A Fast Retrieval Model for the Inversion of Surface, Atmospheric and Cloud properties from Nadir FIR and TIR measurements

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FORUM SCIENZA

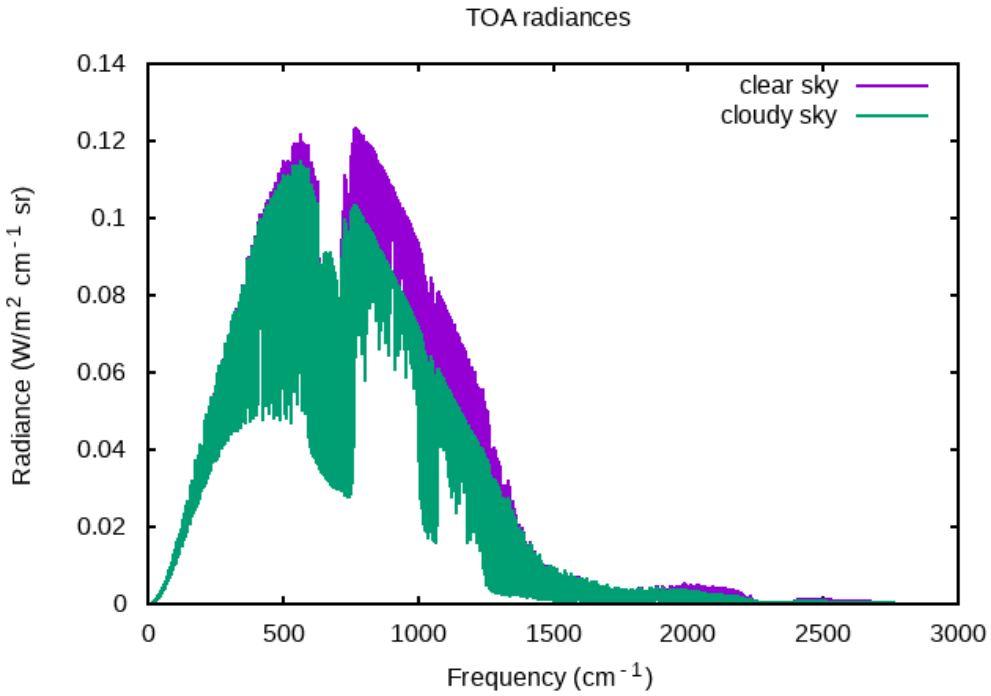
- FORUM SCIENZA is an ASI funded project aiming to create and sustain an Italian community focussed on the EE9-FORUM mission (Accordo Attuativo n. 2019-20-HH.0)
- PI is Luca Palchetti (CNR-INO)
- Participants are from:
  - Italian CNR: INO, ISAC, IFAC, IAC
  - Italian Universities: University of Basilicata, University of Bologna
- 2 separate topics:
  - Studies for upgrading the FIRMOS instrument (demonstrator of FORUM)
  - Studies to compare different Radiative Transfer and Retrieval Models for the FIR and TIR spectral regions and develop a fast and accurate RTM for FORUM

Sigma-FORUM

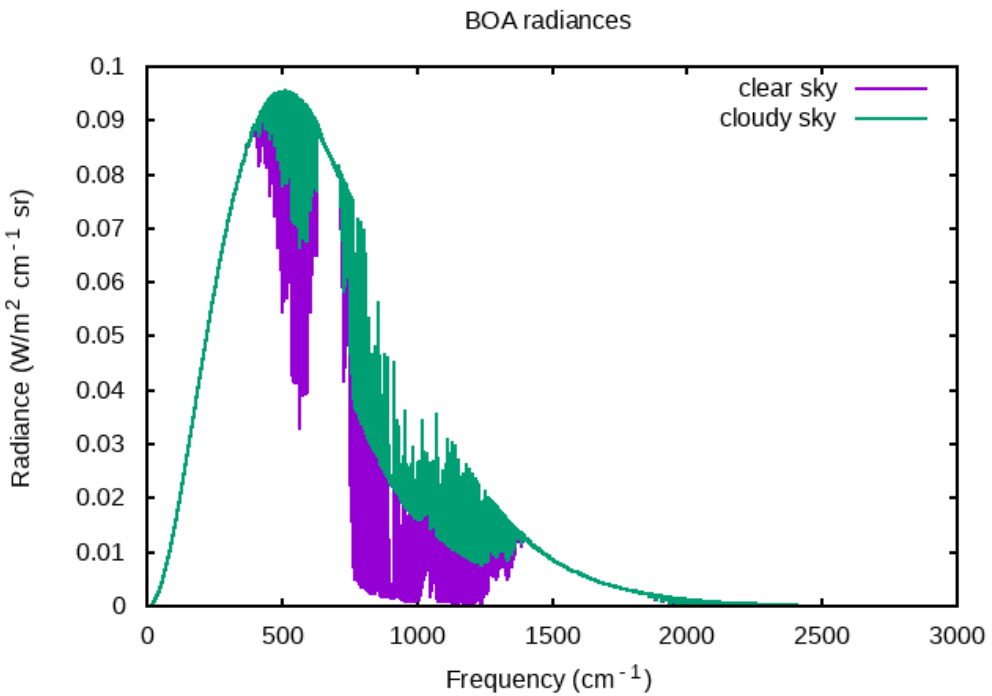
- Sigma-FORUM is the new RTM developed in the frame of FORUM SCIENZA (see Masiello et. al poster).
- It is based on the fast RTM sigma-IASI developed by C. Serio and G. Masiello (UNIBAS) for the simulation of IASI measurements (TIR)
- It can simulate TOA radiances (to simulate observations of nadir looking instruments on board satellites, balloons or aircraft) and BOA radiance(zenith looking instruments on ground)
- It performs simulations on a sufficiently dense frequency grid (0.01 cm^{-1}) that enables the use of different Instrument Response Functions
- It can simulate clear sky or cloudy sky radiances
- The simulation of the FIR+TIR spectrum (5 to 2800 cm^{-1}) uses ~0.7 seconds (clear sky) or ~3.3 seconds (cloudy sky) of CPU time
- It can compute derivatives of the radiance wrt VMR and T profiles, surface properties (emissivity and temperature) and cloud properties (profiles of IWC, LWC and effective radii of the cloud's particles).
- It is based on spectroscopic data from AER-3.8 (database used by LBLRTM), porting to HITRAN2020 in progress.
- Validated with IASI observations and LBLRTM, validation with other line by line codes (KLIMA and GBB-nadir) in progress.

Sigma-FORUM high resolution simulations

TOA radiance – Tropical atmosphere



BOA radiance – Polar atmosphere



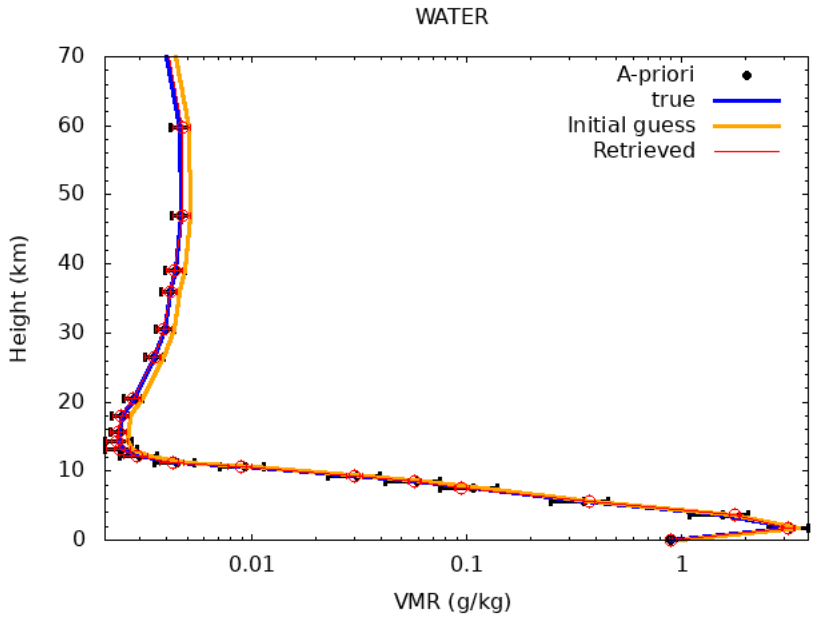
The FARM code

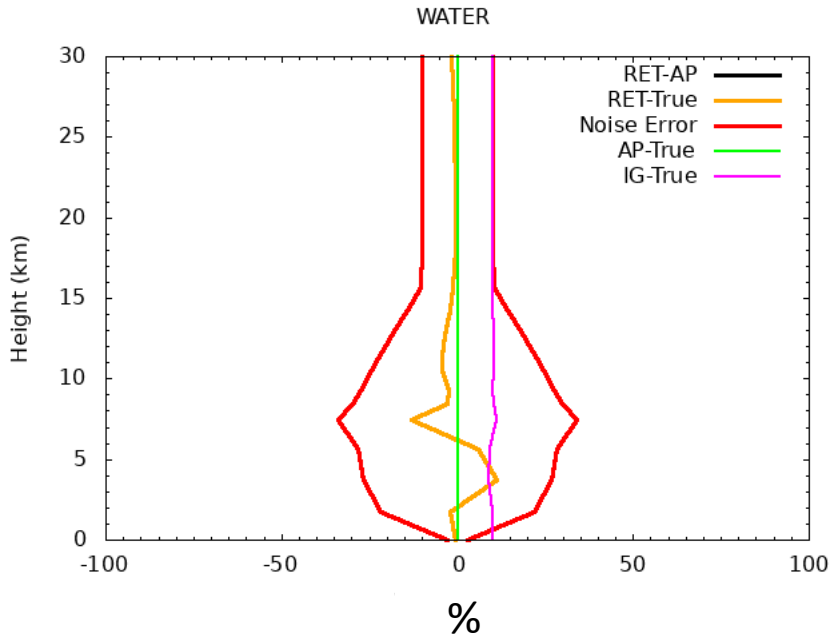
- The FAst Retrieval Model (FARM) is a retrieval code based on the sigma-FORUM RTM
- It can retrieve:
  - Atmospheric temperature profile
  - VMR profiles of the gases: H_2O, CO_2, O_3, N_2O, CO, CH_4, SO_2, HNO_3, NH_3, OCS, HDO, CF_4
  - cloud profiles: R_{wat}, R_{ice}, LWC, IWC
  - Surface properties (Surface emissivity and skin temperature)
  - Constant Frequency shift (to account for inaccurate spectral calibration)
- It can use the measurements of a single instrument or two different instruments
- Retrievals are performed at fixed pressure levels (target dependent) and with a Bayesan approach (optimal estimation)

Simulated retrievals – clear sky

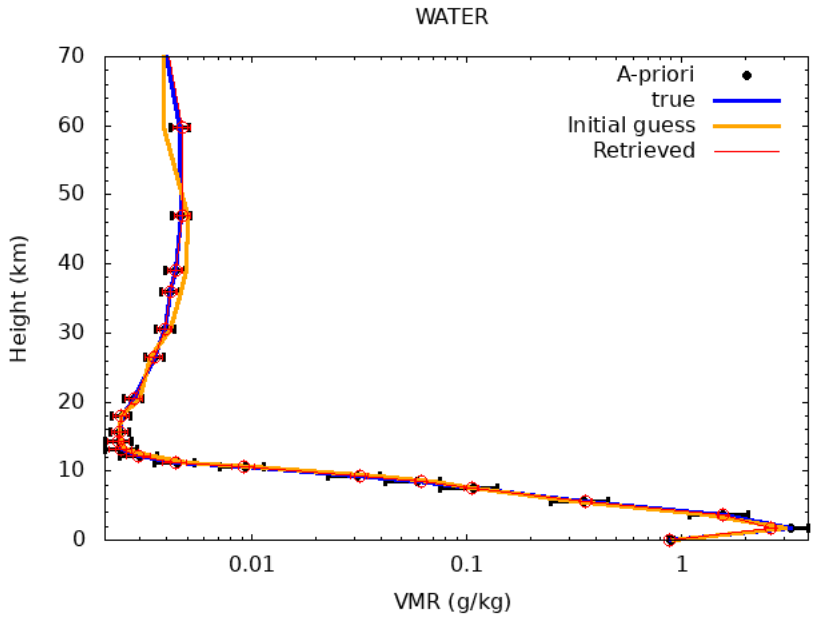
- To test the performances of FARM we have run several simulated retrievals, using different atmospheric conditions (IG2 climatology - 4 seasons 6 latitude bands)
- The simulations of the measurements have been performed with sigma-FORUM, convolved with the FORUM expected instrumental response function and the expected FORUM NESR has been added.
- The retrieval starts with the same atmosphere and surface properties used in the simulations
- The initial values of the retrieval targets have been perturbed with two strategies:
  - Shifted by a constant amount
  - Randomly perturbed

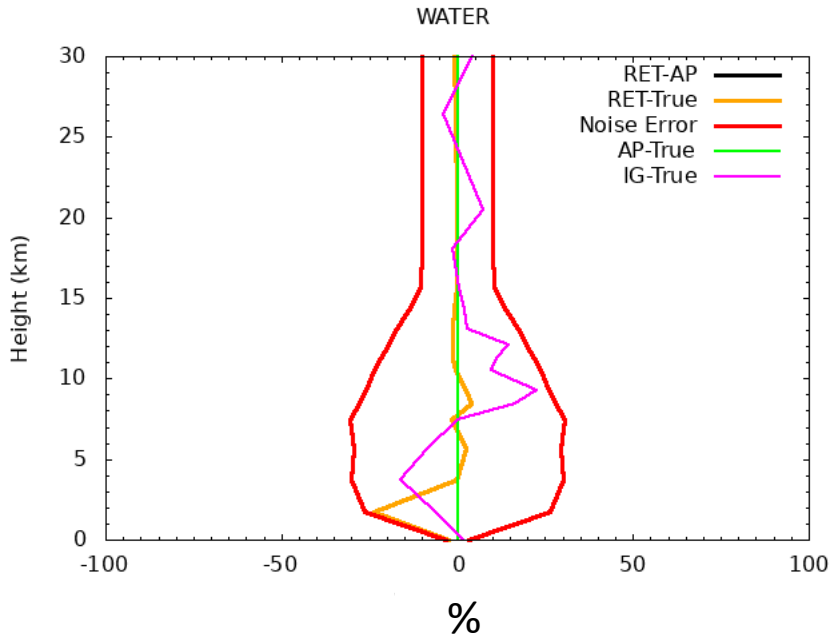
Results H2O – Polar atmosphere – fix pert



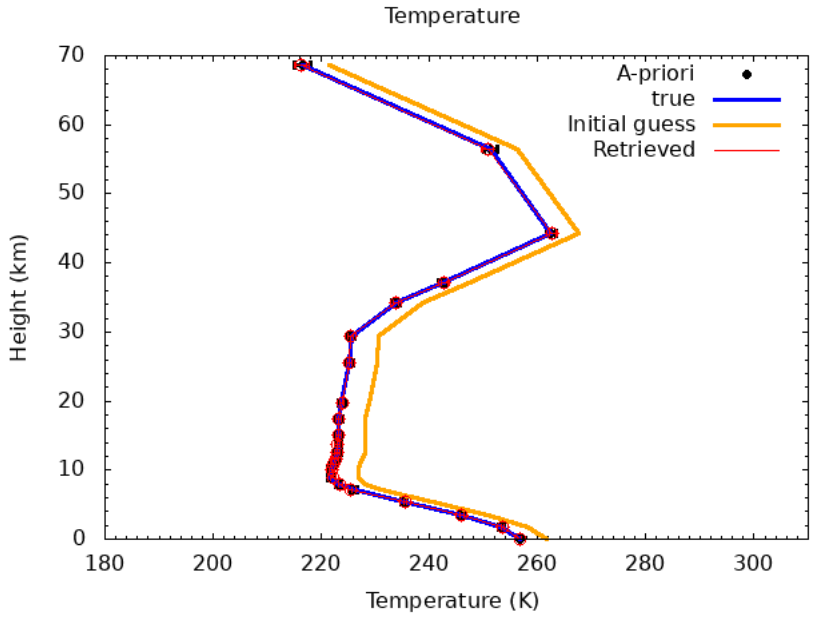


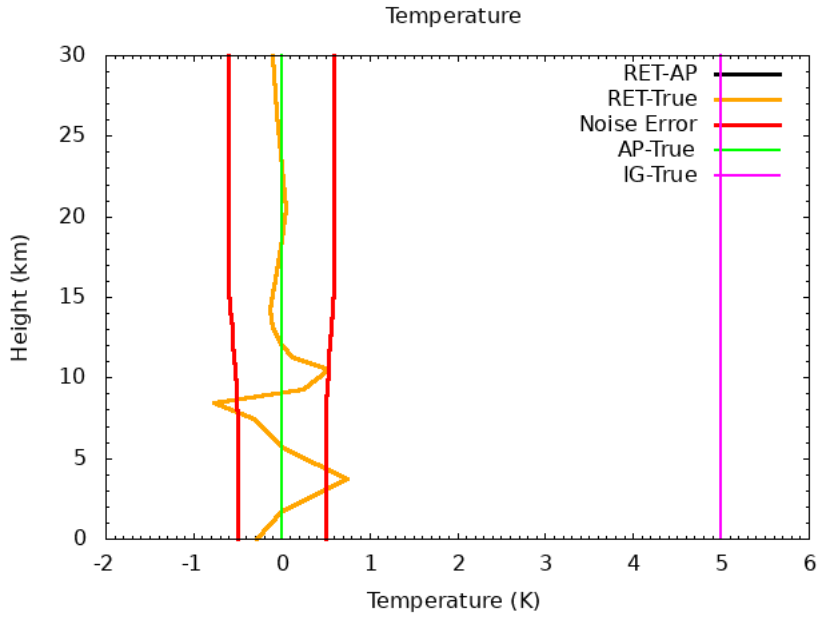
Results H2O – Polar atmosphere – rand. pert.



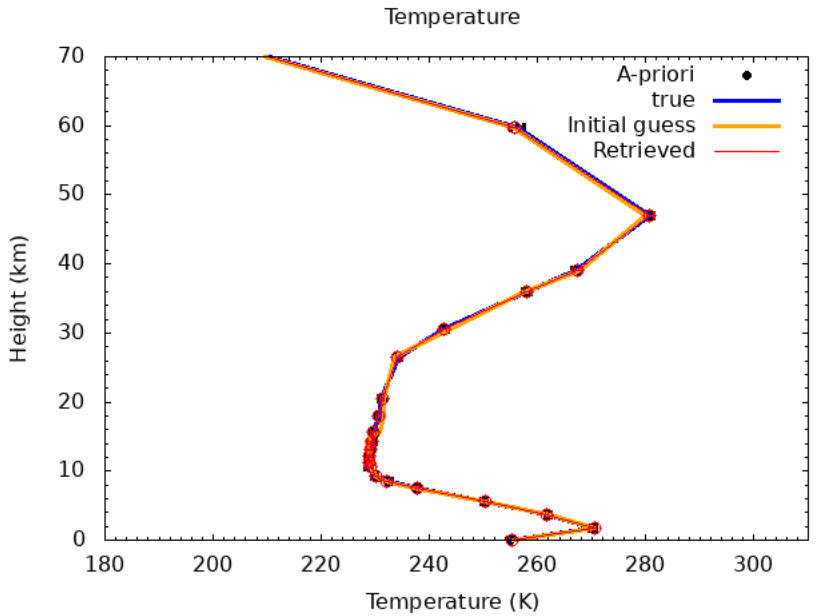


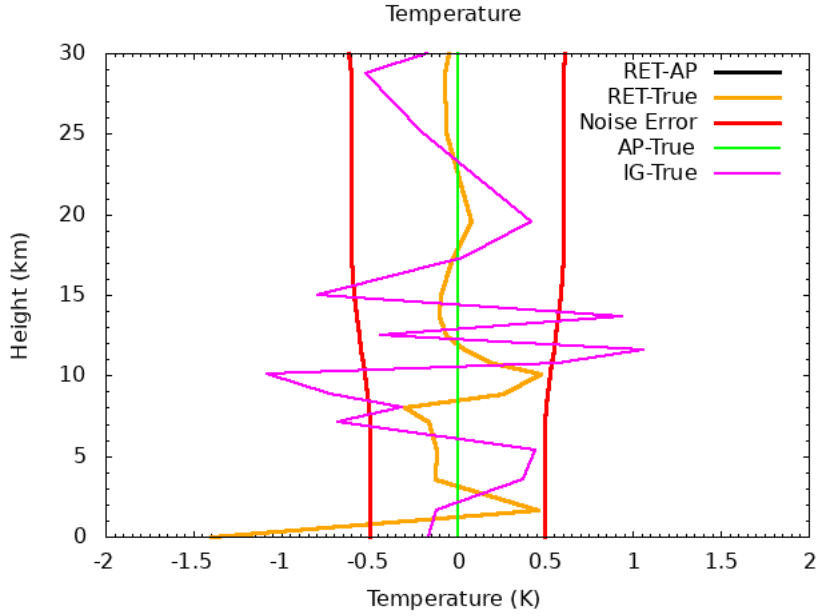
Results T – Polar atmosphere





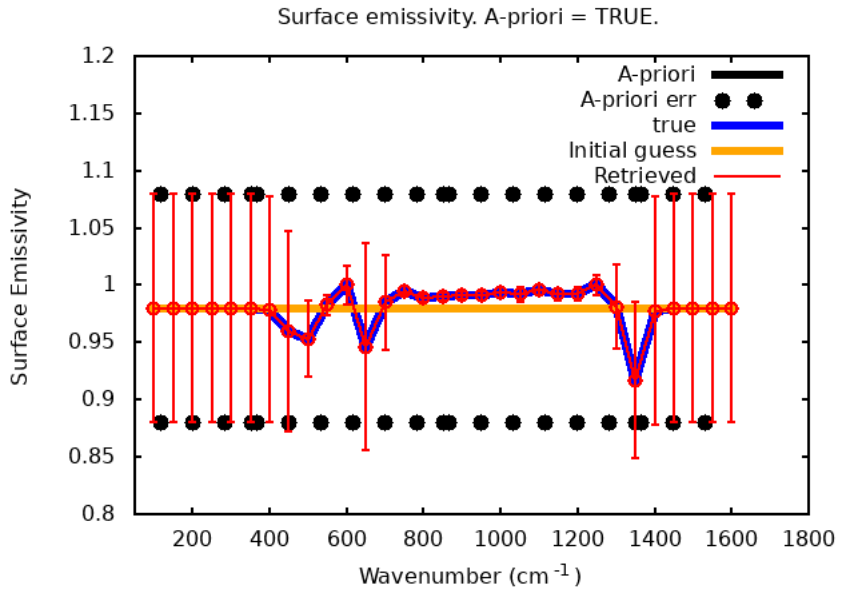
Results T – Polar atmosphere – rand. pert.



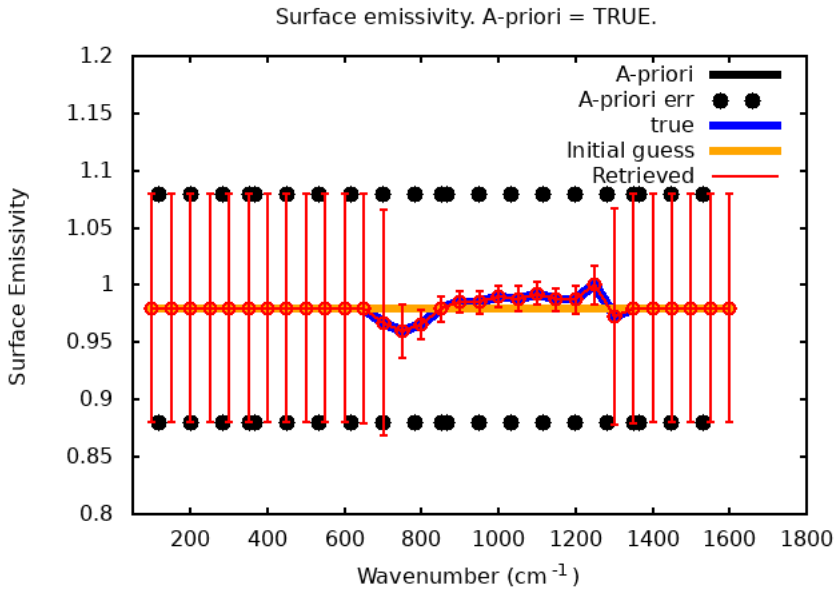


Results emissivity

Polar atmosphere



Tropical atmosphere



Real observations- IASI over Antartica

IASI observation:

DAYTIME: 2016-07-21 13:58:48.756000

LAT: -75.3831939697

LON: 123.499938965

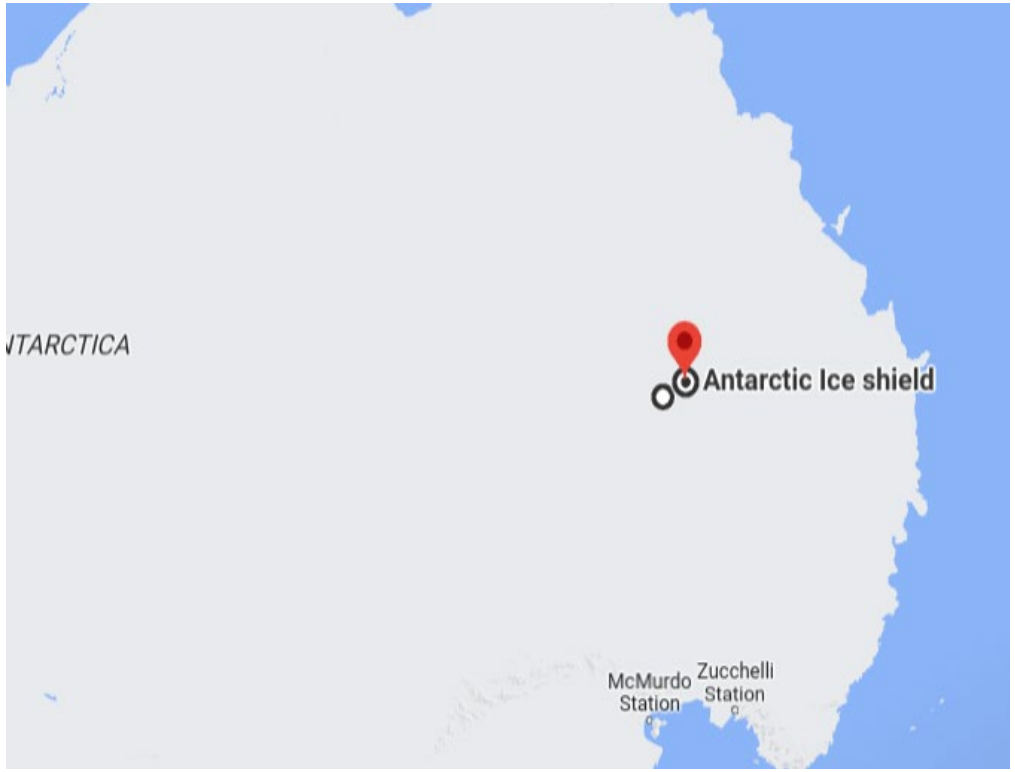
FOR: 4 (RANGE 0-29)

FOV: 3 (RANGE 0-3)

ANGLE: 41.18

T and H_2O also measured by radiosondes located at Dome C

- Space distance between the two measurements: ~ 32 km
- Time lag: ~ 2 hours



Real observations- IASI over Antartica

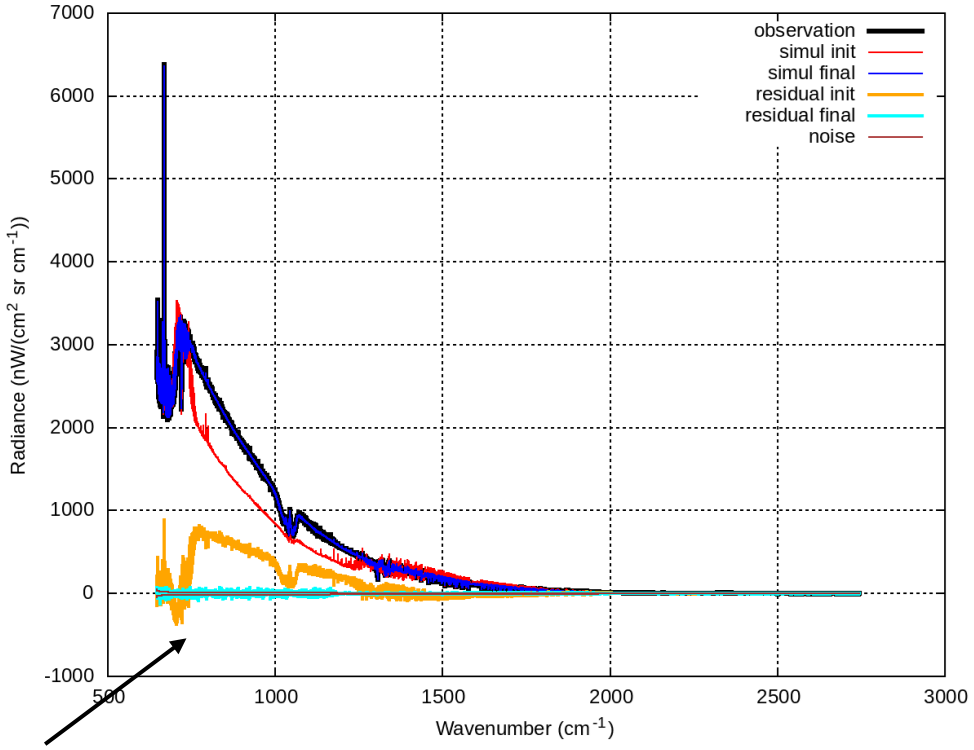
- **TEST 1**
  - retrieval at all sigma-FORUM layers
  - Retrieval of all the FARM targets: Ts,T(p), H_2O(p), CO_2,O_3(p), …, CF_4(p), emissivity at steps of 40 to 50 cm^{-1}
  - Final χ^2 = 1.2715
- **TEST 2**
  - retrieval at all sigma-FORUM layers
  - Retrieval of only Ts,T(p), H_2O(p), O_3(p), retrieved gases are H2O(p) and O3(p)and emissivity at steps of 40 to 50 cm^{-1}
  - Final χ^2 = 1.4572

==> CO_2 band not properly fit, compensations with retrieval variables

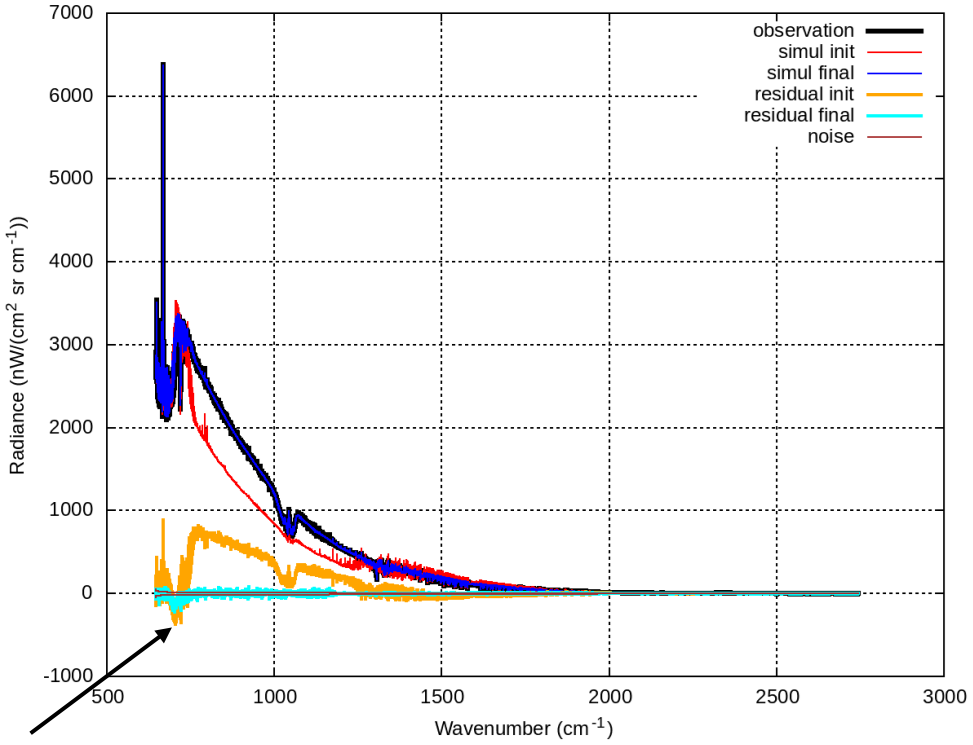
- **TEST 3**
  - retrieval at an optimized vertical retrieval grid
  - Retrieval of all the FARM targets: Ts,T(p), H_2O(p), CO_2,O_3(p), …, CF4(p), emissivity at steps of 40 to 50 cm^{-1}
  - Final χ^2 = 1.2715

Spectra

Test 1

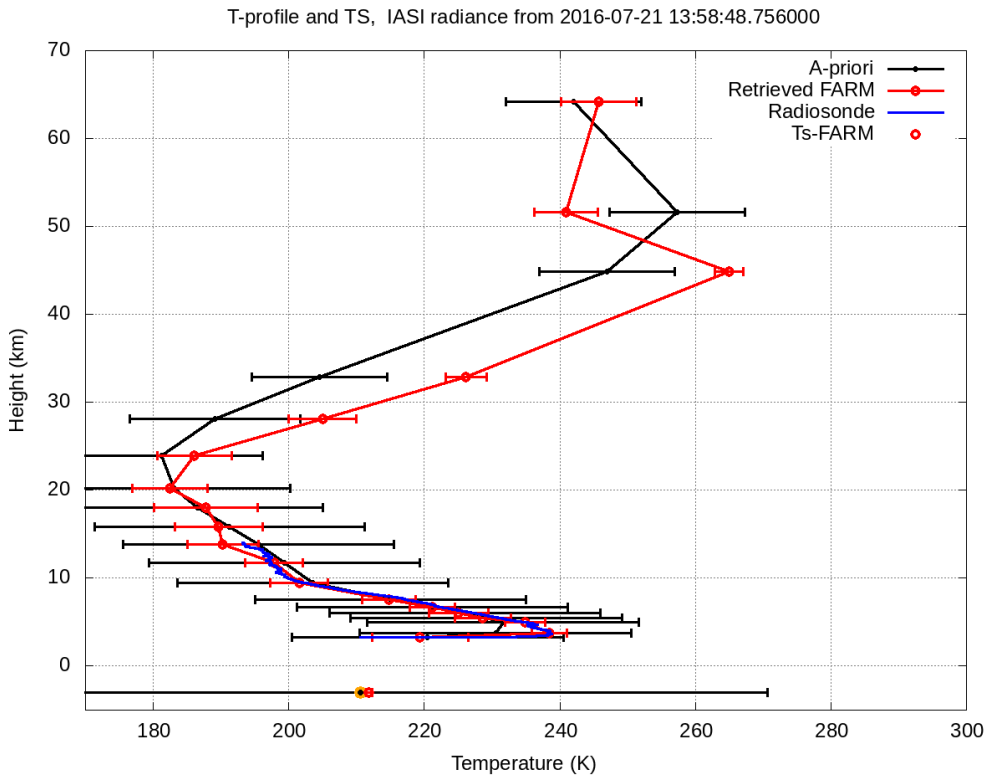


Test 2

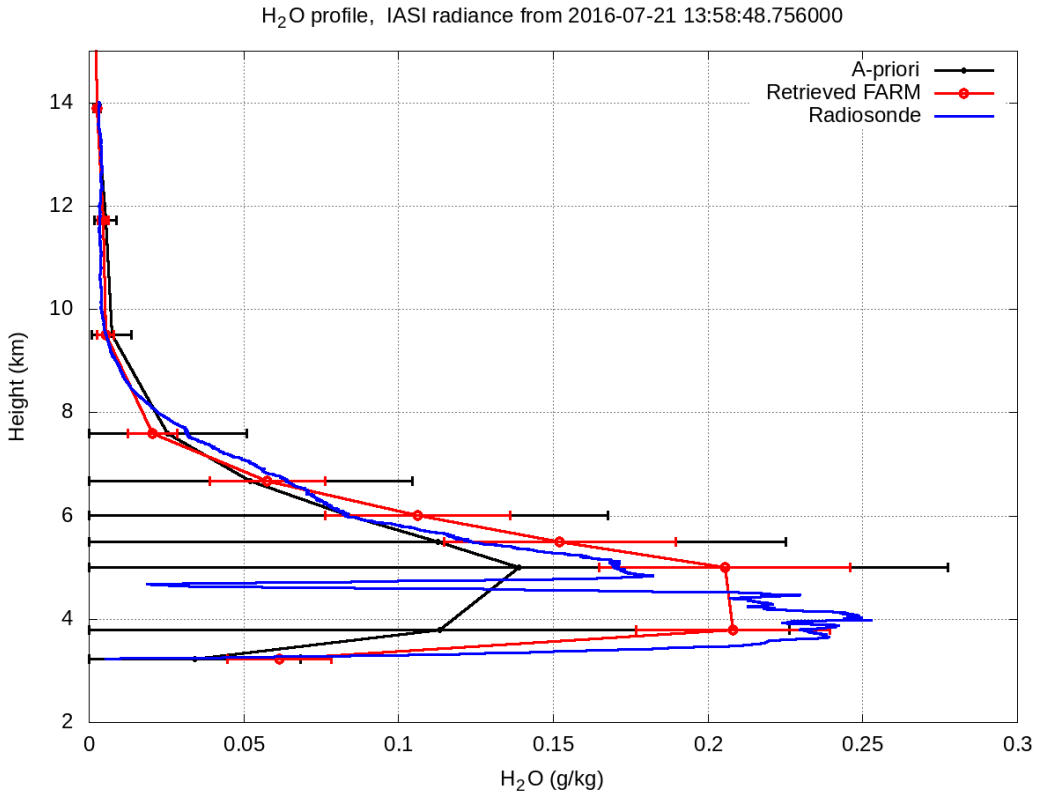


TEST 3 - results

Temperature profile



Water vapor

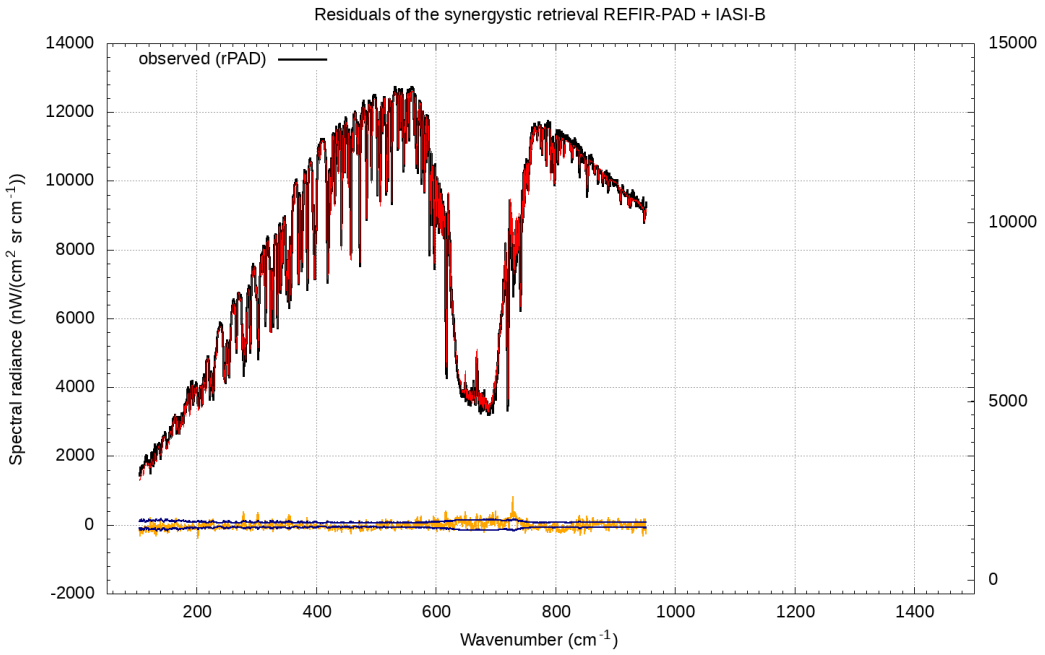


Real observations: REFIR-PAD + IASI Balloon Teresina campaign

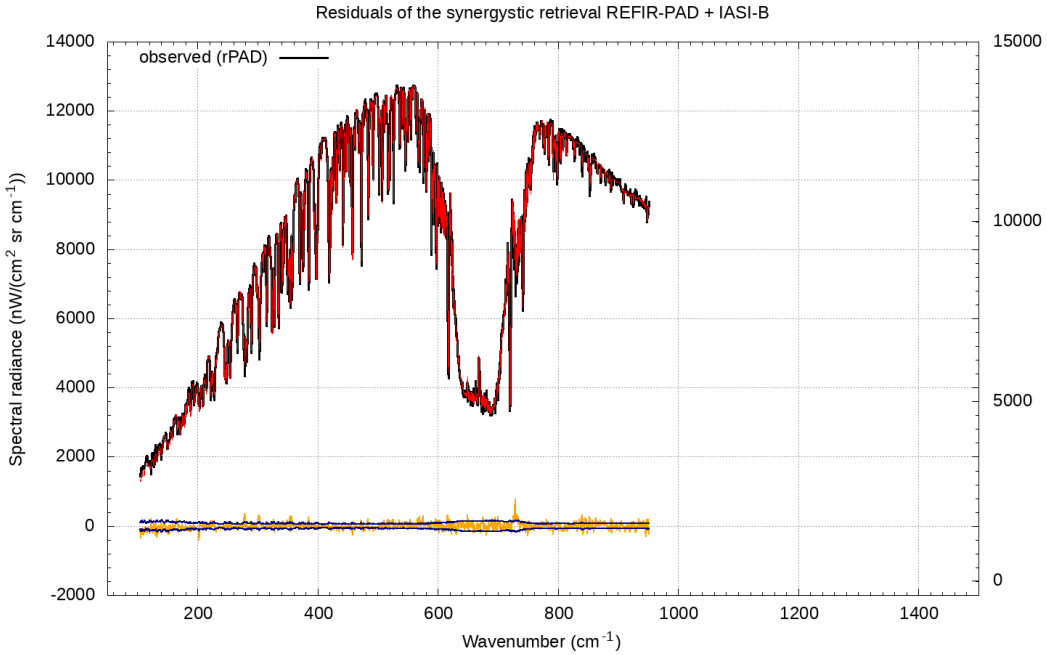
- The FARM code has been applied to the real measurements performed during a balloon measurement campaign in Teresina
- A demonstrator of the FORUM instrument (REFIR-PAD) and of the IASI instrument (IASI- Balloon) were on board.
- The spectra of both instruments observing the same airmasses have been retrieved with FARM to obtain vertical profiles of Temperature, H_2O and surface properties
- We have performed retrievals of REFIR-PAD only, IASI-Balloon only or the joint (synergistic) retrieval

Real observations: REFIR-PAD + IASI Balloon Teresina campaign

REFIR-PAD only

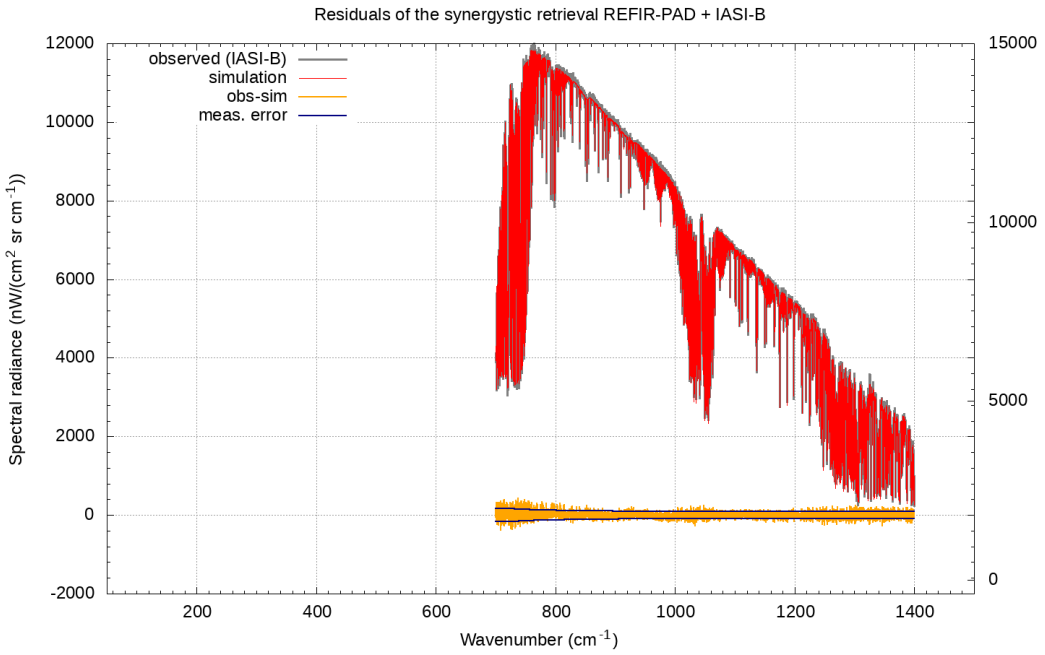


REFIR-PAD+IASI-B

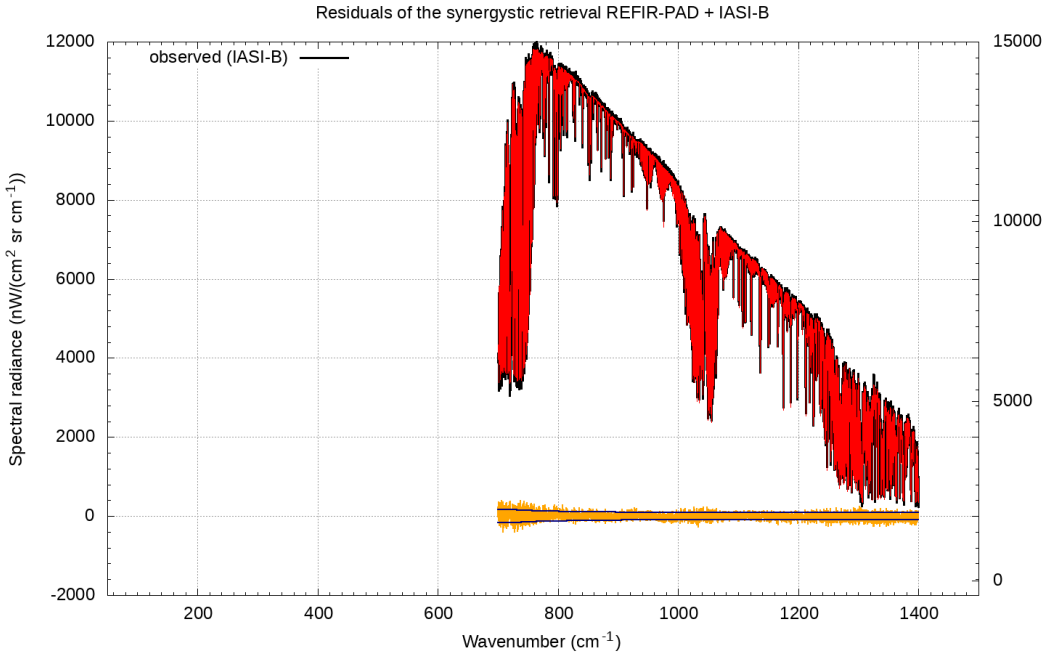


Real observations: REFIR-PAD + IASI Balloon Teresina campaign

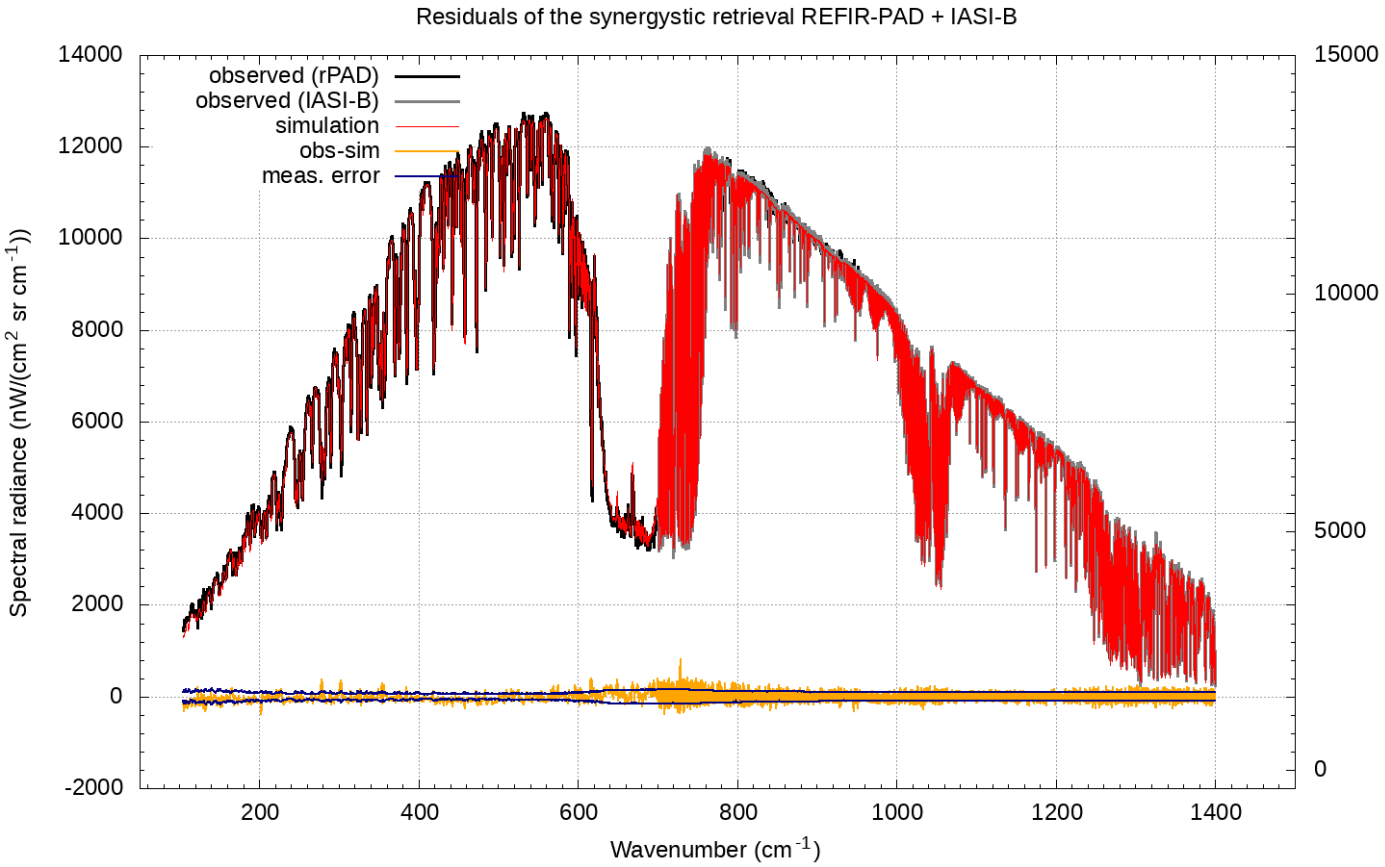
IASI-B only



REFIR-PAD + IASI-B

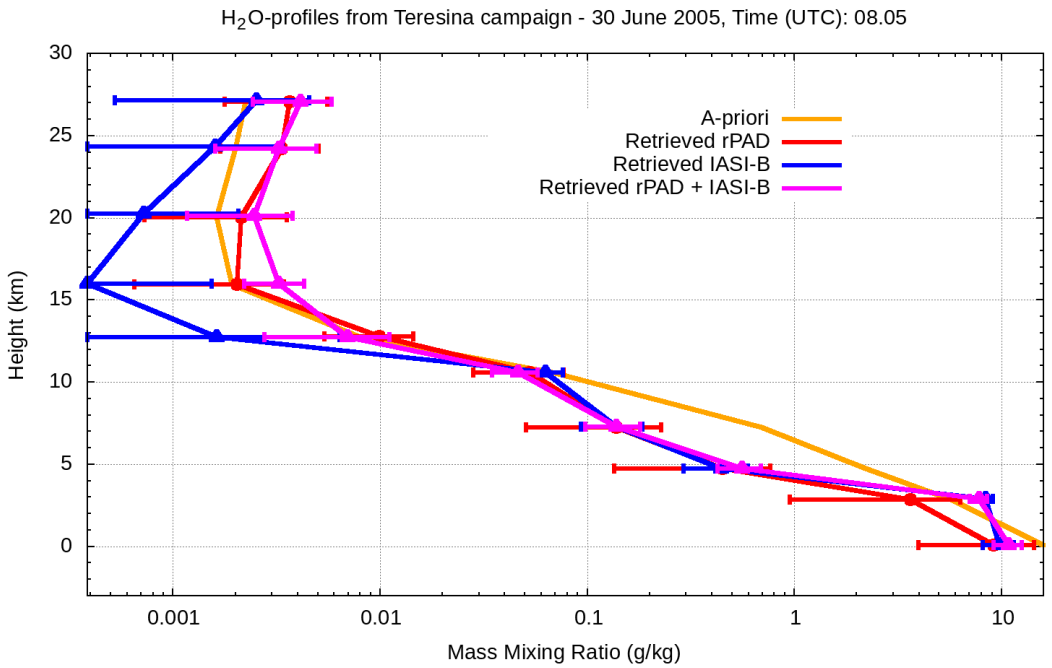


Real observations: REFIR-PAD + IASI Balloon Teresina campaign

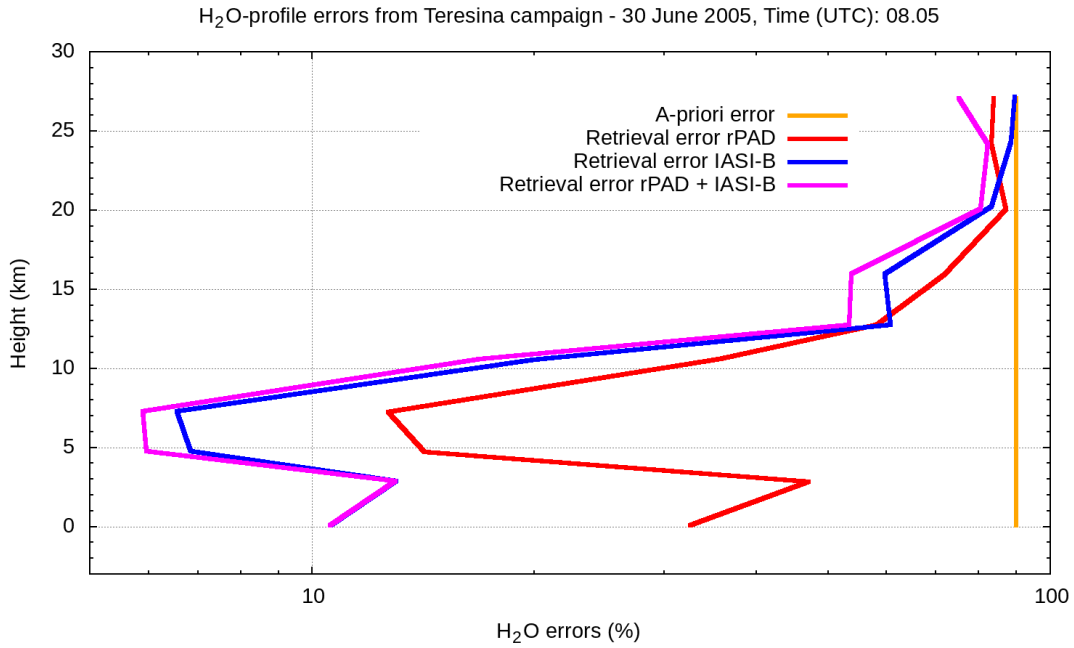


Retrieval REFIR-PAD + IASI Teresina campaign

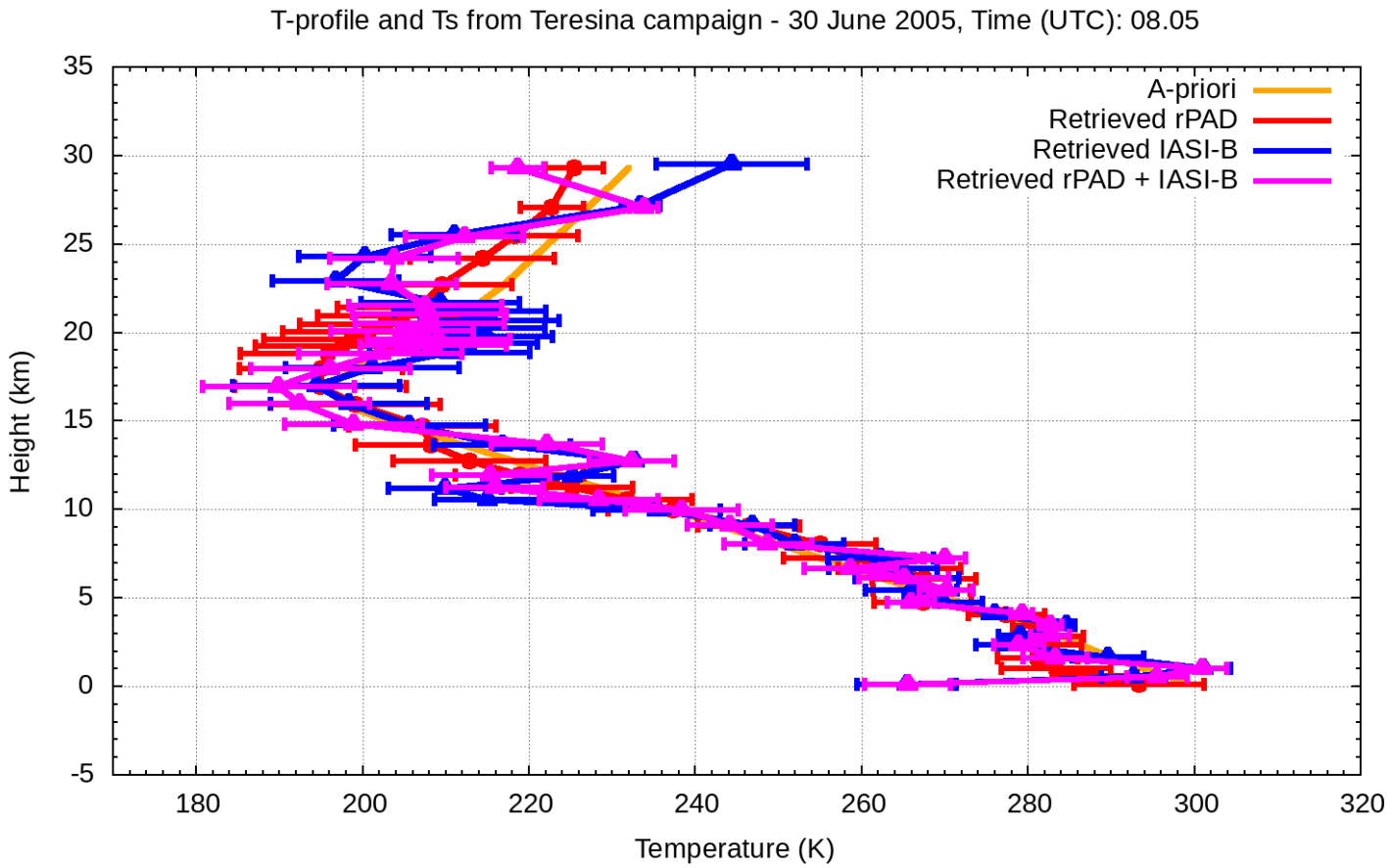
H2O profile



Retrieval errors



Retrieval REFIR-PAD + IASI Teresina campaign



Conclusions

- A fast retrieval code (FARM) has been developed
- The code is based on the sigma-FORUM RTM, that simulates the full FIR+TIR top of atmosphere spectrum with a step of 0.01 cm^{-1} in less than 1 sec (clear sky), less than 3 sec (cloudy sky)
- The code has been successfully applied to simulated observations of FORUM and to real observations of IASI over Antartica and of REFIR-PAD and IASI-Balloon in a balloon borne measurement campaign in Teresina (all in clear sky)
- We are currently working to the optimization of the retrieval of cloud's properties from simulated observations and then from real observations
- The code will be used for the analysis of future FIRMOS-Balloon and FIRMOS ground based measurements.
- The code can be used for any nadir-looking FTIR instrument in the FIR-TIR spectral region