# STSM: MWR brightness temperature assimilation with 1D-Var

## 17 September – 23 October, 2015

F. De Angelis (U. L'Aquila)[1] visiting P. Martinet (Météo France)[2]

In collaboration with Domenico Cimini (1,3)

(1) CETEMPS, University of L'Aquila, Italy

(2) CNRM-GAME, Météo France & CNRS, Toulouse, France

(3) CNR-IMAA, Potenza, Italy

# Motivations (1/2)

- **The PBL is the single most important under-sampled part of the atmosphere***
  - Surface → met data
  - Upper air → satellite
- **Particularly important in nowcasting and severe weather initiation**
- **Four critical atmospheric variables are not adequately measured****
  - wind profiles,
  - **temperature and humidity profiles (in cloudy areas),**
  - precipitation, snow mass.
- **Ground-based MWR provide T and H profiles with:**
  - High temporal resolution (~1 min),
  - Low-to-moderate vertical resolution,
  - Information mostly residing in the PBL.

*U.S.NRC Reports; **WMO guidance on observations for NWP

# Motivations (2/2)

- **Recent experiments have demonstrated the feasibility and impact of MWR data assimilation (DA) (Caumont et al 2015 *)**
  - DA of temperature and humidity profiles
- **Improvements are expected from DA of radiances (Tb)**
  - A fast forward model is needed
- **A fast forward model is available from NWP SAF (MetOffice) for satellite radiometric observations: RTTOV**
  - Suitable for microwave radiometers
  - RTTOV has been adapted to work for ground-based obs (under evaluation)

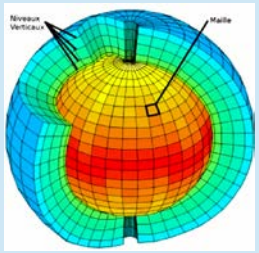
**1D-Var with RTTOV available from NWP SAF (MetOffice):**

- Has been adapted to RTTOV ground-based during previous STSM/SWG
- Evaluation of the 1D-Var retrievals is needed

* Caumont et al 2015 : Assimilation of humidity and temperature observations retrieved from ground -based microwave radiometers into a convective-scale NWP model, QJRMS, in review

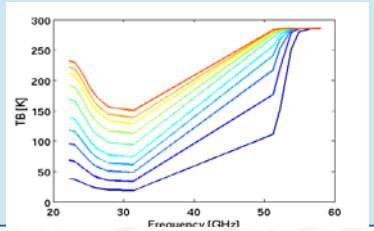
# 1D Variational approach

Model Space: T, q, u, v

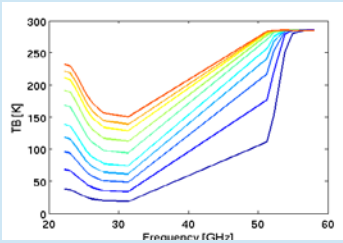


Radiative Transfer = RTTOV-gb

BT simulation from the model




Observation




**Adjustment** of model variables with an iterative scheme.

**Minimisation** of the difference between simulated BT and observed BT

**Minimisation of the cost function :**

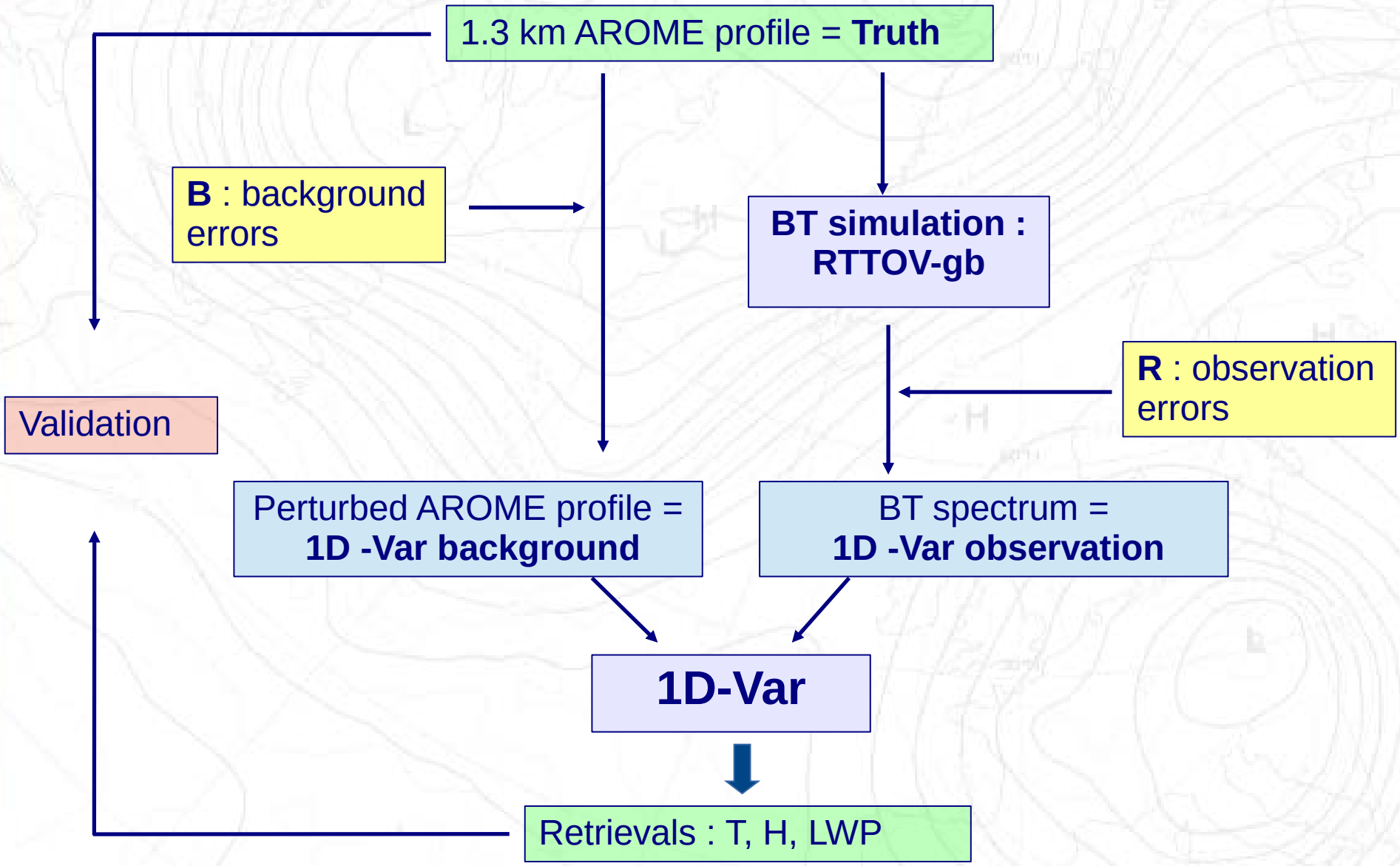
**The solution requires :**

- The forward model (radiative transfer operator) **: F(x)**
- Derivatives of F(x), i.e Jacobians **K** and its transpose $\mathbf{K^T}$

# Objectives of STSM

- Extensive evaluation of the NWPSAF 1D-Var previously interfaced with RTTOV – gb
- Start with T and H profiles in clear-sky and Jacobians computed with brute force
- Modify the 1D-Var to use RTTOV-K module to compute the Jacobians (faster)
- Evaluation of T and H profiles in clear-sky with Jacobians computed with RTTOV-K
- Cloudy-sky evaluation: retrieval of T, H and liquid water path at the same time.

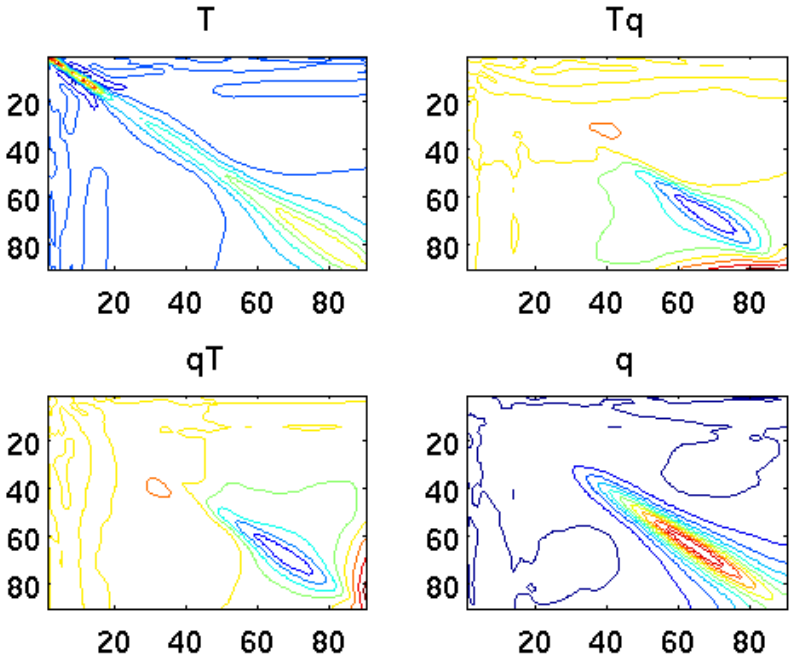
# Methodology: Simulated Experiments



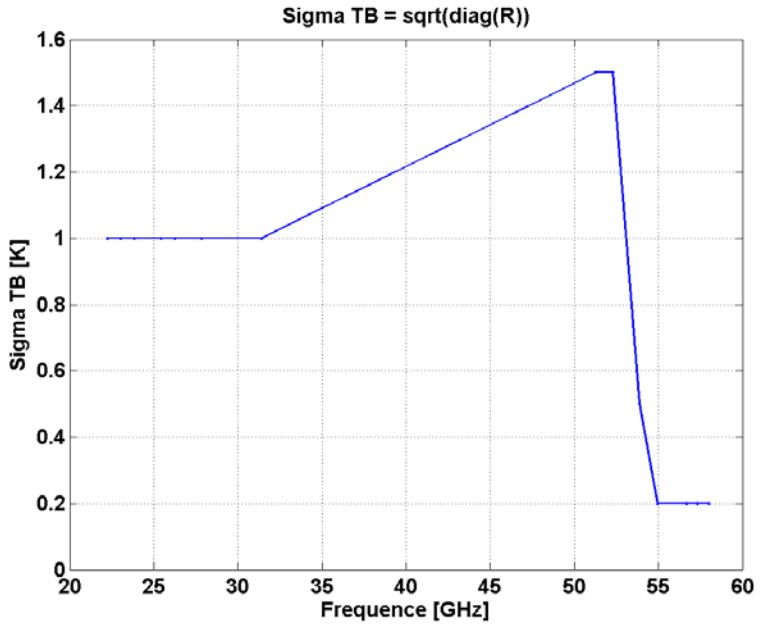
# Methodology: Dataset

- **224** Arome analyses in February 2015 over the Alps;
- Profiles specific of Alpine Valley and mountainous regions in winter;

**B matrix**: AROME background errors computed from an AROME ensemble assimilation system. Couplings between variables (T and H) + hydrometeors




**R matrix**: diagonal, reasonable values have been chosen according to Hewison 2007, 22-31 GHz: 1K, 51-52 GHz: 1.5 K, 53 GHz= 0.5 K, 53-58 GHz: 0.2 K.

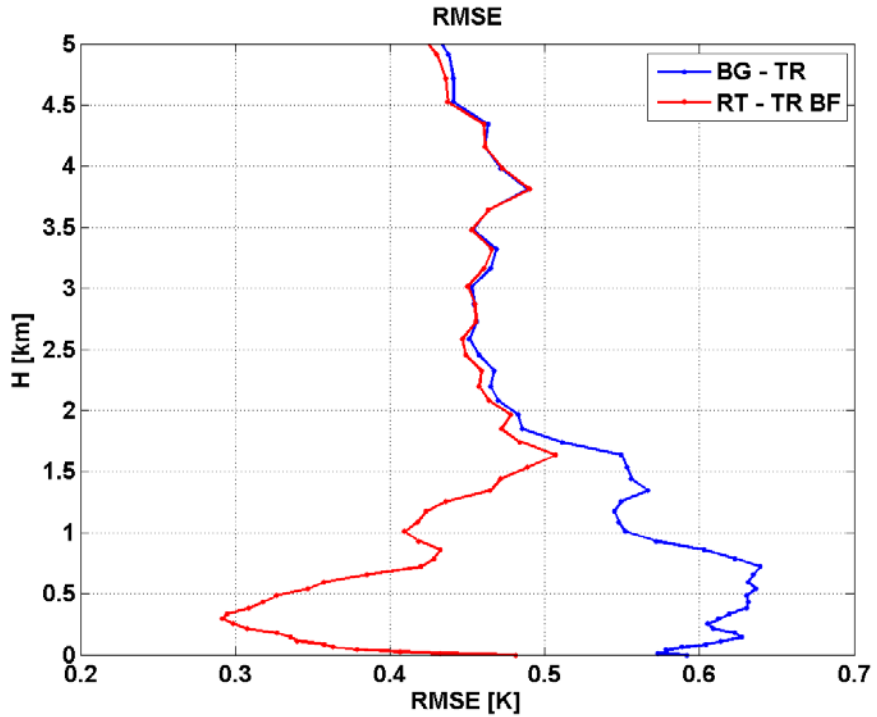


# Results: Clear-sky retrievals T and H, brute force Jacobians

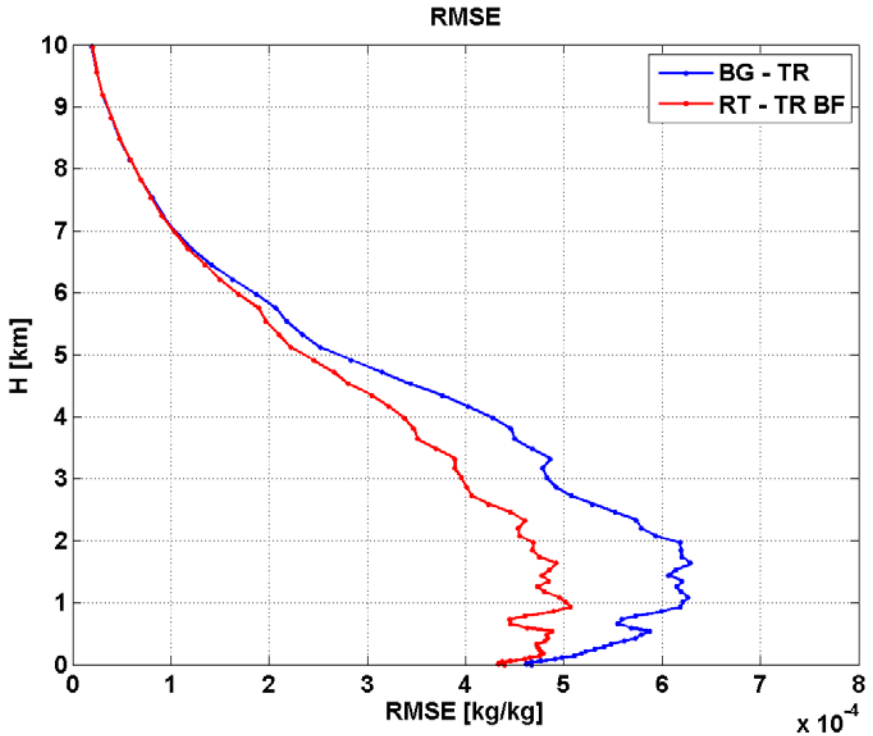
- Statistics over 224 profiles, 180 profiles converge when H is retrieved (rate of convergence 80%) within 2 iterations.

RMSE between background and « truth »
RMSE between retrievals and « truth »

**Temperature (K)**




**Humidity (kg/kg)**

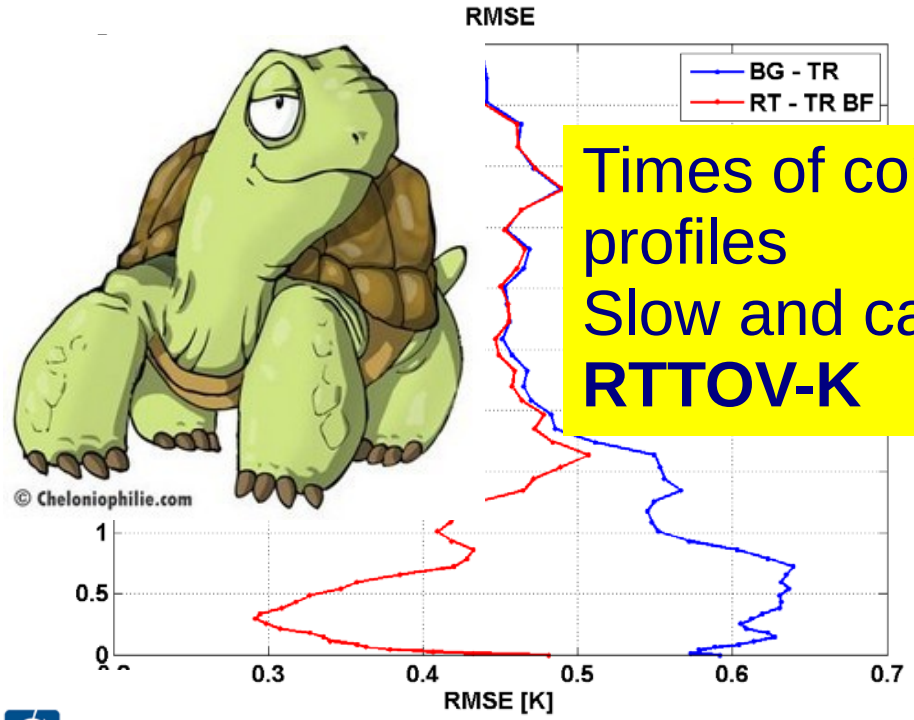


# Results: Clear-sky retrievals T and H, brute force Jacobians

- Statistics over 224 profiles, 180 profiles converge when H is retrieved (rate of convergence 80%) within 2 iterations.

RMSE between background and « truth »
RMSE between retrievals and « truth »

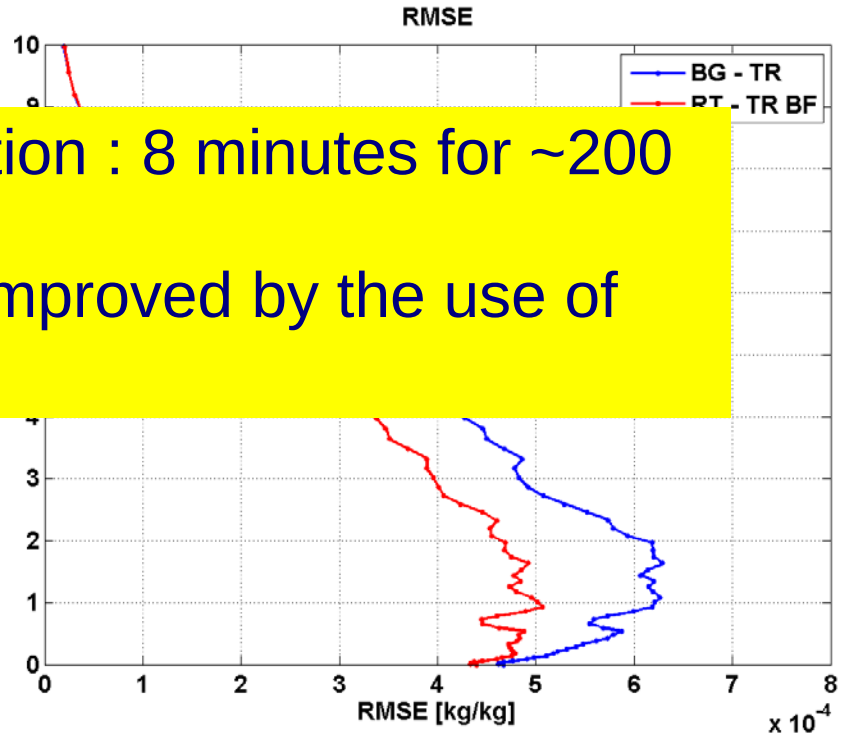
**Temperature (K)**







**Humidity (kg/kg)**



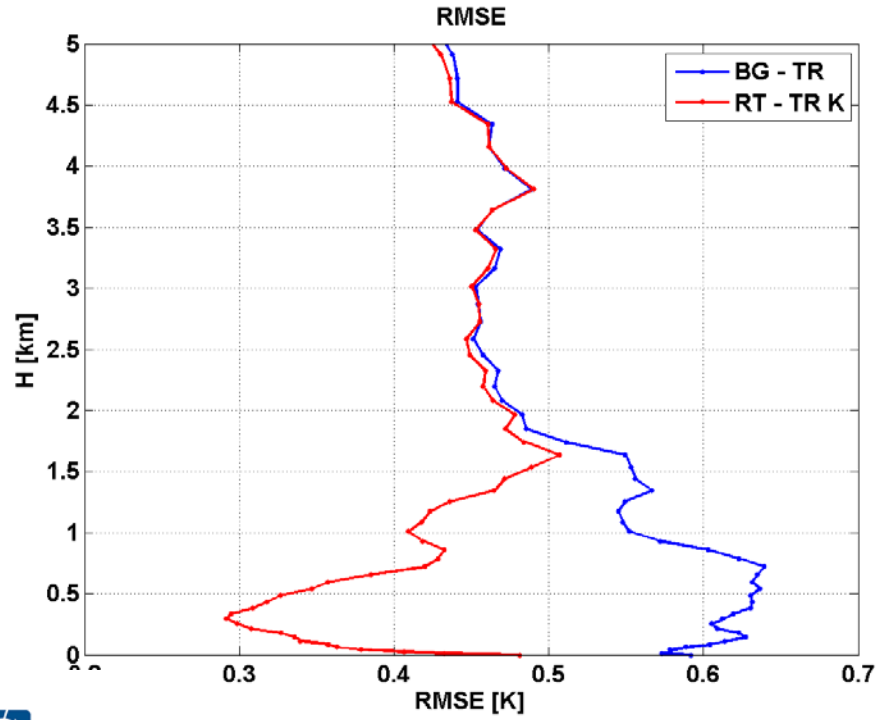

Times of computation : 8 minutes for ~200 profiles
Slow and can be improved by the use of **RTTOV-K**

# Results: Clear-sky retrievals T and H, RTTOV-K Jacobians

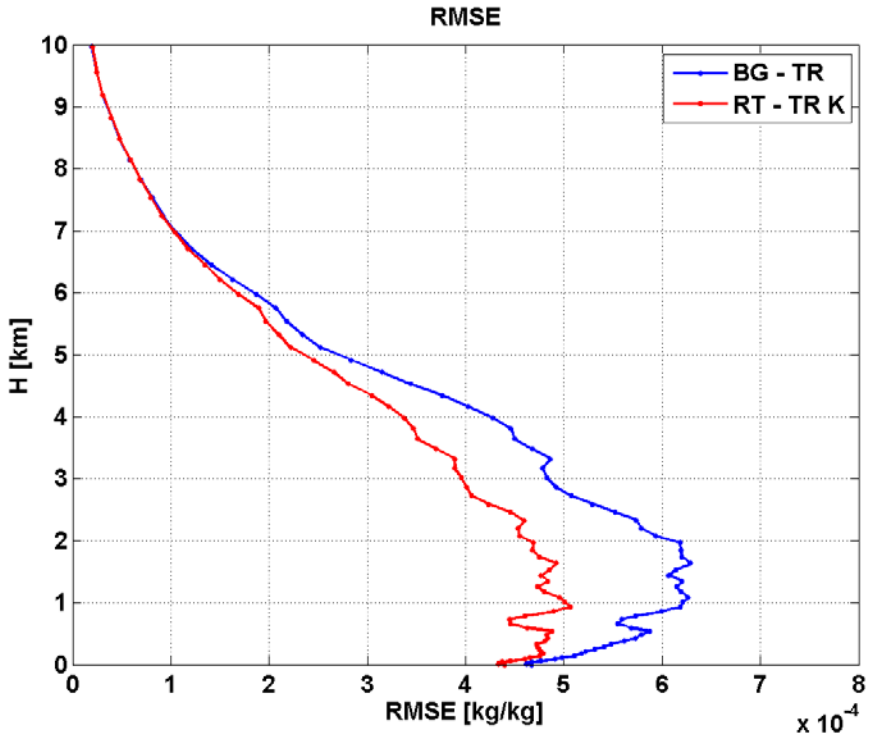
- Statistics over 224 profiles, 180 profiles converge when H is retrieved (rate of convergence 80%)

RMSE between background and « truth »
RMSE between retrievals and « truth »

**Temperature (K)**




**Humidity (kg/kg)**

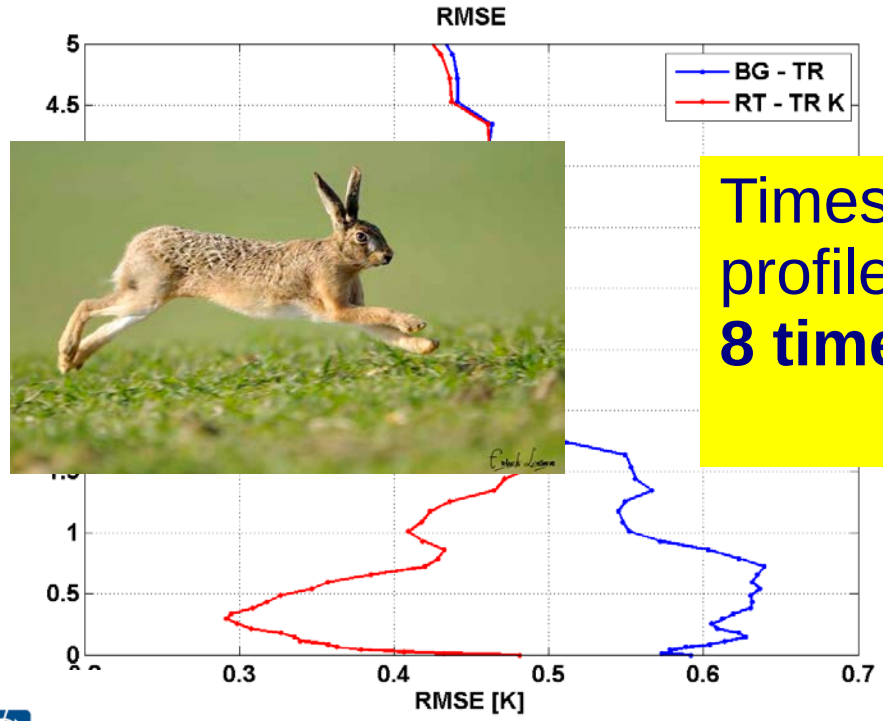


# Results: Clear-sky retrievals T and H, RTTOV-K Jacobians

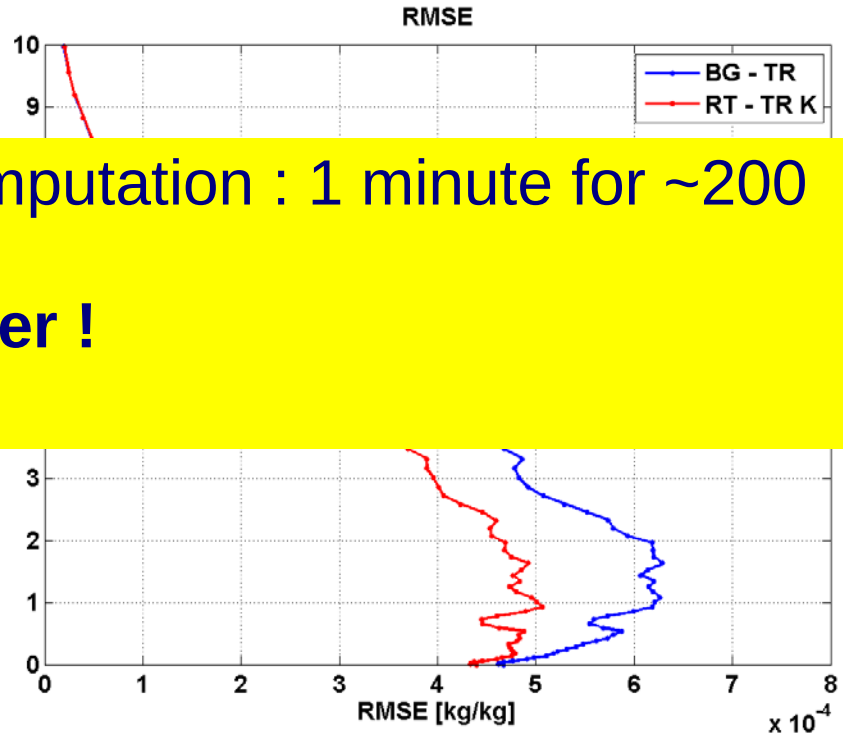
- Statistics over 224 profiles, 180 profiles converge when H is retrieved (rate of convergence 80%)

RMSE between background and « truth »
RMSE between retrievals and « truth »

**Temperature (K)**




**Humidity (kg/kg)**



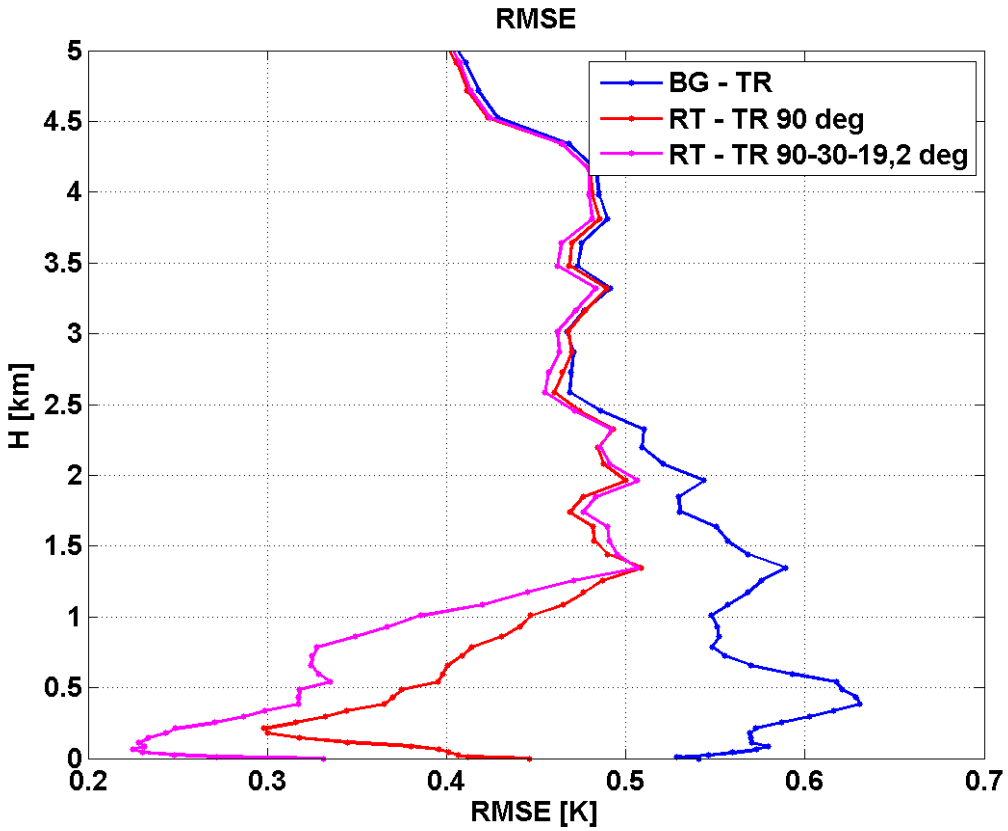



Times of computation : 1 minute for ~200 profiles
**8 times faster !**

# Results: Temperature profile , low elevation angles

RMSE between background and « truth »
RMSE between retrievals and « truth » : **zenith** angle only
RMSE between retrievals and « truth » : **90° + 30 ° + 19.2 °**

- Improvement of the 1D-Var retrievals below 1.5 km altitude



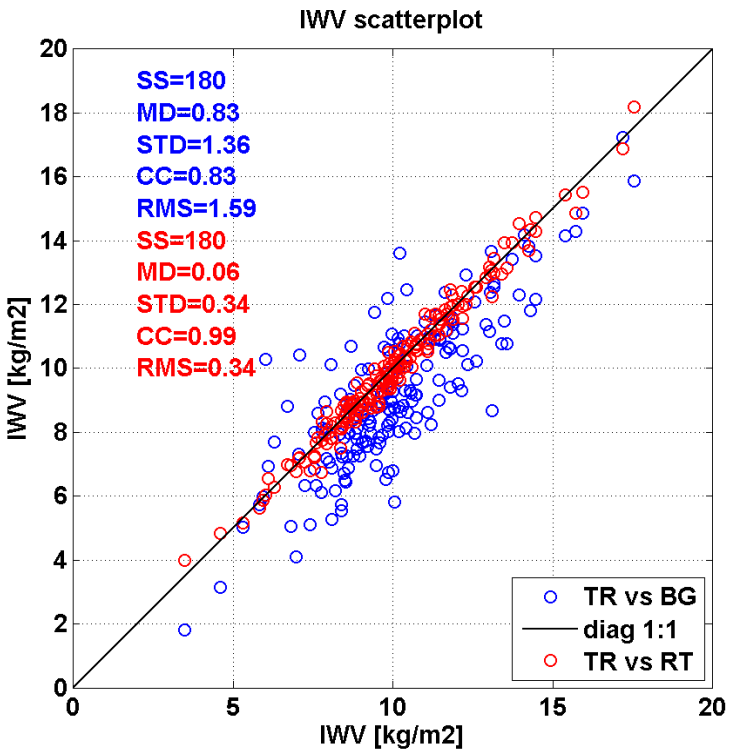
# Results: Integrate Water Vapor , clear-sky

H profile as control variable

Convergence rate : **80 %** (180 prof.)

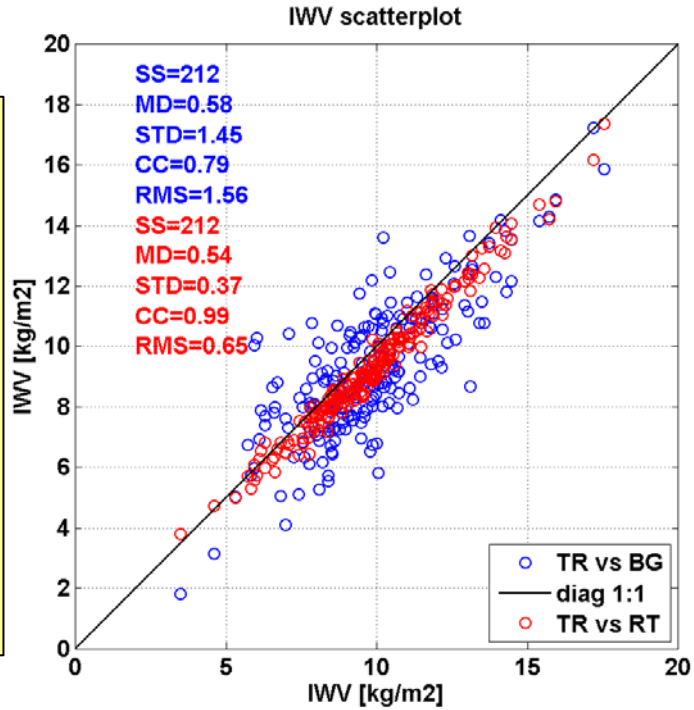
IWV as control variable

Convergence rate : **95 %** (2121 prof.)




- Large improvement of the convergence rate with IWV as control variable

- But retrievals slightly biased (dry bias), RMSE=0.65 instead of 0.34 $g.m^{-2}$



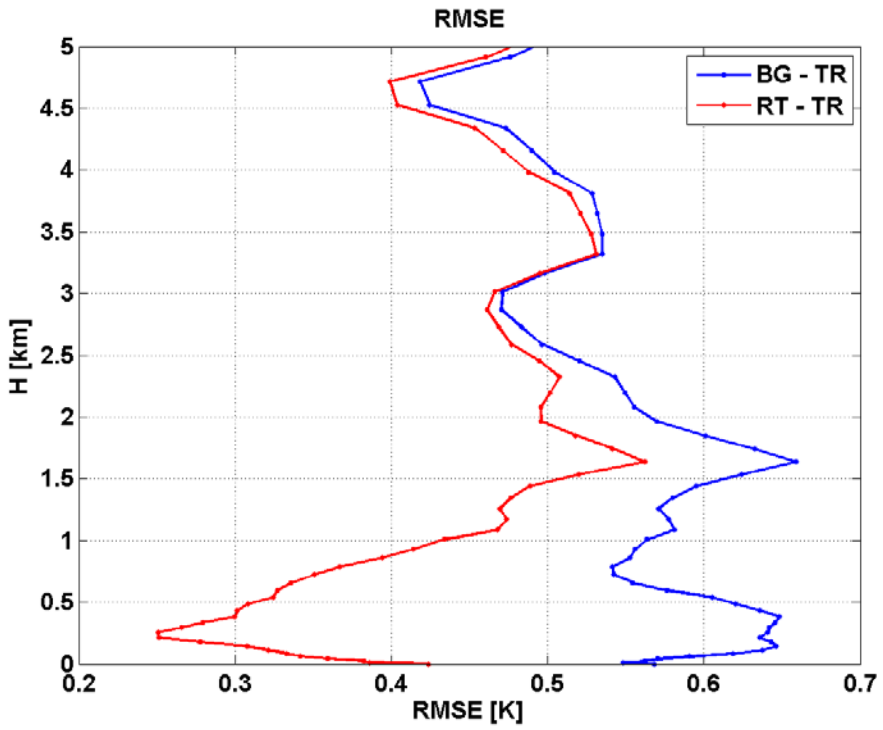
# Results: Cloudy-sky retrievals T, H and LWP

- Lack of thick clouds in AROME: the LWC profiles are x 10
- Statistics for profiles with LWP > 5 g.m$^{-2}$ : 70 profiles in the dataset, 64 converge within less than 4 iterations.

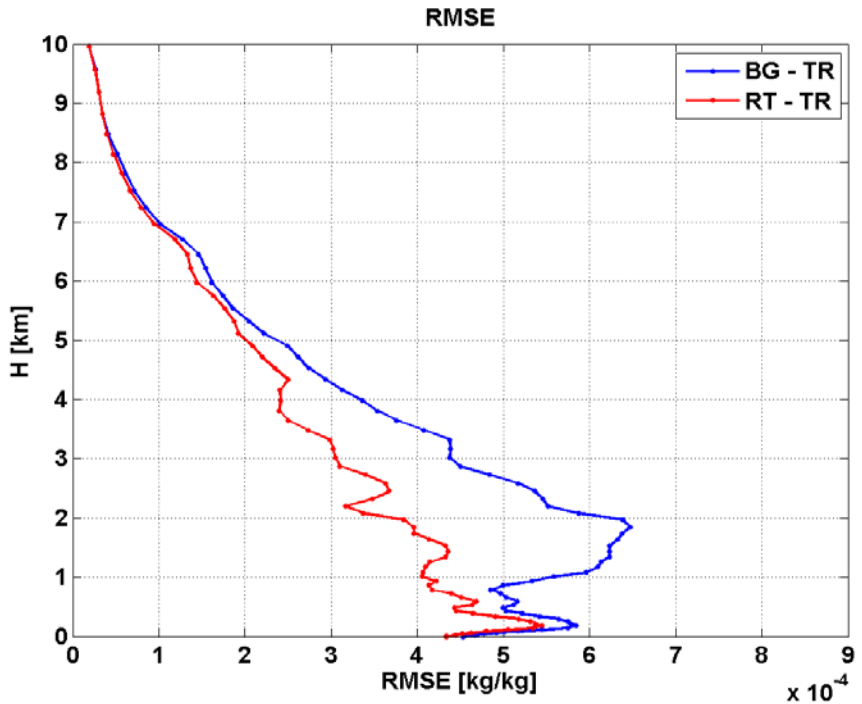
RMSE between background and « truth »

RMSE between retrievals and « truth »

**Temperature (K)**




**Humidity (kg/kg)**

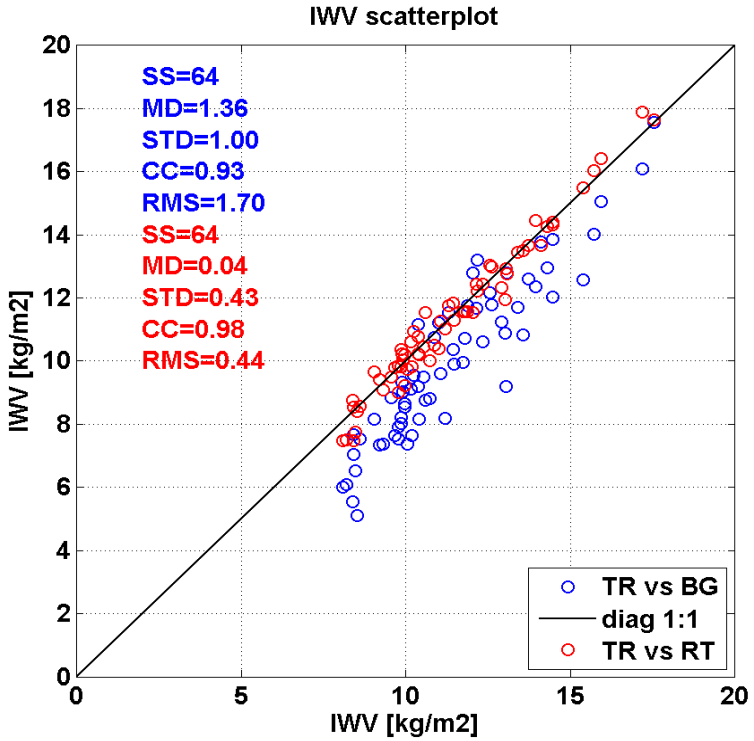


# Results: Cloudy-sky retrievals IWV and LWP

- Lack of thick clouds in AROME: the LWC profiles are x 10
- Statistics for profiles with LWP > 5 g.m$^{-2}$ : 70 profiles in the dataset, 64 converge within less than 4 iterations.

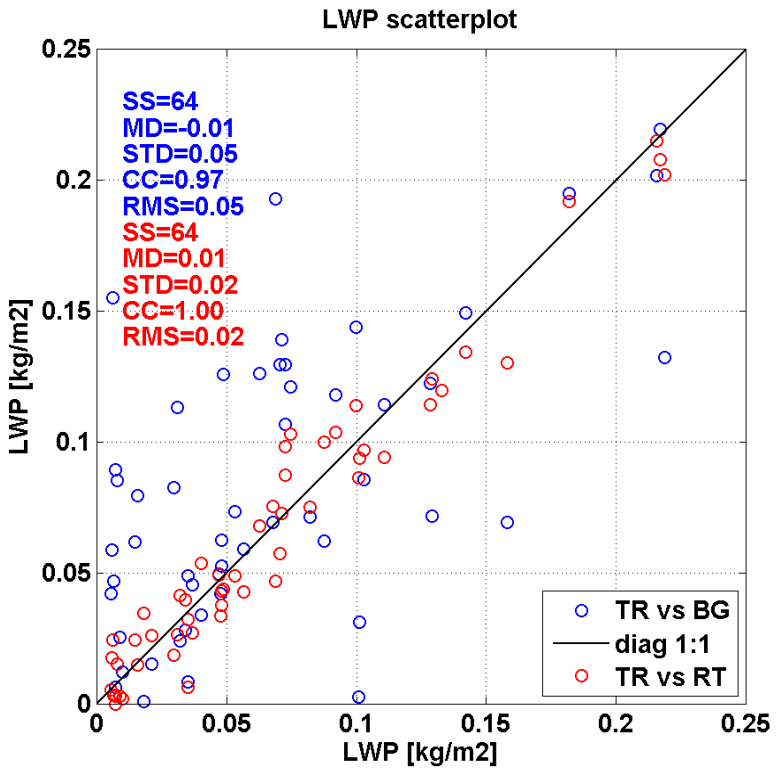
## Integrated Water Vapor (kg/m2)

RMSE background : 1.70 kg.m$^{-2}$
RMSE 1D-Var : 0.44 kg.m$^{-2}$




## Liquid Water Path (kg/m2)

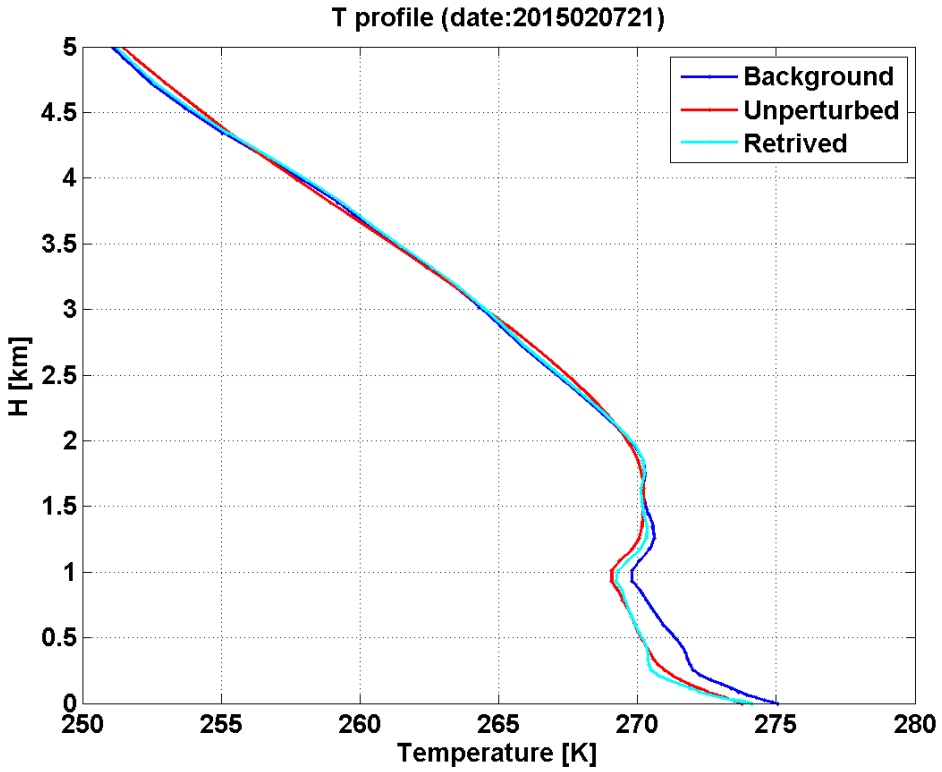
RMSE background : 50 g.m$^{-2}$
RMSE 1D-Var : 20 g.m$^{-2}$



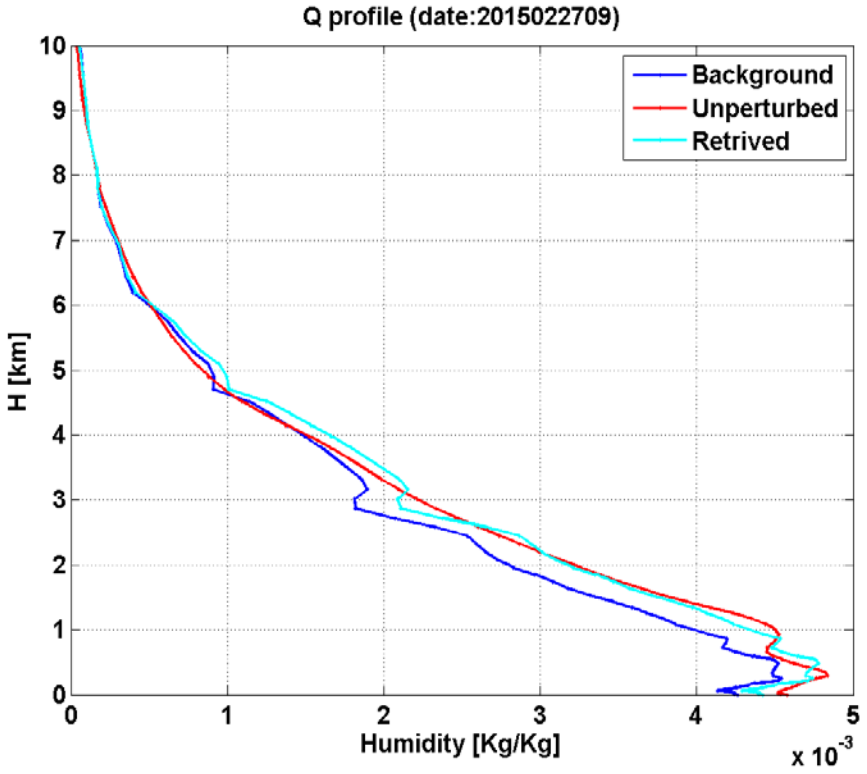
# Results: A nice example of very good 1D-Var retrievals

Background
True Profile
1D-Var retrieval

## Temperature (K)




## Humidity (kg/kg)



# Conclusions

- 1D-Var works well with **low elevation angles** down to 19° for the retrieval of temperature and humidity profiles and liquid water path;
- 1D-Var has been modified to use **RTTOV-K** to compute Jacobians
- 1D-Var with RTTOV-K was successfully tested and **8 times faster** !
- Successful modification of RTTOV ground-based to **include LWC** as a cloud absorbing species enabling 1D-Var retrievals in cloudy-sky.
- **Expected accuracy in clear-sky conditions**
  - Temperature: Bias < 0.02 K RMSE < 0.5 K
  - Humidity: Bias < 0.5 $10^{-4}$ kg.kg$^{-1}$ RMSE < 5.$10^{-4}$ kg.kg$^{-1}$
  - Integrated Water Vapor: Bias = 0.06 kg.m$^{-2}$ , RMSE=0.34 kg.m$^{-2}$
- **Expected accuracy in cloud-sky conditions:**
  - Temperature: Bias < 0.07 K, RMSE < 0.5
  - Humidity: Bias < 1.$10^{-4}$ kg.kg$^{-1}$, RMSE < 5.10-4 kg.kg-1
  - IWV: Bias < 0.06 kg.m$^{-2}$ , RMSE < 0.34 kg.m$^{-2}$
  - LWP: Bias < 10 g.m$^{-2}$, RMSE = 20 g.m$^{-2}$

# Remaining work

- The bias of the retrievals when **IWV** as used as control variables is not fully understood, needs some investigations + no convergence in cloudy retrievals if IWV is used;
- Development on RTTOV-gb to allow **lower elevation angles** (below 19°) for temperature profiles in the boundary layer;
- Test the 1D-Var on **real measurements** and compared to colocated radiosondes to demonstrate the performances.


Thank you very much for your attention!!