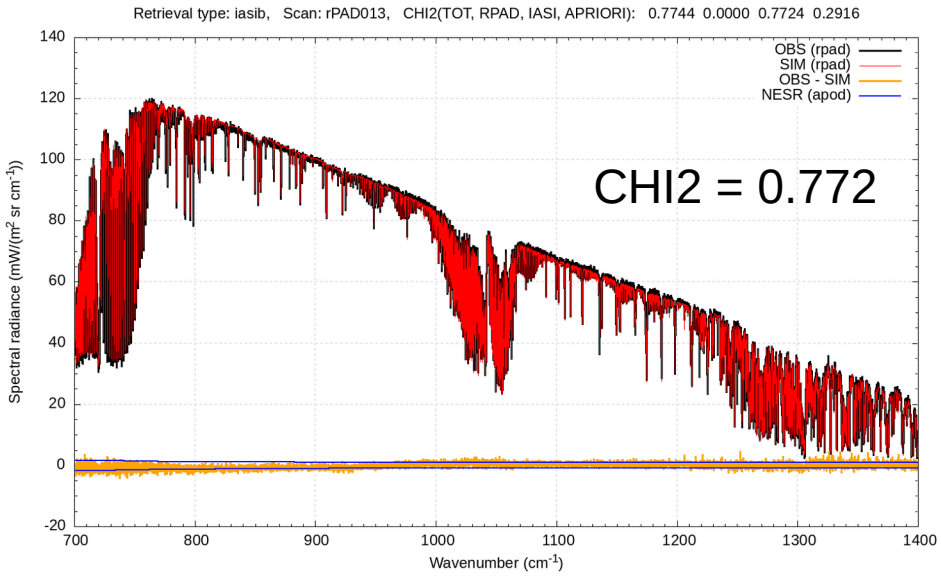
Slant views are supported,
limb views are not supported.

Teresina, 30 June 2005 – **clear sky** (results_20251004-00)

Retrieval of: **T**(p), **H2O**(p), **O3**(p), Ts, **e**(v)

Matching: rPAD013_050630_080452_0383 and IA030120_050630_080925



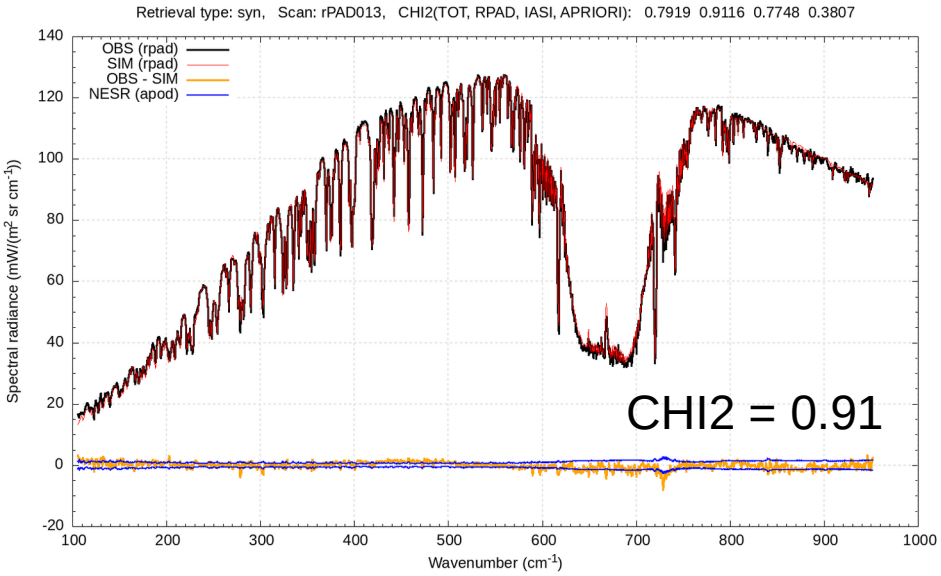


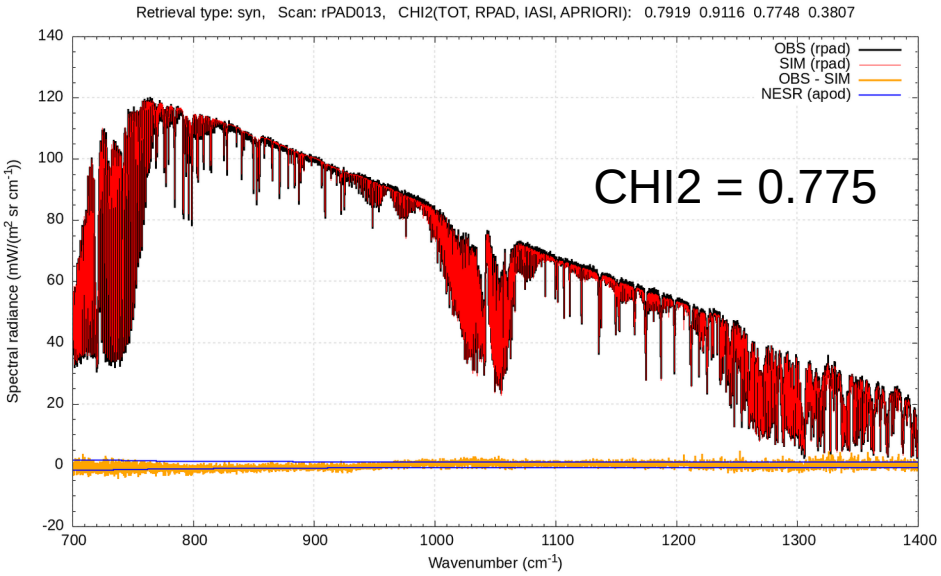
Individual inversions, retrieval of two different atmospheric state vectors

Teresina, 30 June 2005 – **clear sky**

Retrieval of: **T**(p), **H2O**(p), **O3**(p), Ts, **e**(v)

Matching: rPAD013_050630_080452_0383 and IA030120_050630_080925



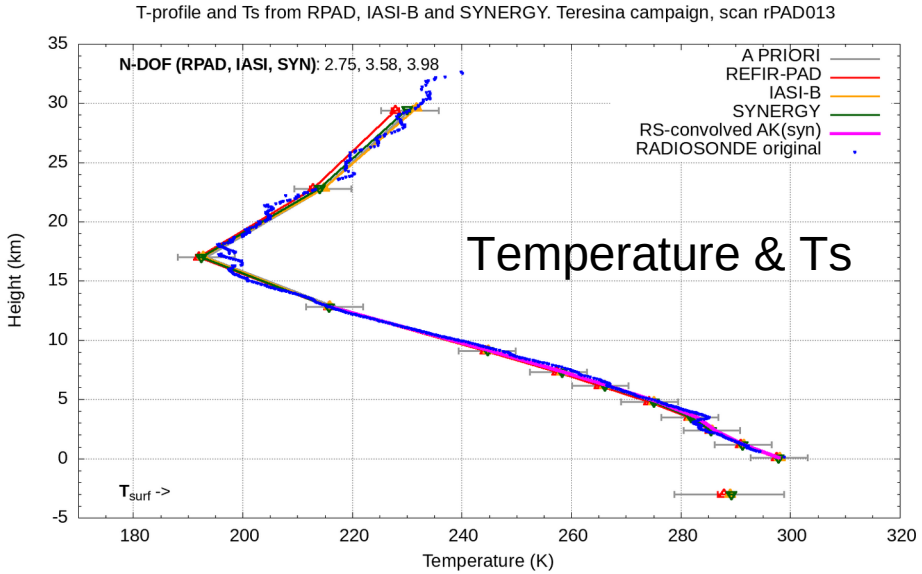


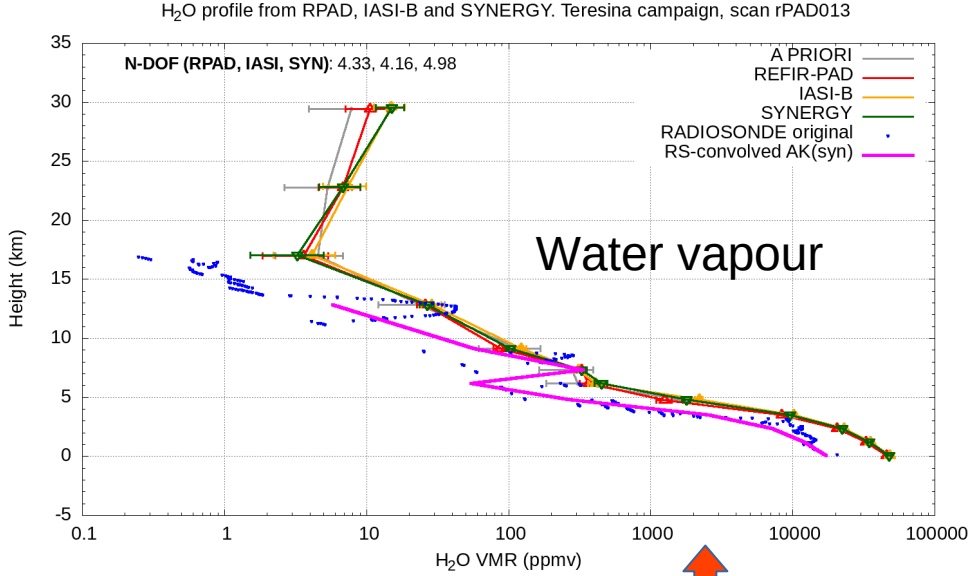
Synergistic inversion of 2 spectra, retrieval of a single atmospheric state vector

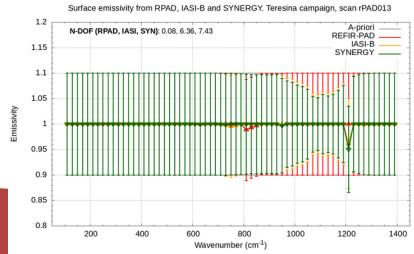
Teresina, 30 June 2005 – clear sky

Retrieval of: **T**(p), **H2O**(p), **O3**(p), Ts, **e**(v)

Matching: rPAD013_050630_080452_0383 and IA030120_050630_080925







Surface spectral emissivity

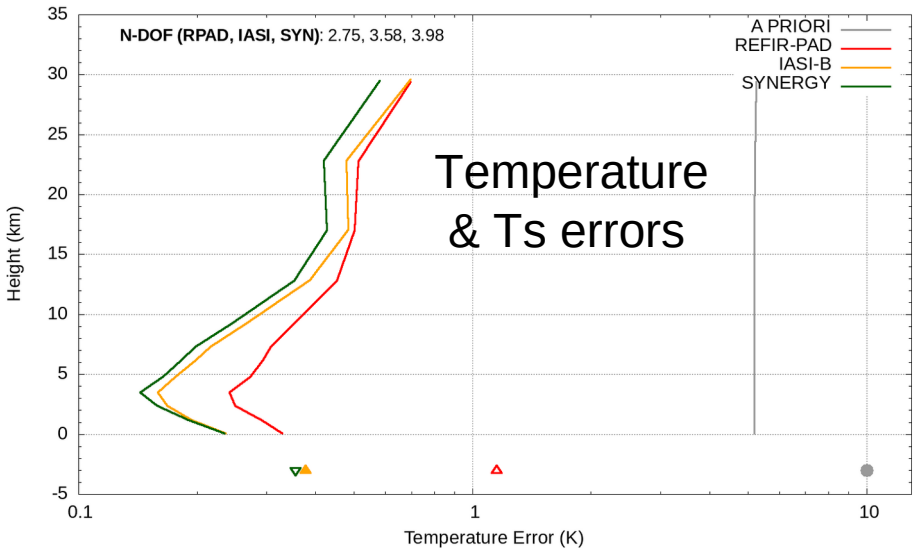
(*) RS is ~3.5 hrs and ~70 km apart from this rPAD measurement… + lost GPS...

Teresina, 30 June 2005 – clear sky

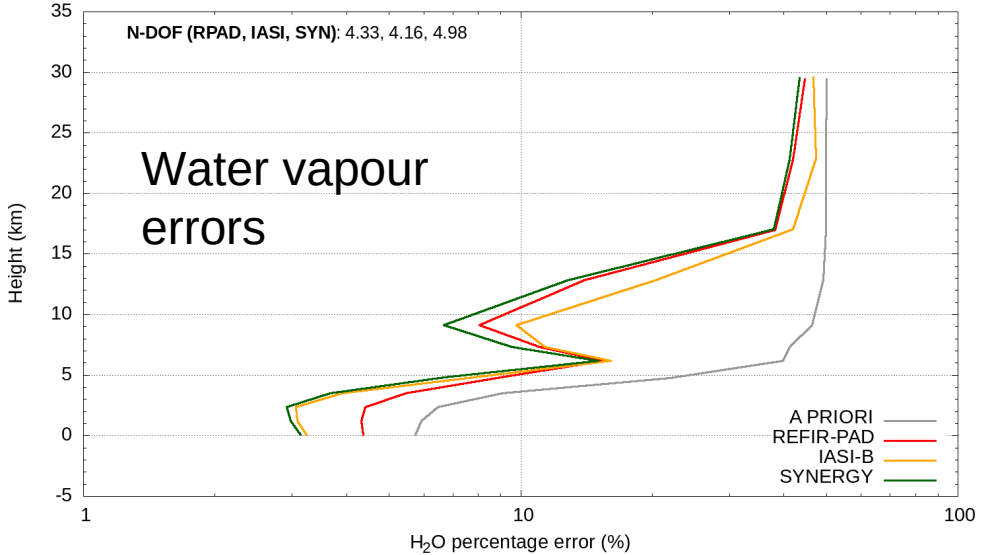
Retrieval of: **T**(p), **H2O**(p), **O3**(p), Ts, **e**(v)

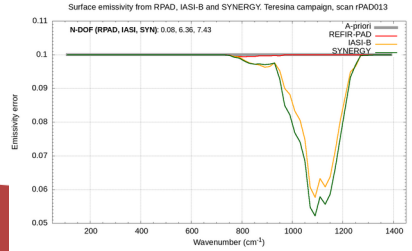
Matching: rPAD013_050630_080452_0383 and IA030120_050630_080925

T-profile and Ts from RPAD, IASI-B and SYNERGY. Teresina campaign, scan rPAD013



H_2O profile from RPAD, IASI-B and SYNERGY. Teresina campaign, scan rPAD013



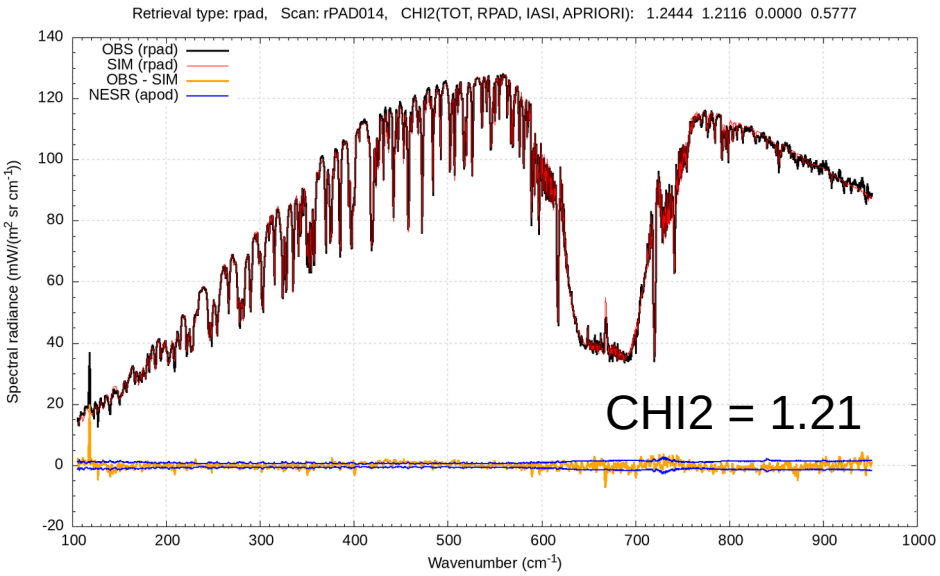


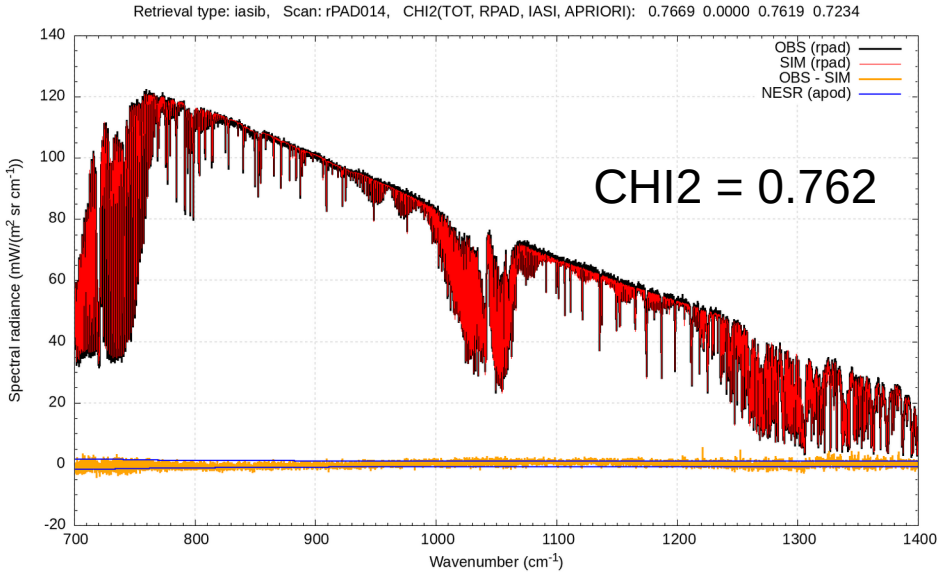
Surface spectral emissivity error

Teresina, 30 June 2005 – **clear sky**

Retrieval of: **T**(p), **H2O**(p), **O3**(p), Ts, **e**(v)

Matching: rPAD014_050630_081518_0378 IA030126_050630_081522



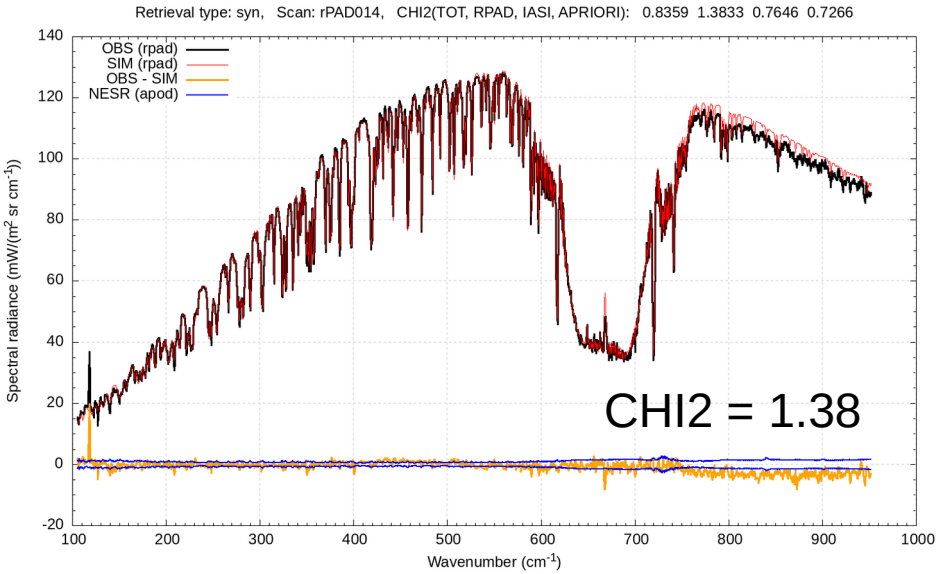


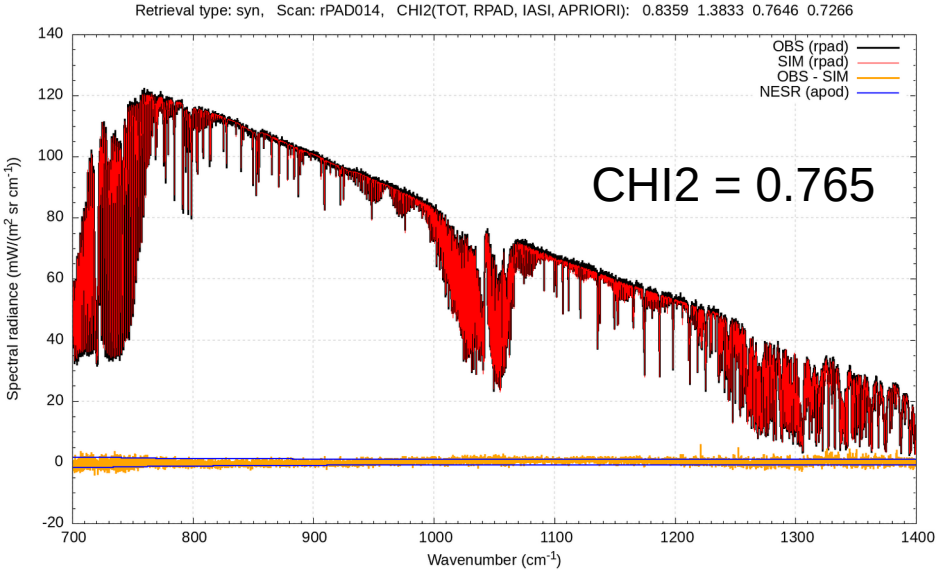
Individual inversions, retrieval of two different atmospheric state vectors

Teresina, 30 June 2005 – **clear sky**

Retrieval of: **T**(p), **H2O**(p), **O3**(p), Ts, **e**(v)

Matching: rPAD014_050630_081518_0378 IA030126_050630_081522





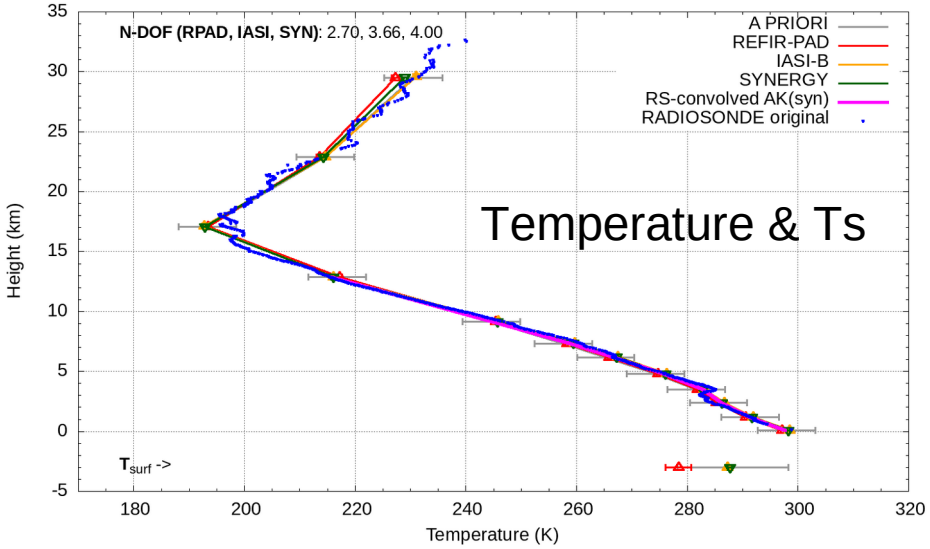
Synergistic inversion of 2 spectra, retrieval of a single atmospheric state vector

Teresina, 30 June 2005 – clear sky

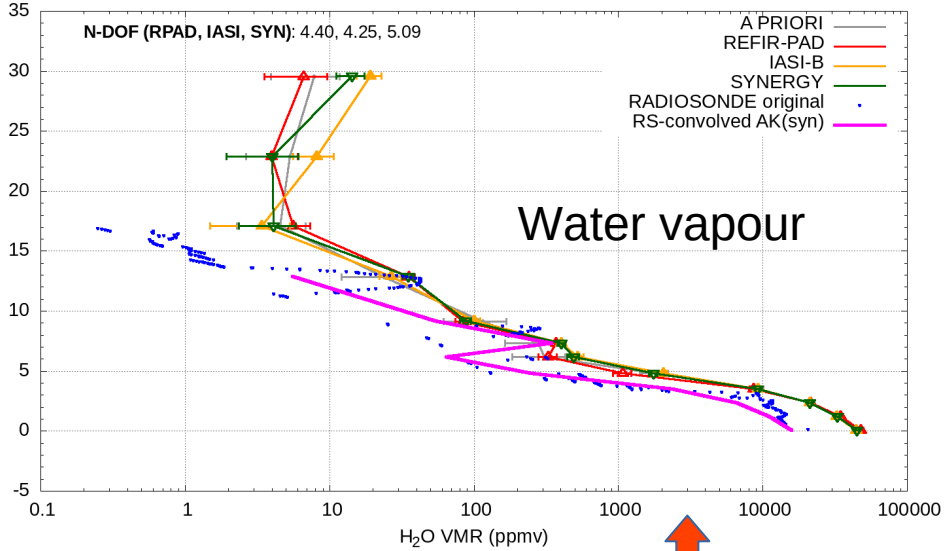
Retrieval of: **T**(p), **H2O**(p), **O3**(p), Ts, **e**(v)

Matching: rPAD014_050630_081518_0378 IA030126_050630_081522

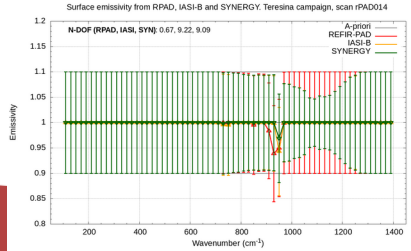
T-profile and Ts from RPAD, IASI-B and SYNERGY. Teresina campaign, scan rPAD014



H_2O profile from RPAD, IASI-B and SYNERGY. Teresina campaign, scan rPAD014



Surface emissivity from RPAD, IASI-B and SYNERGY. Teresina campaign, scan rPAD014



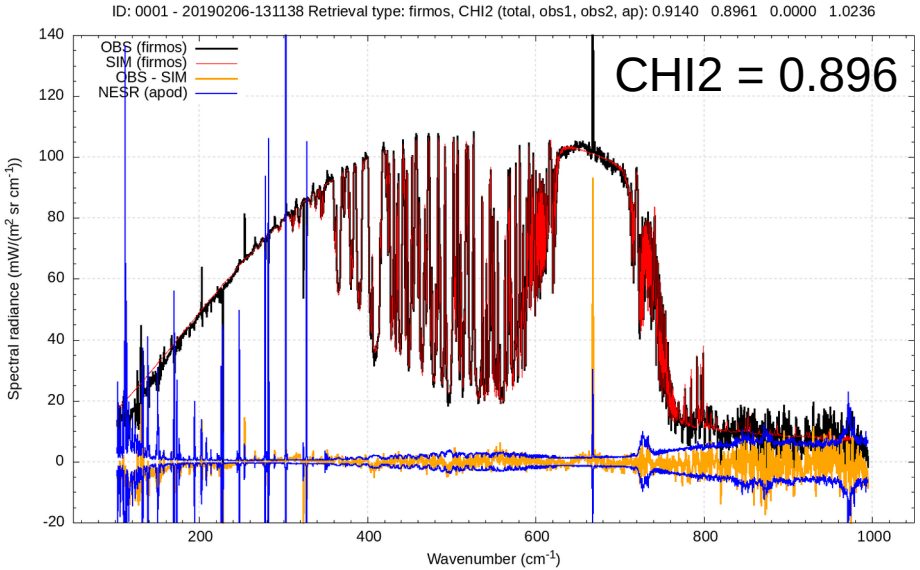
Surface spectral emissivity

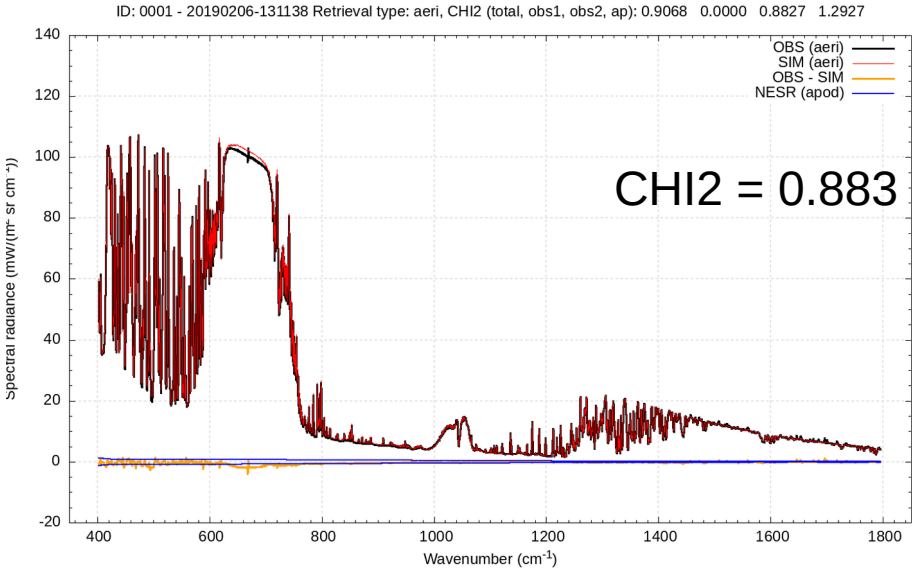
(*) RS is ~3.5 hrs and ~70 km apart from this rPAD measurement… + lost GPS...

Zugspitze, 6 February 2019 – **ice cloud** (results_20251008-00)

Retrieval of: **T**(p), **H2O**(p), **O3**(p), CBH, IWC, R_{ice} - With fixed CTH - CBH = 2.2 km

Matching: FIRMOSs_20190206_131138_0212_019_v2 AERI_190206130849



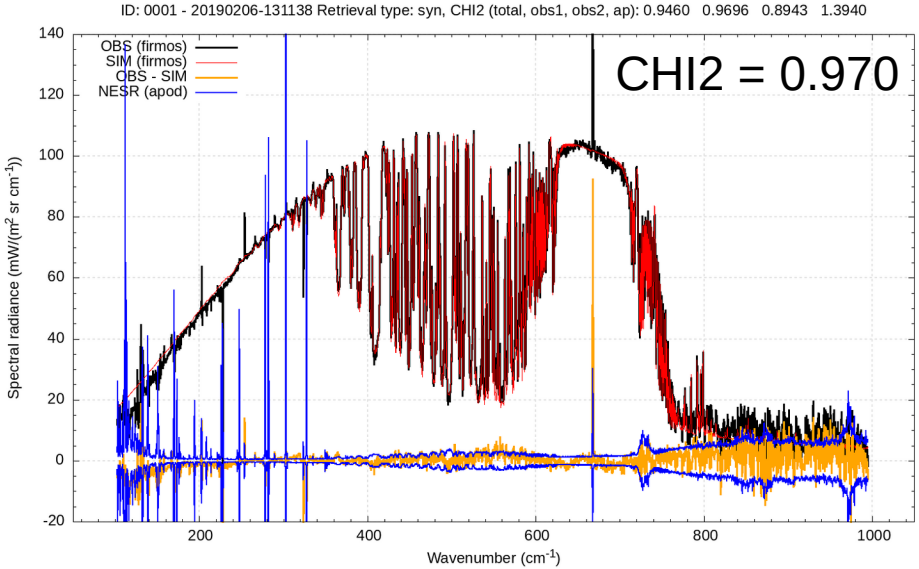


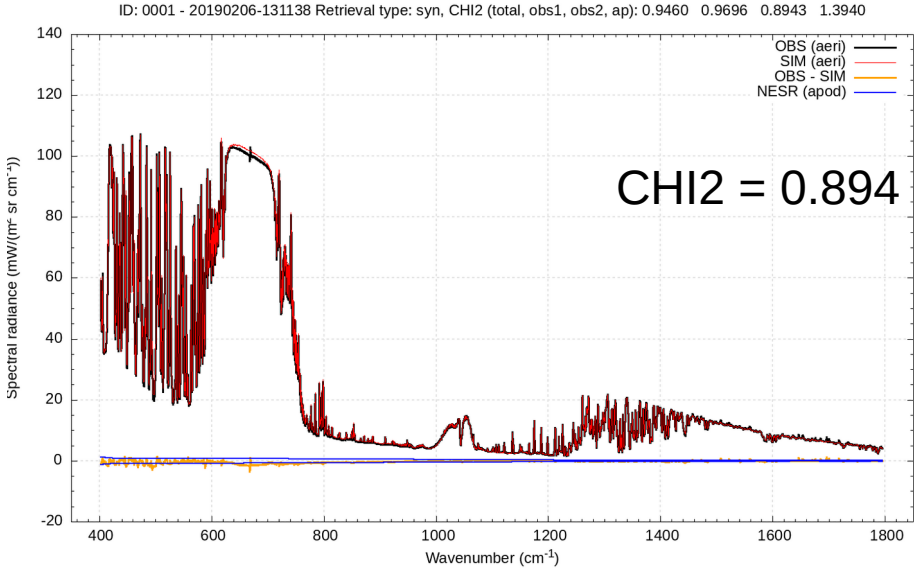
Individual inversions, retrieval of two different atmospheric state vectors

Zugspitze, 6 February 2019 – **ice cloud**

Retrieval of: **T**(p), **H2O**(p), **O3**(p), CBH, IWC, R_{ice} - With fixed CTH - CBH = 2.2 km

Matching: FIRMOSs_20190206_131138_0212_019_v2 AERI_190206130849



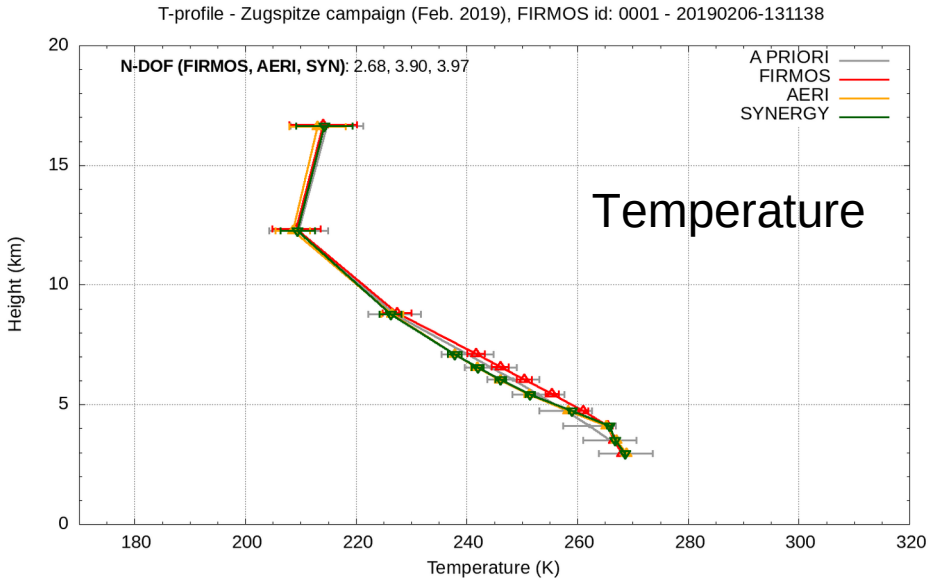


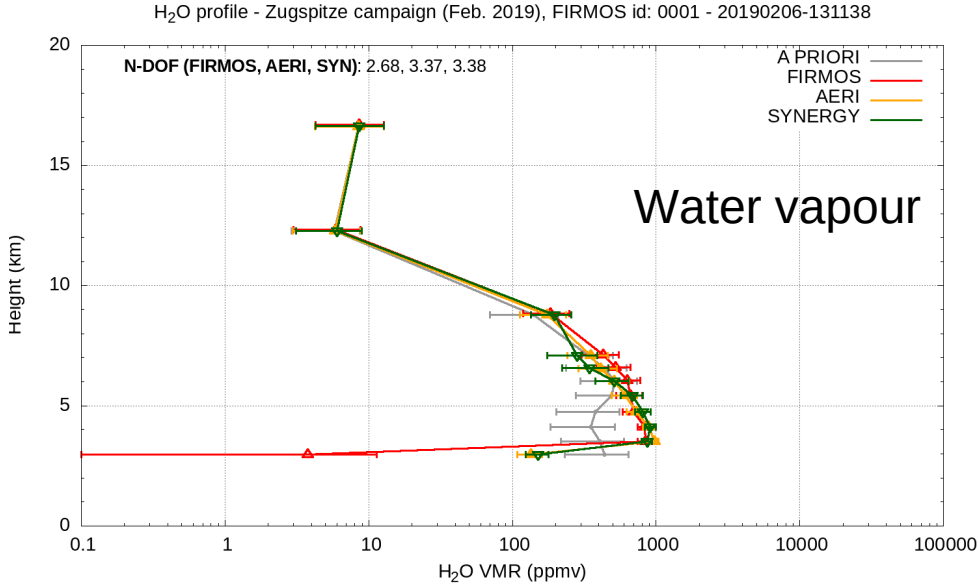
Synergistic inversion of 2 spectra, retrieval of a single atmospheric state vector

Zugspitze, 6 February 2019 – ice cloud

Retrieval of: **T**(p), **H2O**(p), **O3**(p), CBH, IWC, R_{ice} - With fixed CTH - CBH = 2.2 km

Matching: FIRMOSs_20190206_131138_0212_019_v2 AERI_190206130849





Zugspitze, 6 February 2019 – **ice cloud**
Retrieval of: **T**(p), **H2O**(p), **O3**(p), CBH, IWC, R_{ice} - With fixed CTH - CBH = 2.2 km
Matching: FIRMOSs_20190206_131138_0212_019_v2 AERI_190206130849

Cloud parameters (retrieved and a-priori)

	FIRMOS	AERI	SYNERGY	A - PRIORI
CBH (km)	3.4 ± 1.3	7.7 ± 0.4	7.8 ± 0.4	7.7 ± 3.5
OD	0.36 ± 0.03	0.44 ± 0.01	0.45 ± 0.01	0.4 ± 0.4
R_{ice} (µm)	30 ± 12	18 ± 2	18 ± 2	15 ± 20

(*) from **lidar**: CBH ~ 7.8 km, CTH ~ 10.0 km

CONCLUSIONS

The FARM (+ σ-IASI/F2N) is able to reproduce also real measurements acquired in field campaigns (until recently it was used only for synthetic test retrievals). The fixed layering used by the σ-IASI RTM may require caution when the code is used to simulate down-welling radiances acquired from high-altitude.

The synergistic retrieval approach to Level 2 analysis may be critical in case of measurement mismatch in space / time. Especially the different FOV aperture of the two instruments involved may easily cause different cloud coverage, different ground pixel emission, etc.

A method to effectively take into account the measurement's space- and time- mismatch should be studied. See also the poster of C. Tirelli et al. regarding the Complete Data Fusion (CDF) approach.

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Italian Space Agency (ASI)

Agreements:

- FIT-FORUM – n. 2023-23-HH.0, CUP n. F33C23000240005
- MC-FORUM – n. 2023-4-HB.0, CUP n. F93C23000460001
- CASIA – n. 2023-3-HB.0, CUP n. F93C23000430001

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