Towards a strengthening of the coupling of NWP and CTM to improve the retrieval of thermodynamic fields from infra-red passive sounders: the ozone case

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I – Current context at Météo-France:

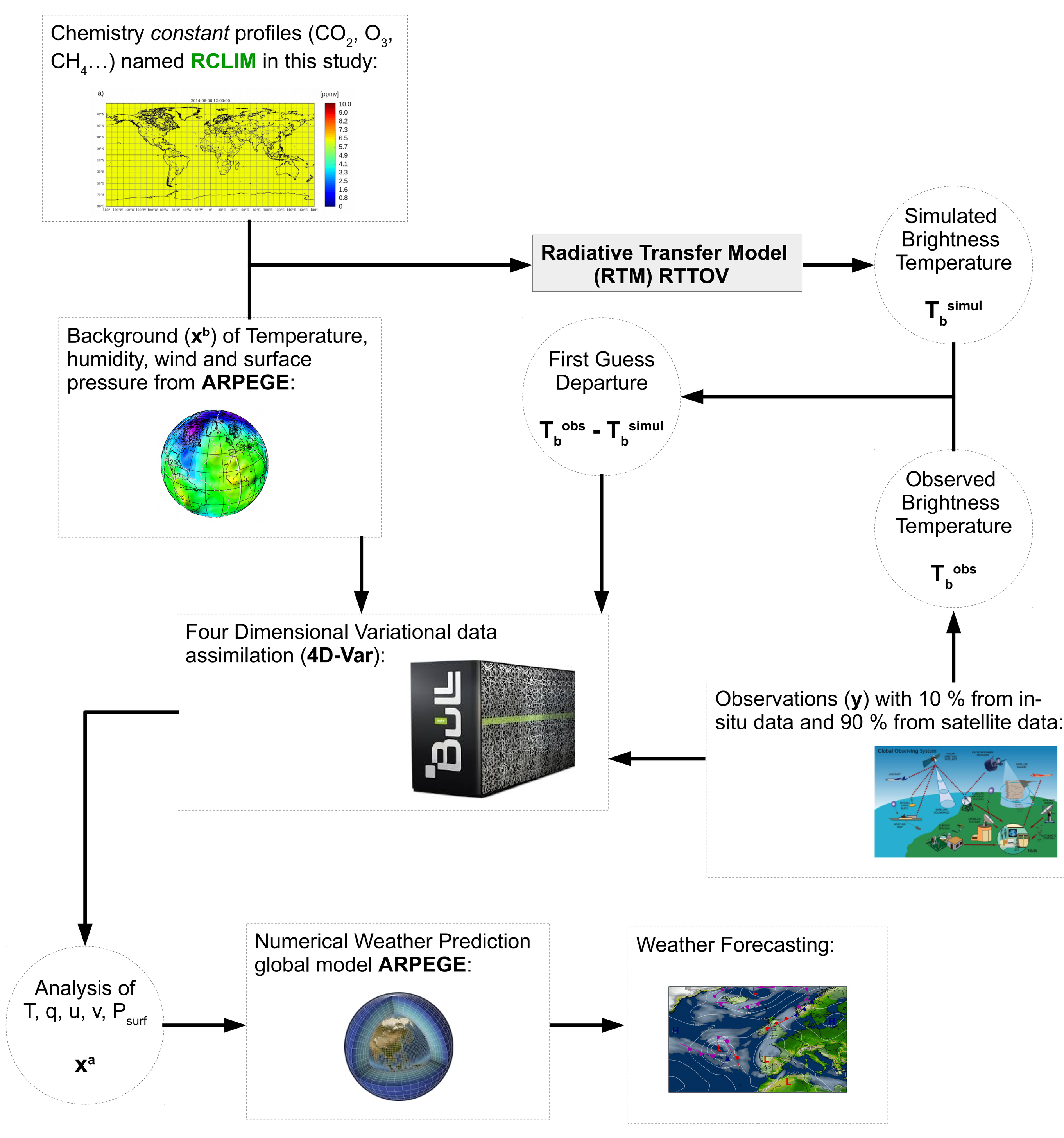


Figure 1. Simplified cheme of Numerical Weather Prediction system at Météo-France.

● Hyper-spectral infra-red sounding instruments, such as the Atmospheric Infra-red Sounder (AIRS), the Infra-red Atmospheric Sounding Interferometer (IASI) and the Cross-Track Infra-red Sounder (CrIS), provide 70 % of the data used in the NWP global model ARPEGE (Action de Recherche Petite à Échelle Grande à Échelle) of Météo-France (IASI-A and IASI-B alone account for 46 %). IASI was jointly developed by CNES (Centre National d'Études Spatiales) and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites). Its spectrum ranges from 645 to 2760 cm^{-1} with a spectral sampling of 0.25 cm^{-1} and a spectral resolution of 0.5 cm^{-1} leading to a set of 8461 radiances at the top of the atmosphere. This sounder allows to obtain indirect information on temperature and humidity profiles and also on cloud cover, aerosols, atmospheric chemistry compounds such as O_3, CO_2, CO, CH_4, HNO_3 and N_2O and surface properties.

● In this work, we first consider a channel selection that was performed by [Collard, 2007] for NWP purposes. Channels were mainly chosen in the CO2 long wave (LW) band (for temperature retrievals), in the atmospheric window region and in the water vapour (WV) band. This selection of 300 channels also included 15 ozone-sensitive channels. CNES added 14 other channels for monitoring purposes. This subset of 314 channels is routinely monitored at Météo-France and up to 123 channels are assimilated in operation (99 temperature channels in the LW CO2 band, 4 window channels and 20 WV channels) [see Fig 2].

● The objective of the present study is to improve thermodynamic and chemistry retrievals from IASI data using realistic ozone information, adding 15 IASI ozone-sensitive channels available at Météo-France [see Fig 2 and 3] and adding ozone in the control variable. We carried out experiments in a One Dimensional Variational data assimilation (1D-Var). The realism of two different ozone information is assesed, viz a climatology from RTTOV model (Radiative Transfer for TOVS) hereafter referenced as **RCLIM** and an ozone field, provided by the French Chemistry Transport Model (CTM) MOCAGE (Modèle de Chimie Atmosphérique à Grande Échelle) hereafter referenced as **MOC60L** [see Fig 4].

➢ Which sensitivity of simulations to ozone informations?

➢ Which impact of IASI ozone-sensitive channels and ozone in the control variable to 1D-Var data assimilation?

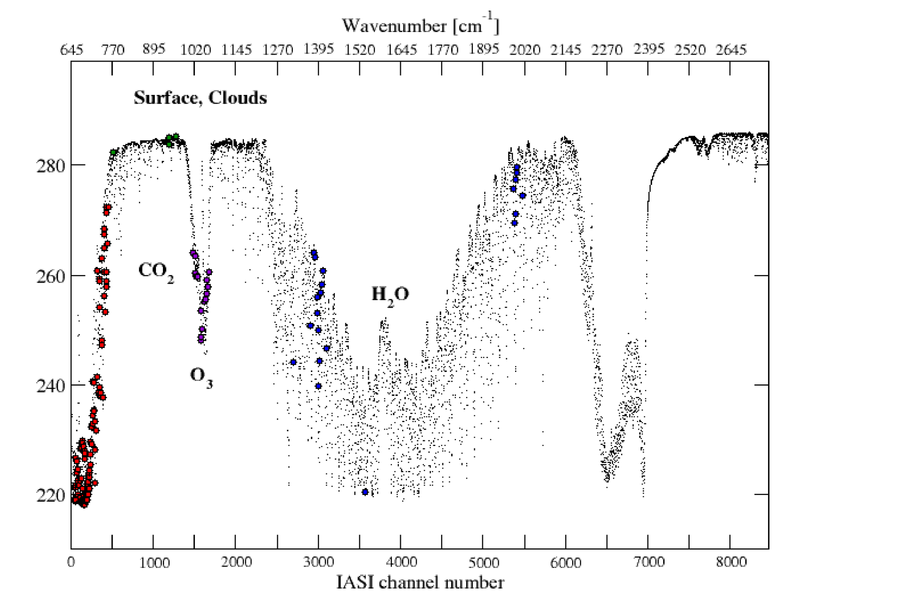


Figure 2. IASI spectrum up to 123 channels assimilated in operation + 15 ozone-sensitive channels among the 314 channels monitored at Météo-France.

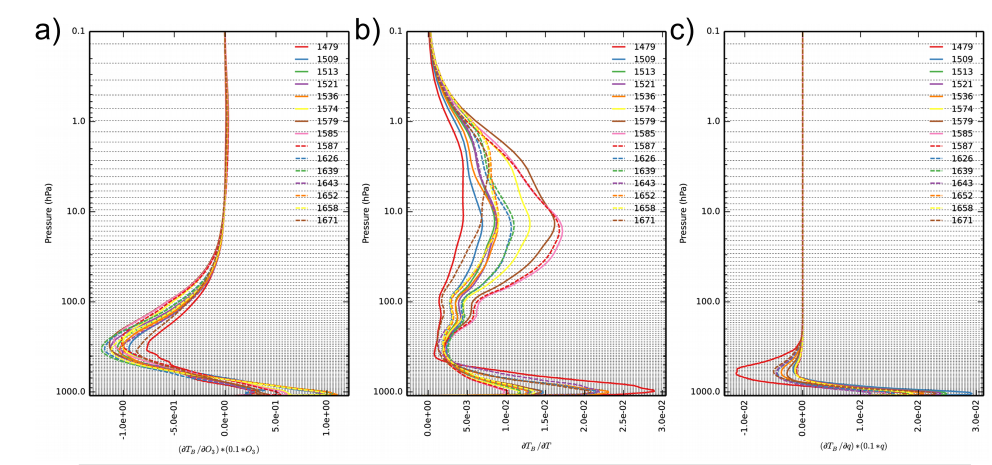


Figure 3. Jacobians of ozone (a), temperature (b) and humidity (c) for 15 IASI ozone-sensitive channels range from 1014.5 to 1062.5 cm^{-1}.

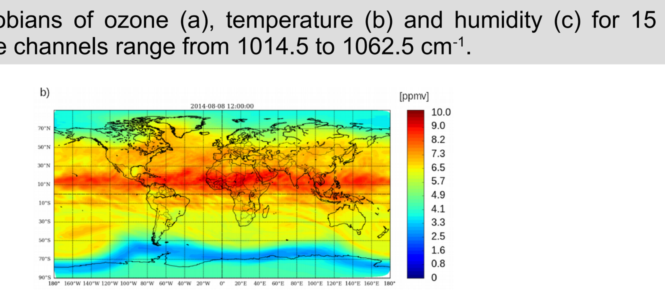


Figure 4. Example of ozone field at a particular level pressure (20 hPa) for MOC60L on 2014-08-08 at 12 UTC.

II – Sensitivity of simulation to ozone informations:

II-1 Methodology:

● Two experiments carried out on a one year period from April 2014 to March 2015 with 161 IASI clear-sky pixels on the see collocated with 161 radiosoundings (T, q and O_3) among 3 latitude bands (Poles, Mid latitudes and tropics) [see fig 5].

● The sensitivity of brightness temperature simulations to both **RCLIM** and **MOC60L** ozone fields is assessed. Temperature, humidity and surface parameters are taken from ARPEGE. The scan geometry comes from IASI observations. Average and standard deviation of brightness temperature differences between IASI observations and simulations [T_b^{obs} - T_b^{simul}], which represents the First Guess Departure, are displayed in Figure 6.

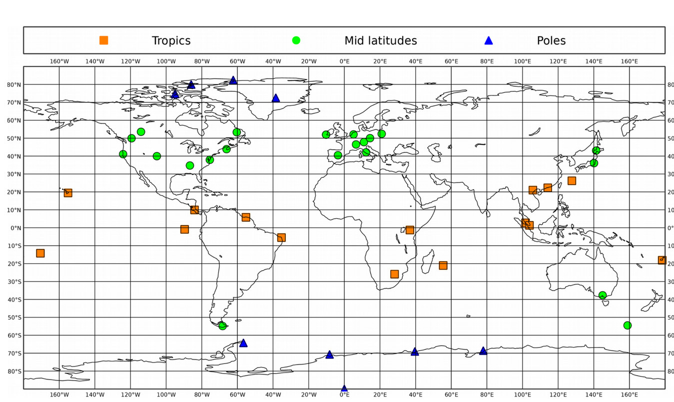


Figure 5. Stations of radiosounding from (WOUDC, SHODOZ and NOAA) networks by latitude bands (Poles, Mid latitudes and Tropics.

II-2 Results:

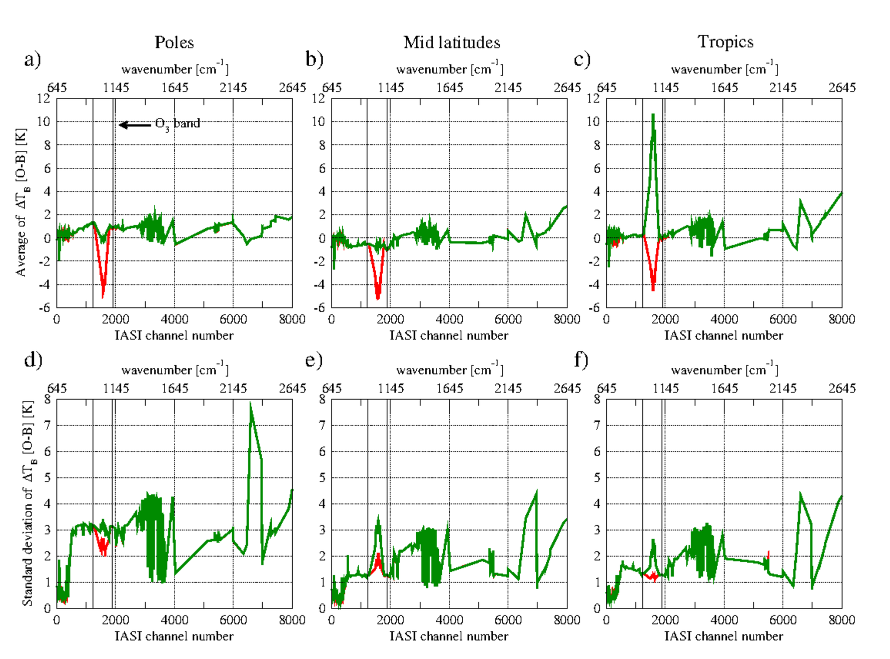


Figure 6. Average (first row) and standard deviation (Second row) of brightness temperature (BT) differences between real observations and simulations [O-B] with RCLIM (green line) and MOC60L (red line) ozone fields for IASI channels for the Poles (a and d), the Mid latitude (b and e) and the Tropics (c and f) with respect to IASI channel number and wavenumber (operational 314-subset).

● Differences are mainly located in the ozone band between 1014.5 and 1062.5 cm^{-1}. A consistent bias for MOC60L with values around -5 K over all regions is observed. On the other hand the RCLIM ozone bias remains low over the Poles (-0.2 K) and the Mid latitudes (-0.4 K) but is very high over the Tropics around 10 K. This bias is explained by an erroneous representativeness of the RCLIM ozone fields over the Tropics. RCLIM standard deviations for the ozone band are relatively similar over the Poles (Figure 6.d) and the Mid latitude (see Figure 6.e), with values around 3.5 K. Over the Tropics (see Figure 6.f) a lower bias around 2.5 K is found. The CO_2 channels appear to be sensitive to ozone between 650 cm^{-1} and 800 cm^{-1}. Inaccurate surface temperature possible presence of the sea-ice over the Poles may lead to higher standard deviations. At all latitudes, MOC60L low standard deviation values are a signature of a better representativeness of the variability than RCLIM.

III – 1D-Var data assimilation experiments:

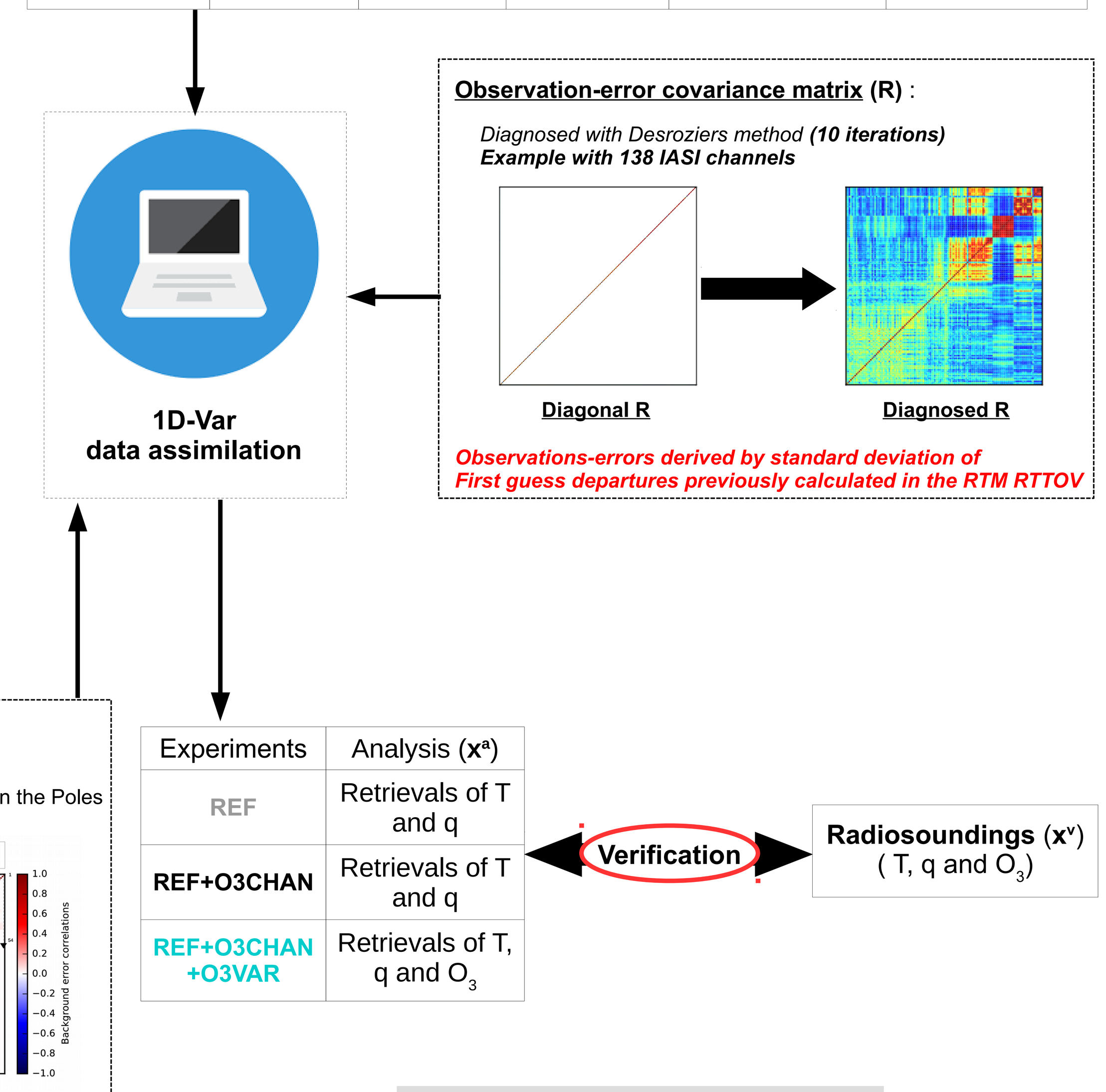
III-1 Methodology:

● One 1D-Var assimilation experiment, REF, with 123 IASI channels using the background (x^b), observation (**y**) data and background-error covariance matrix **B** was carried out following the operational Météo France 4D-Var assimilation scheme expected for the observation-error covariance matrix **R**. Indeed, we have calculated a diagnosed **R** matrix using [Desroziers et al., 2005] method with initial variances from the observation-errors (σ^{simul}) derived by standard deviation of first guess departures previously calculated in the RTM RTTOV.

● These revised matrices can be used for a new series of 1D-Var (a sketch of this implementation is given in Figure 7). This iterative method provides an updated version of the observation-error covariance matrix **R**. A set of 10 diagnostic iterations has been carried out. The updated **R** matrix allows to calculate a new analysis $\mathbf{x}^a$.

● Then, we have carried out two experiments with operational channels + 15 IASI ozone-sensitive channels named **REF+O3CHAN** and in addition ozone in the control variable named **REF+O3CHAN+O3VAR**.

	Observation (y)		Background (x^b)		
Experiments	IASI Operational channels	IASI ozone-sensitive channels	Ozone informations	Thermodynamic informations	Ozone in the control variable
REF	123		RCLIM or MOC60L	ARPEGE	
REF+O3CHAN	123	15	RCLIM or MOC60L	ARPEGE	
REF+O3CHAN +O3VAR	123	15	RCLIM or MOC60L	ARPEGE	



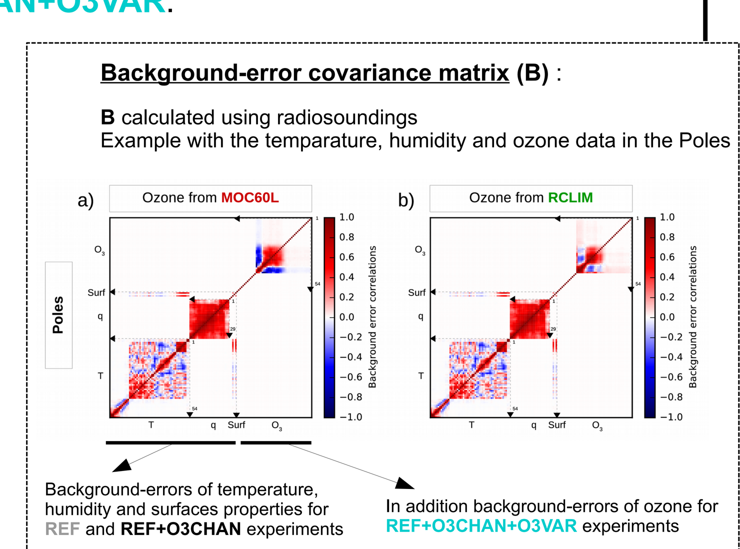


Figure 7. Scheme of 1D-Var methodology.

III-2 Results:

● Both the impacts of adding ozone-sensitive channels and including the ozone concentration in the control variable of the 1D-Var are evaluated. Figure 8 shows the relative improvement brought by **REF+O3CHAN** and **REF+O3CHAN+O3VAR** (**O3VAR** = ozone retrieved in addition to temperature and humidity) compared to REF for temperature with respect to pressure up to 10 hPa and humidity with respect to pressure up to 100 hPa using ozone information from **MOC60L** or **RCLIM**. These statistics have been calculated for the 161 profiles and for the same period as previously. Negative values mean that retrievals from **REF+O3CHAN** or **REF+O3CHAN+O3VAR** are worse than REF (-). Conversely, positive values mean that retrievals from **REF+O3CHAN** or **REF+O3CHAN+O3VAR** are better than REF (+).

● Almost the same results are observed with RCLIM ozone information (Figure 8.c) for retrievals from **REF+O3CHAN** except in the lower troposphere. A relative improvement for humidity from **REF+O3CHAN** retrievals using MOC60L ozone information compared to REF is observed. Results in Figure 8.b show improvements and degradations. A large degradation of retrievals from **REF+O3CHAN** compared to REF around 200 and 300 hPa with RCLIM ozone information is noticed in Figure 8.d. These results for **REF+Q3CHAN** experiments compared to REF show that adding ozone-sensitive channels leads to gain information on atmospheric levels which are not probed by operational channels. But, we note that improvement induced by the 15 IASI ozone-sensitive channels may also need realistic ozone information such as MOC60L from CTM MOCAGE because a non-realistic ozone field such as RCLIM, can aliase into error on temperature or humidity retrievals.

● In **REF+O3CHAN+O3VAR** experiment, ozone was added to the control variable using the new background error covariance matrix. A positive impact of **REF+O3CHAN+O3VAR** compared to **REF+O3CHAN** for temperature and humidity is noticed. Indeed, having ozone in the control variable allows to gain more potential of information from 15 IASI ozone-sensitive channels. There is no significant improvement using ozone either in MOC60L or RCLIM. Whatever the ozone a priori information, ozone in the control variable allows to minimize ozone sensitive channels throughout the assimilation process. Ozone-sensitive channels are more efficient when ozone is added to the control variable for improving the thermodynamic retrievals.

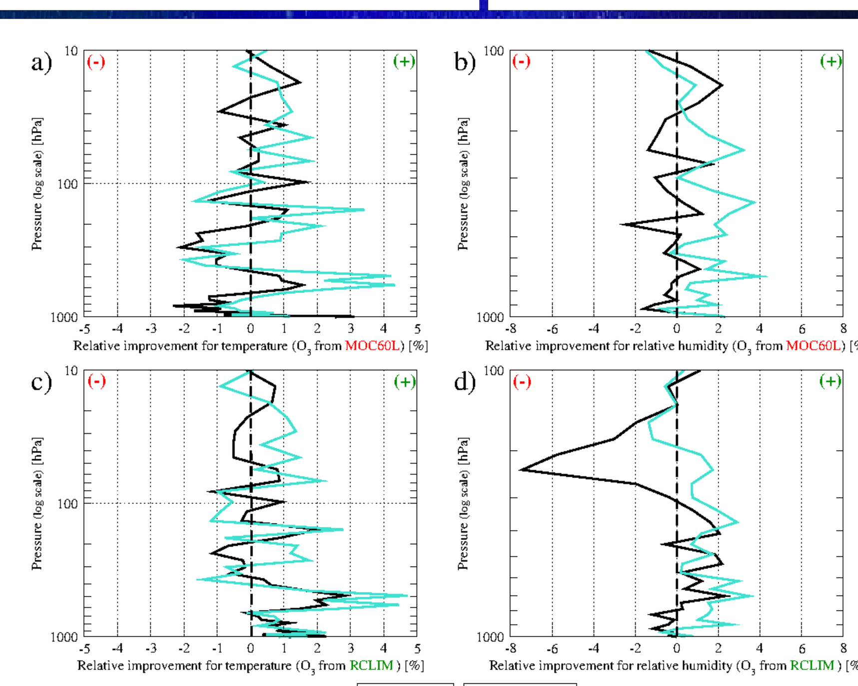


Figure 8. Relative improvement between **REF+O3CHAN** (black lines) and **REF+O3CHAN+O3VAR** (turquoise lines) experiments with respect to pressure until 10 hPa with ozone information from MOC60L for temperature (a) and humidity (b); and with ozone information from RCLIM for temperature (c) and humidity (d).

● To summarize the results of the main experiments, Table 1 shows the percentage of the averaged error reduction weighted by the number of profiles for temperature AVG_T , humidity AVG_Q and AVG_{O3} :

O_3 from	MOC60L			RCLIM		
[%]	AVG_T	AVG_Q	AVG_{O3}	AVG_T	AVG_Q	AVG_{O3}
REF	- 2,51 %	- 5,15 %		- 2,48 %	- 5,07 %	
REF+O3CHAN	- 2,37 % (↓ 0,14 %)	- 5,67 % (↑ 0,52 %)		- 2,83 % (↑ 0,35 %)	- 4,48 % (↓ 0,59 %)	
REF+O3CHAN +O3VAR	- 2,63 % (↑ 0,12 %)	- 6,22 % (↑ 1,07 %)	-0.59%	- 2,82 % (↑ 0,34 %)	- 6,07 % (↑ 1,00 %)	-0.17%

IV Conclusions and future work:

● The prime aim of this study was to add information on atmospheric composition for the assimilation of radiances from the IASI infrared sounder in the global NWP model ARPEGE (which uses some gases that do not vary neither in time nor in space in operations). This study has shown that using a realistic ozone information from CTM into RTM allows to better simulate IASI radiances and thus to diagnose more optimal observation errors σ_{simul} compared to those used operationally.

● More precisely, we wanted to improve thermodynamics retrievals and forecasts by the addition of ozone sensitive channels. At present, Météo-France 4D-Var (Four dimensional variational data assimilation) assimilation system uses only 123 IASI channels out of 314 possible. We have investigated within a simplified framework such as the one dimensional variational data assimilation. Indeed, 1D-Var is a common method used in research because of its low computing cost.
It is already interesting to use diagnosed observation errors within a diagonal observation-error covariance matrix. The use of a more optimal observation-error covariance matrix calculated from the Desroziers method shows an additional improvement of thermodynamic retrievals with 123 operational channels. The addition of 15 ozone sensitive channels provides information on the lower troposphere and the stratosphere previously uncovered in temperature and humidity.

● The impact of the 15 additional ozone-sensitive channels varies with the ozone information. AVGQ values in **REF+O3CHAN** using MOC60L are improved, less so for AVGT ones, but it is the reverse for **REF+O3CHAN** using RCLIM. As temperature and humidity are affected when ozone is absent from the control variable, its addition the **REF+O3CHAN+O3VAR** experiment improved both AVGT and AVGQ . The ozone changes during the assimilation process allow to correct the error of ozone fields and avoid aliasing ozone error information on temperature or humidity. Retrievals improve by about **2.5 %** for temperature and **6 %** for humidity compared to background. In addition, we note a improvement by about **0.6 %** for ozone using a prior ozone information from MOC60L and **0.2 %** using ozone from RCLIM compared to background. Using observation errors from simulations combined with the Desroziers' diagnostic method, plus the addition of ozone-sensitive channels and ozone in the control vector lead to improved thermodynamic retrievals.

An article about this study has been submitted to ***Journal of Geophysical Research Atmosphere***.

● It may be more efficient to identify other sensitive channels from the 8461 available channels and this paves the way to similar studies with future sensors such as IASI-NG, [Crevoisier et al., 2014] which will have 16921 channels. Furthers studies should include CO_2, CH_4 , N_2O and many more.

● Furthermore, we started to assess the impact of additional ozone-sensitive channels using ozone information from MOCAGE and add the ozone in the ARPEGE 4D-Var control variable. The same approach as in the 1D-Var experiment is used. The first step of results are very promising and will be the subject of an upcoming article.

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