Improvement of brightness temperature simulations from Radiative Transfer Model and chemistry retrievals using O_3, CO_2 and CH_4 vertical profiles from APOGEE campaign

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I – APOGEE (Atmospheric Profiles Of GreenhousE gasEs) campaign:

Objective of **APOGEE** compaign is to realized measurements of temperature, pressure, humidity and different atmospheric chemical profiles (**O_3**, **CO_2** and **CH_4**) up to 30 km.

- Ozone is measured using Vaisala sonde with electrochemical cell (*see Picture 1*).

Picture 1. Picture of ozone radiosounding (left) and ozone-sonde (right).

- Carbon dioxide and methane are measured using **AMULSE** (Atmospheric Measurement Ultralight SpEctrometer) instrument developed by **GSMA** (Groupe de Spectrométrie Moléculaire et Atmosphérique) laboratory in Reims University (*see Picture 2*).

AMULSE spectrometer of infrared diod laser characteristics:

- **Weighting**: 2.9 kg
- **Accuracy**: 1 % @ 1 s
- **Limit condition**: 1 to 1100 mbar & -100°C to +50°C
- **Additional data**: GPS, Pressure, Temperature, Relative Humidity & plug and play

Picture 2. Picture of AMULSE radiosounding (left) and AMULSE instrument (right).

II – Scientific objectives:

- Realized collocation between radiosoundings and pixels come from infrared instruments (**IASI** and **CrIS**) onboard polar satellites [**MetopA&B** and **SUOMI-NPP**] (*see Picture 3*) or infrared imager (**SEVIRI**) onboard geostationary satellite [**MeteoSat**] (*see Picture 4*) to assess simulations of brightness temperature.

Satellite observations provide brightness temperature at the top of atmosphere and a indirect information on temperature and humidity profiles, cloud cover, surface properties, aerosols and atmospheric compounds O_3, CO_2, CH_4, CO, HNO_3, N_2O...

- Chemical profiles used for verification of chemistry fields coming from a Chemistry Transport Model (**MOCAGE** or **CAMS**).

- Opportunity to analyse physico-chemical process in stratosphere and into **UTLS** (Upper Troposphere – Lower Stratosphere) under weather balloon.

- To have accurate chemical profiles to improve Chemistry Transport Model especially in lower troposphere to carried out chemical forecast for pollution episode (*see Figure 1*).

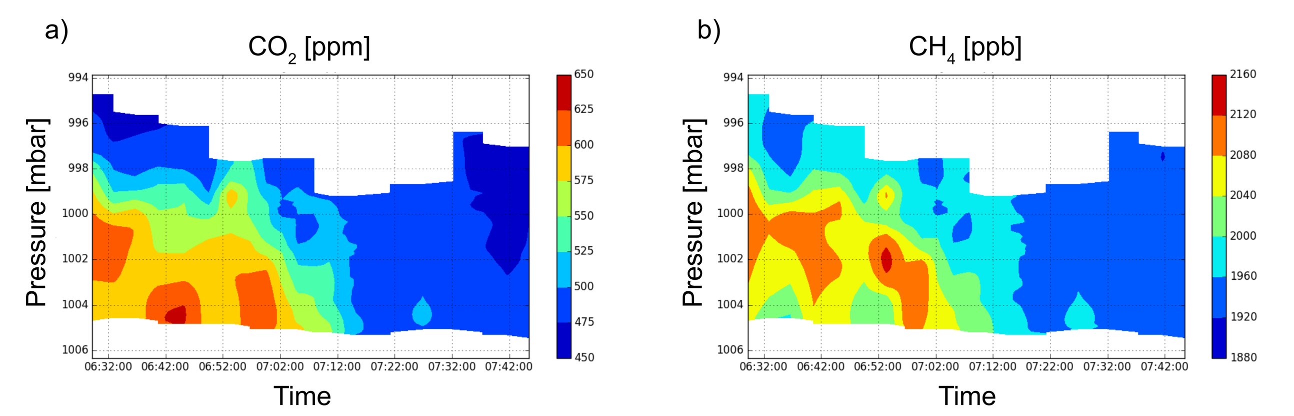
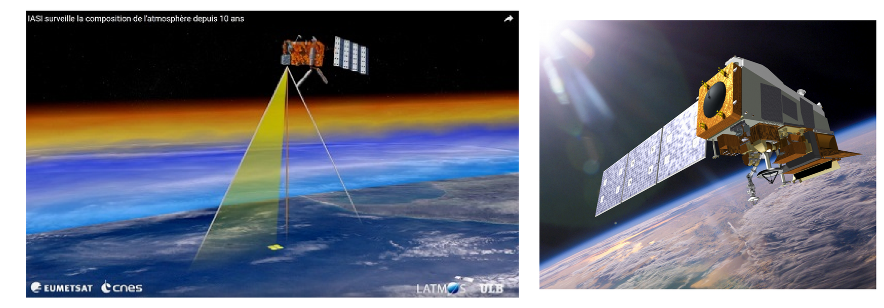
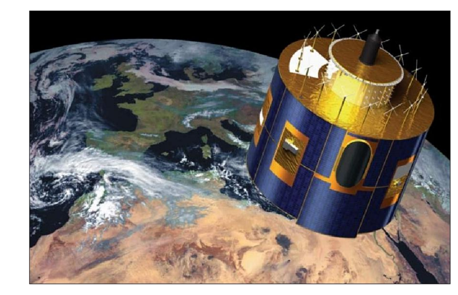


Figure 1. Example of CO_2 (a) and CH_4 (b) vertical profiles with respect to time in lower troposphere with 21 profiles (*GSMA*).



Picture 3. IASI onboard MetopA&B (left) and CrIS onboard SUOMI-NPP (right).



Picture 4. SEVIRI onboard MeteoSat.

IASI:

- Infrared Atmospheric Sounding Interferometer
- Onboard the Metop**A** & **B** - (MetopC **2018**) (IASI-NG **2021**)
- **8461** channels – Spectrum ranges from **645** to **2760** cm^{-1}

CrIS:

- Infrared Atmospheric Sounding Interferometer
- Onboard the SUOMI-NPP
- **1305** channels - Spectrum ranges from **3.92** µm to **15.38** µm

SEVIRI:

- Spinning Enhanced Visible and Infrared Imager
- Onboard the Meteosat
- **8** channels - Spectrum ranges from **0,5** µm to **15** µm

III – Sensitivity of simulation to O_3, CO_2 and CH_4 informations:

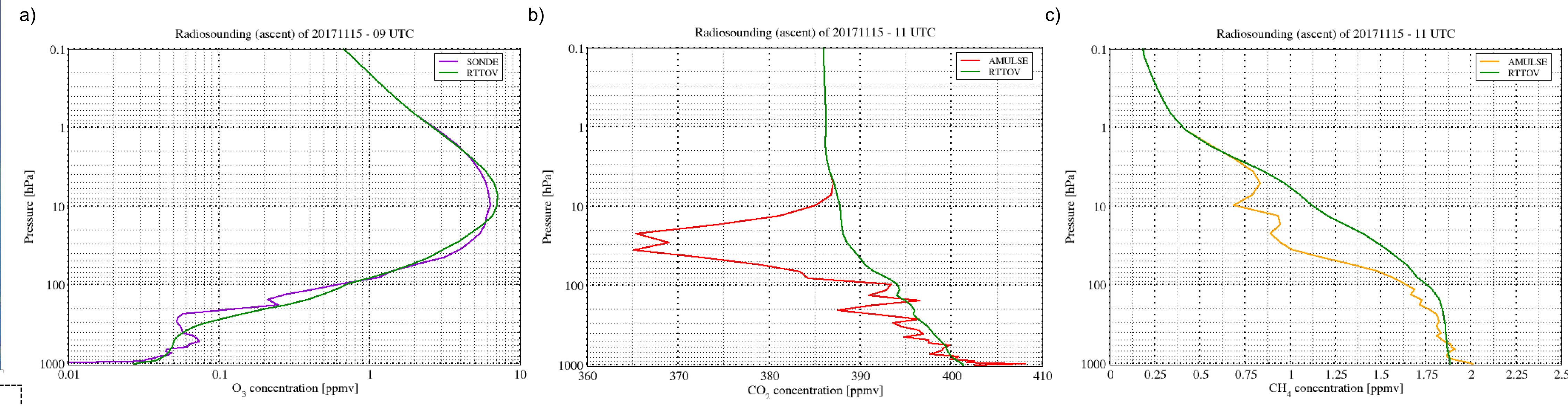


Figure 2. Example of O_3 (a), CO_2 (b) and CH_4 (c) vertical profiles coming from SONDE and AMULSE measurements and Climatology from RTTOV for the fall season of campaign in 20171115 – 09 and 12 UTC.

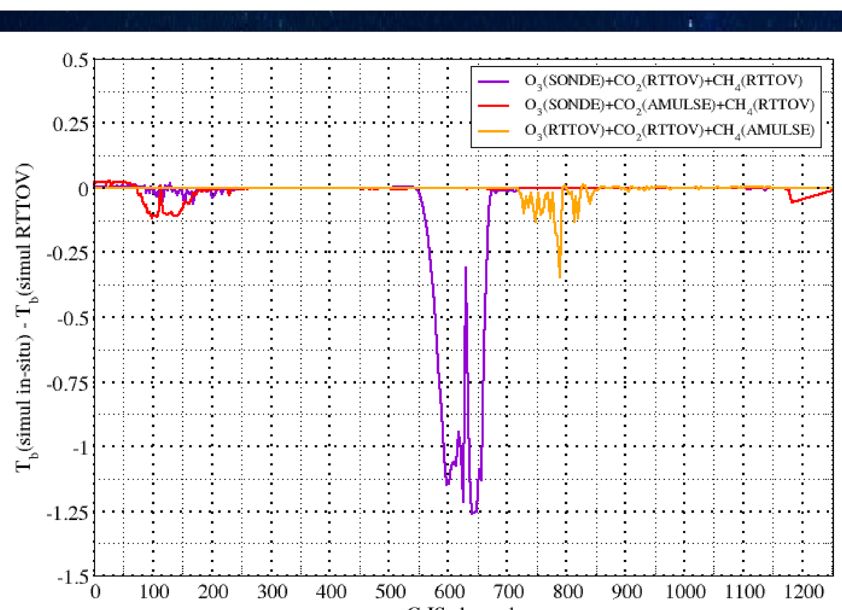


Figure 3. Difference between simulated brightness temperature with O_3 (CO_2 or CH_4) rp *in-situ* vertical profile from SONDE or AMULSE and simulated brigtness temperature with (O_3, CO_2 and CH_4) from Climatology RTTOV for radiosounding at 20171115 – 09 or 12 UTC collocated with CrIS pixels.

Sensitivity of simulations:

$T_b^{simul}[O_3^{SONDE}, CO_2^{CLIM}, CH_4^{CLIM}] - T_b^{simul}[O_3^{CLIM}, CO_2^{CLIM}, CH_4^{CLIM}]$

$T_b^{simul}[O_3^{CLIM}, CO_2^{AMULSE}, CH_4^{CLIM}] - T_b^{simul}[O_3^{CLIM}, CO_2^{CLIM}, CH_4^{CLIM}]$

$T_b^{simul}[O_3^{CLIM}, CO_2^{CLIM}, CH_4^{AMULSE}] - T_b^{simul}[O_3^{CLIM}, CO_2^{CLIM}, CH_4^{CLIM}]$

- Sensitivity of simulations to *in-situ* O_3 information come from SONDE compared to O_3 information come from RTTOV around -1.25 K in ozone band and a less sensitivity in CO_2 band.

- Sensitivity of simulations to *in-situ* CO_2 information come from AMULSE compared to CO_2 information come from RTTOV around -0.125 K in CO_2 band between 645 and 707.25 cm^{-1}.

- Sensitivity of simulations to *in-situ* CH_4 information come from AMULSE compared to CH_4 information come from RTTOV around -0.25 K in CH_4 band between 819.75 and 857.25 cm^{-1}.

Figure 2.a show O_3 *in-situ* vertical profile come from ozone-sonde (violet) and Climatology RTTOV (green) with respect pressure in log scale. Differences between both informations are in troposphere and especially in UTLS.

We observe a large differences between CO_2 *in-situ* vertical profile come from AMULSE (red) and Climatology RTTOV (green) with respect pressure (around 50 ppm at 20 hPa), in Figure 2.b in troposphere and lower stratosphere.

Figure 3.c also show difference between in-situ CH4 come from AMULSE (orange) and Climatology RTTOV (green) with respect pressure (around 0,5 ppm) in troposphere and lower stratosphere.

It is important to note that we have not data above 7 hPa for three three radiosoundings as measurements are made under weather balloons. Then, we carried out polynomial projection between *in-situ* and climatological profiles. Thermodynamic data come from global model ARPEGE (Numerical Weather Prediction in Météo-France).

IV – Improvement of simulated T_b and chemistry retrievals – Ozone case:

1 – Using IASI pixels:

Selection of IASI clear-sky pixel collocated with radiosounding of APOGEE campaign summer season (20170601 – 10UTC) in Reims, France (see Figure 4).

Difference between real IASI observation and simulated IASI observation in Figure 5, show that using ozone *in-situ* is better than ozone *a priori* from MOCAGE and CAMS to simulate IASI radiances. Figure 6 show ozone *in-situ* vertical profile (a and b), ozone *a-priori* vertical profile from MOCAGE (a) and CAMS (b) and ozone retrievals using **1D-Var** method assimilation come from **[Coopmann et al. in poster 8p.09]** assimilating 123 operational + 15 ozone-sensitive IASI channels using diagnosed observation error covariance matrix with ozone in the control variable. Both experiments use in this study thermodynamic data from global model ARPEGE (Numerical Weather Prediction in Météo-France).

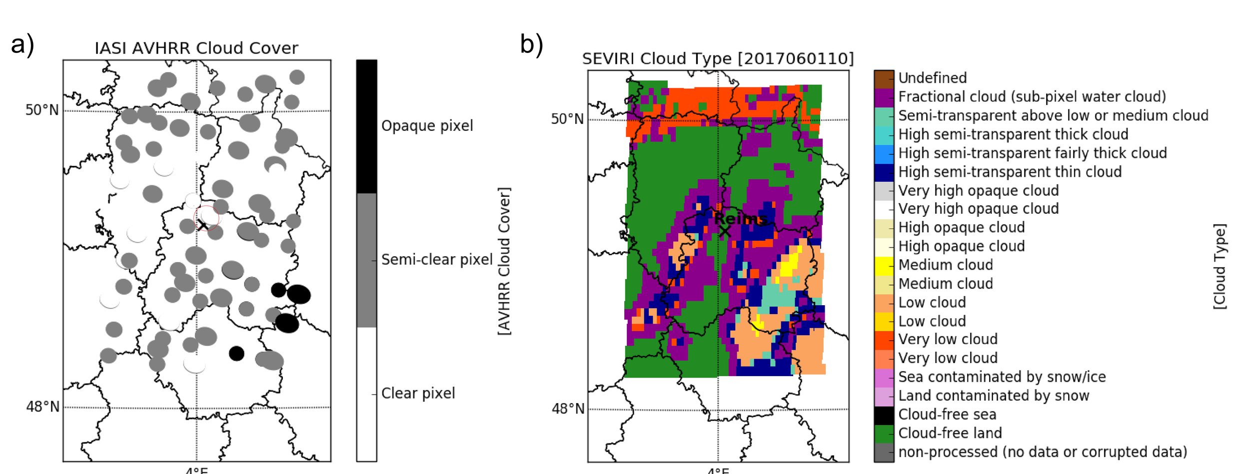


Figure 4. IASI AVHRR (Advanced Very High Resolution Radiometer) Cloud Cover (a) and SEVIRI Cloud Type (b) around radiosounding in Reims, France at 20170601 – 10 UTC.

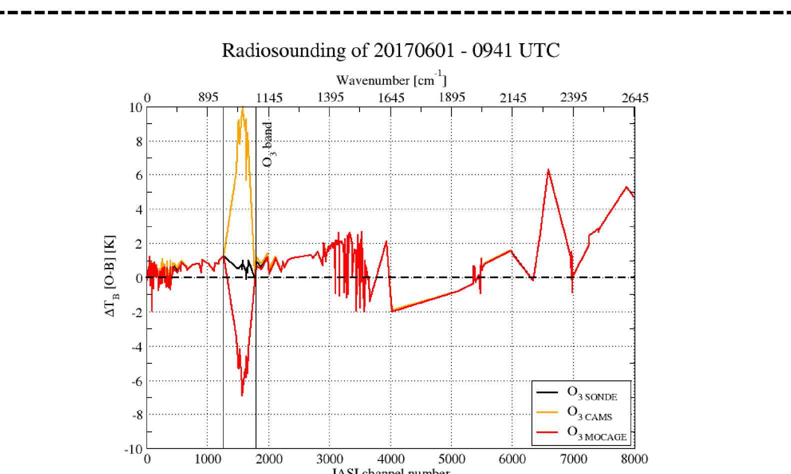


Figure 5. Difference between real IASI observation and simulated IASI observation using ozone information from SONDE, CAMS and MOCAGE with respect to IASI channel number for radiosounding of 20170601 – 10 UTC.

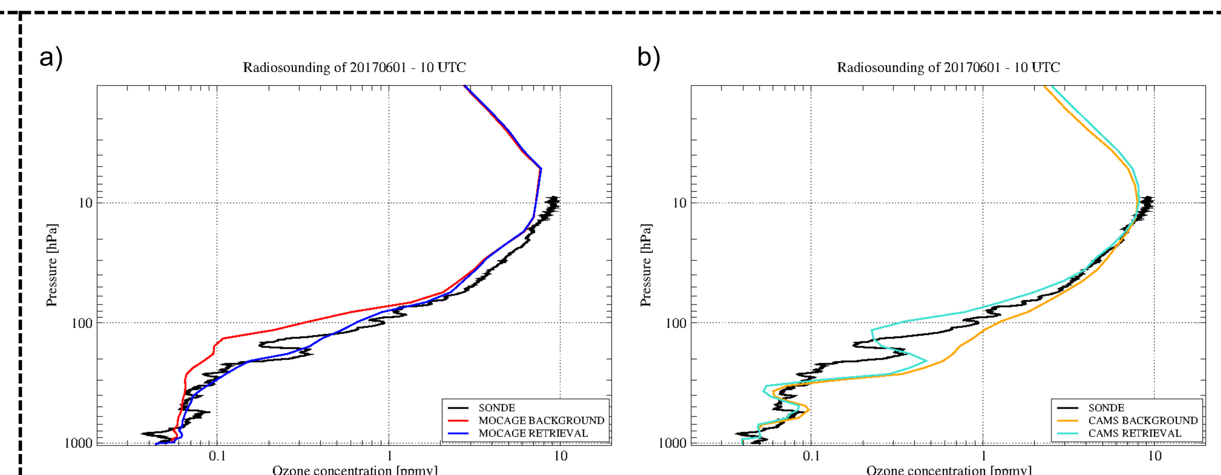


Figure 6. Ozone *in-situ* vertical profile (**black**) (a and b), ozone *a-priori* vertical profile from MOCAGE (red) (a) and CAMS (orange) (b) and ozone retrievals using ozone information from MOCAGE (blue) (a) and CAMS (turquoise) (b) with respect to pressure for radiosounding of 20170601 – 10 UTC.

2 – Using CrIS pixels:

Selection of CrIS clear-sky pixel collocated with radiosounding of APOGEE campaign summer season (20170704 – 02UTC) in Reims, France (see Figure 7).

In the same way of previously, difference between real CrIS observation and simulated CrIS observation in Figure 8, show that using ozone *in-situ* is better than ozone *a priori* from MOCAGE and CAMS to simulate IASI radiances. Figure 9 show ozone *in-situ* vertical profile (a and b), ozone *a-priori* vertical profile from MOCAGE (a) and CAMS (b) and ozone retrievals using **1D-Var** method assimilating 68 operational + 13 ozone-sensitive CrIS channels using diagonal observation error covariance matrix with ozone in the control variable. Both experiments use in this study thermodynamic data from global model ARPEGE (Numerical Weather Prediction in Météo-France).

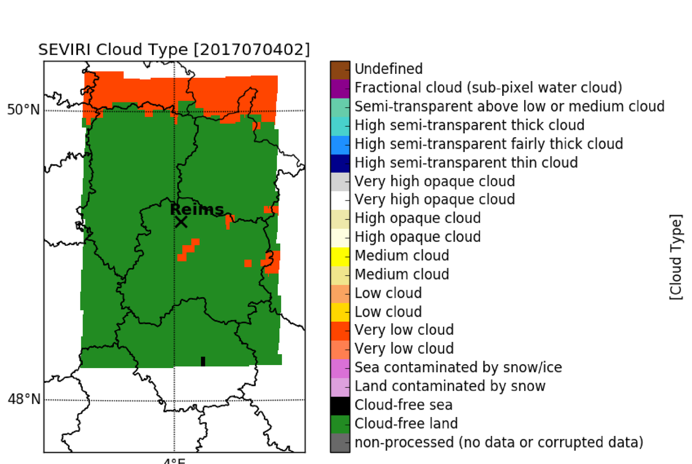


Figure 7. SEVIRI Cloud Type around radiosounding in Reims, France at 20170704 – 02 UTC.

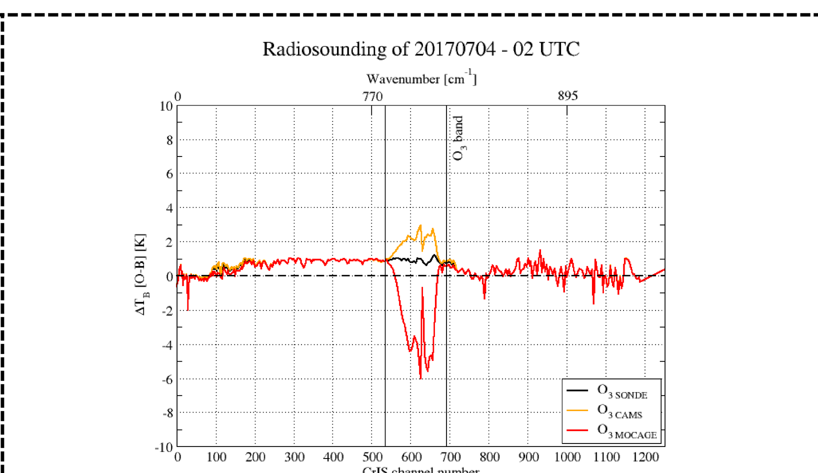


Figure 8. Difference between real CrIS observation and simulated CrIS observation using ozone information from SONDE, CAMS and MOCAGE with respect to CrIS channel number for radiosounding of 20170601 – 10 UTC.

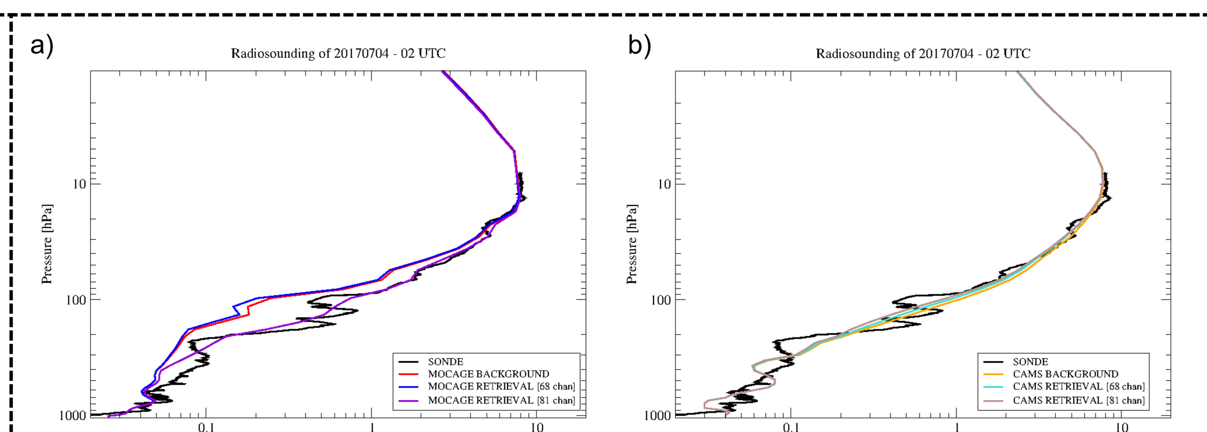


Figure 9. Ozone *in-situ* vertical profile (**black**) (a and b), ozone *a-priori* vertical profile from MOCAGE (red) (a) and CAMS (orange) (b) and ozone retrievals using ozone information from MOCAGE (blue) (a) and CAMS (turquoise) (b) by assimilating 68 operational CrIS channels, ozone retrievals using ozone information from MOCAGE (purple) (a) and CAMS (brown) (b) by assimilating 68 operational + 13 ozone-sensitive CrIS channels with respect to pressure for radiosounding of 20170601 – 10 UTC.

These 1D-Var experiments show the importance of assimilating ozone-sensitive channels with ozone in the control variable to improve chemical retrievals compared to *a-priori* profile.

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V – Conclusions and Perspectives:

The new technology developed in AMULSE allows us to measure atmospheric vertical profiles of (CO_2, CH_4, Water Vapour) to assess infrared satellite observations. These *in-situ* chemical profiles allows to evaluate chemical retrievals. This is the first step of use to APOGEE campaign data, with encouraging results for ozone allows a good representation of physico-chemical process in UTLS. These improvement can be help Chemistry Transport Model. The next observing periods will take place in winter and spring. [Coopmann et al. submitted to Journal of Geophysical Research Atmosphere]

Reference : *Maamary, Rabih, et al. "" Atmospheric Measurements by Ultra-Light SpEctrometer"(AMULSE) dedicated to vertical profile measurements of greenhouse gases (CO2, CH4) under stratospheric balloons: instrumental development and field application." EGU General Assembly Conference Abstracts. Vol. 18. 2016.*