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Consolidation of Scientific Baseline for MTG-IRS Processing: Effect of Trace Gases

Executive summary

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Consolidation of Scientific Baseline for MTG-IRS Processing: Effect of Trace Gases: Executive summary

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1. Introduction

The hyperspectral infrared sounder (IRS) is one of the instruments considered in the phase B MTG activities. The main objective of this instrument is to provide frequent information on the atmospheric temperature, humidity and also wind profiles based on measurements of upwelling radiances at the top of atmosphere in two spectral bands: 700 – 1210 cm^{-1} and 1600 and 2175 cm^{-1}. A secondary objective that is also explored concerns the utility of the instrument to provide information concerning atmospheric pollution, namely the concentrations of trace gases such as CO and O_3.

In the current phase of activities, a prototype processor is being developed in order to demonstrate with the help of proxy data that the objectives set by the users for the IRS instrument can be met. The objective of the study carried out by NOVELTIS in collaboration with LATMOS and ULB was to explore the impact of trace gases on the retrieval of H_2O and temperature and to propose an optimal retrieval strategy.

The work in this project was organised in three separate phases. In **Phase I**, the question of proxy data used for inversions was addressed. A brief review of proxy datasets existing at EUMETSAT was done and recommendations were issued concerning specifications for generation of a proxy data set allowing testing the impact of trace gases on the retrieval of T/H_2O. In **Phase II** a database with a small number of representative atmospheric conditions was used in order to analyse the need to include trace gas retrievals in the main L2 processor to derive state vectors within accuracy required by the users. In addition, a recommendation was made on the strategy of retrieval of T and H_2O in the presence of trace gases. This strategy was tested in **Phase III** on proxy data describing a situation with a strong perturbation of O_3 in the upper troposphere caused by a tropopause folding event.

2. Specification of Proxy Data for testing the impact of trace gases on the retrieval of T/H2O (Phase I)

The MTG-IRS proxy data existing at EUMETSAT consist of spectra that were simulated for conditions corresponding to atmospheric and surface conditions obtained with the help of regional (WRF, MetOffice regional model) and global (ECMWF) meteorological models. These models do not contain chemistry transport modules for simulating trace gases and thus the radiative transfer simulations were done without considering coupling between meteorological and chemical variables.

In order to test the impact of trace gases on the retrieval of T and H_2O it is necessary to consider this coupling and have profiles of trace gases that are coherent with variables calculated by the meteorological models. Such coupling can be simulated with the help of chemistry transport models forced by the meteorological fields used for radiative transfer calculations.

The specifications for generation of proxy data examined in this study considered three stages of the simulation process:

1. the simulation of the geophysical state with surface and atmospheric variables;
2. the simulation of the MTG-IRS spectra with a radiative transfer model;
3. and specification of the statistical errors (in the form of error covariance matrices) of the surface and atmospheric variables as well as the *a priori* and first guess for the variables to be retrieved. These data are necessary to have a complete proxy data set for the inversions.

Particular attention is paid to the point 1 above. Various aspects for the specifications of the geophysical state were considered: importance of coupling of the chemistry transport models with meteorological models, horizontal and vertical resolution, frequency of output, list of variables, source inventory used in simulations, as well as a size of the region, period and length of the simulations.

3. Sensitivity Analysis Phase (Phase II)

The main objective of this phase was to provide recommendations on the retrieval method of temperature and H_2O in the presence of CO and O_3. The tool used for this analysis was the NOVELTIS 1 dimensional variational inversion tool. In particular the tool was used to perform information content analysis for the different retrieval strategies used. This method allows computing of the theoretical error reduction related to the retrieval process.

The information content analysis was performed for four different scenarios:

- reference case, for which only the surface temperature and profiles of temperature and H_2O are inverted. The impact of CO and O_3 is calculated only through the transport of *a priori* climatological errors of CO and O_3.
- ideal case, with prior errors on CO and O_3 set to zero.
- combined retrieval, in which CO, O_3, T and H_2O are retrieved in a one step inversion.
- sequential retrieval in which CO and O_3 are inverted in a first step retrieval (with transport of *a priori* errors of temperature and H_2O), and then surface temperature, and profiles of H_2O/T are inverted in the second step by using the reduced errors on CO and O_3.

The tests were performed on a small set of 10 IRS-MTG spectra simulated with 4AOP radiative transfer model for a wide spectrum of atmospheric conditions over north-western Europe (cases over land and sea, in winter and summer, with and without surface pollution, with and without boundary layer temperature inversions, and with and without CO and O_3 anomalies). The chemical profiles were generated by KNMI with the TM5 chemical transport model (version with a 1°x1° zoom) forced by ECMWF meteorological analysis.

The comparison of the reference case and the ideal case allows estimating the impact of trace gases on the T/H_2O retrieval error:

- This impact is weak (0.1K for T and 0.0001 VMR for H_2O) (figure 1)., but non negligible, especially if these errors correspond to a systematic bias. The O_3/CO induced errors are one order of magnitude weaker than the temperature and H_2O error retrievals, and as shown by additional tests, are also weaker than the impact of surface emissivity error.
- The impact of CO/O3 on T/H2O was shown to be small independent of the hypotheses on T/H_2O prior knowledge (two error-covariance matrices mere used: NWP Forecast and climatology).
- The impact of CO/O_3 on water vapour is not direct, as shown by the small impact of CO/O_3 on the H_2O information content (DOFS). The observed impact of CO/O_3 on H_2O retrieval error is induced by the retrieval error correlation between H_2O and temperature.

In the combined retrieval, the risk of bias in the retrieval due to erroneous prior CO/O_3 knowledge is removed, but our results show that the statistical error remains at the same level as for the reference case. The statistical error could be decreased by considering proper cross correlation errors between T/H_2O and

CO/O_3 in background covariances, however these correlations are not available, and are strongly case dependent.

The alternative strategy is the sequential retrieval which shows a small improvement in T/H_2O errors for certain cases as compared with the reference case. This approach offers a good compromise: a way for reducing/removing the impact of CO/O_3 on the T/H_2O retrieval without the need of having proper cross correlations between *a priori* errors on T/H_2O and O_3/CO. This method was recommended for the tests in the Evaluation Phase (more detailed analysis is given at the end of this document).

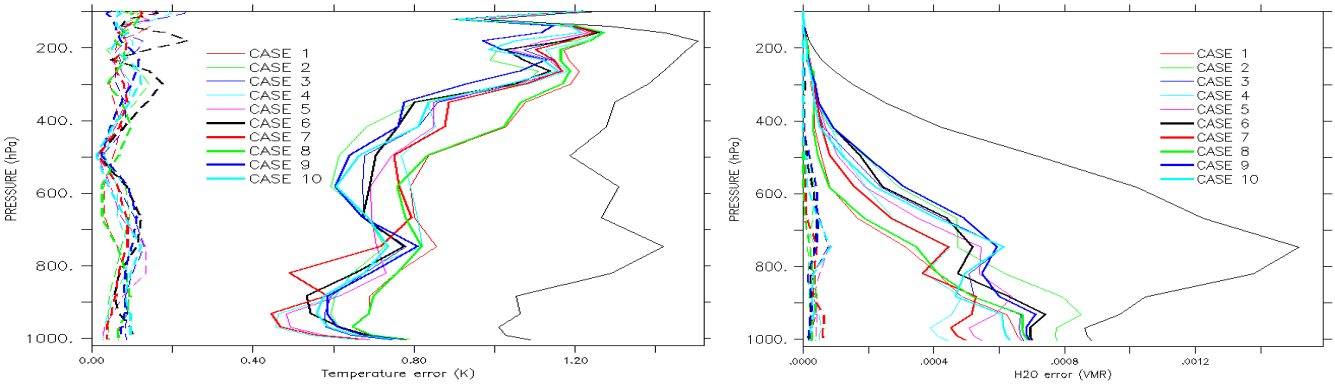

Figure 1 : Black solid curve: prior errors for temperature (left figure) and H_2O (right figure). Remaining solid curves: total posterior errors for 10 geophysical cases. Dashed curves: Absolute contribution due to the impact of CO and O_3 uncertainties on the total retrieved profile errors.

4. Evaluation Phase (Phase III)

In this section we have analysed the impact of O_3 on the retrieval of temperature and water vapour for an atmospheric scenario containing a strong O_3 perturbation in the UTLS region caused by a tropopause folding event. We have chosen to focus on the O_3 perturbations, shown in figure 2, as the impact of O_3 is likely to be stronger than that of CO.

To better quantify the impact of the O_3 perturbation on T and H_2O retrievals, we have considered four different retrieval scenarios. Scenario 1 (perfect knowledge of O_3: errors set to zero and first guess equal to true profile) is the reference scenario against which other scenarios are compared. In Scenario 2, climatological O_3 profile was used as first guess and the O_3 error covariance matrix was set to 0. Scenario 3, in which climatological O_3 *a priori* and covariance matrix are used and Scenario 4, which is the sequential case (O_3 from first step sequential inversion), allow evaluating the potential benefit of the sequential approach. Channel selection was not applied in the retrieval of T and H_2O in these scenarios.

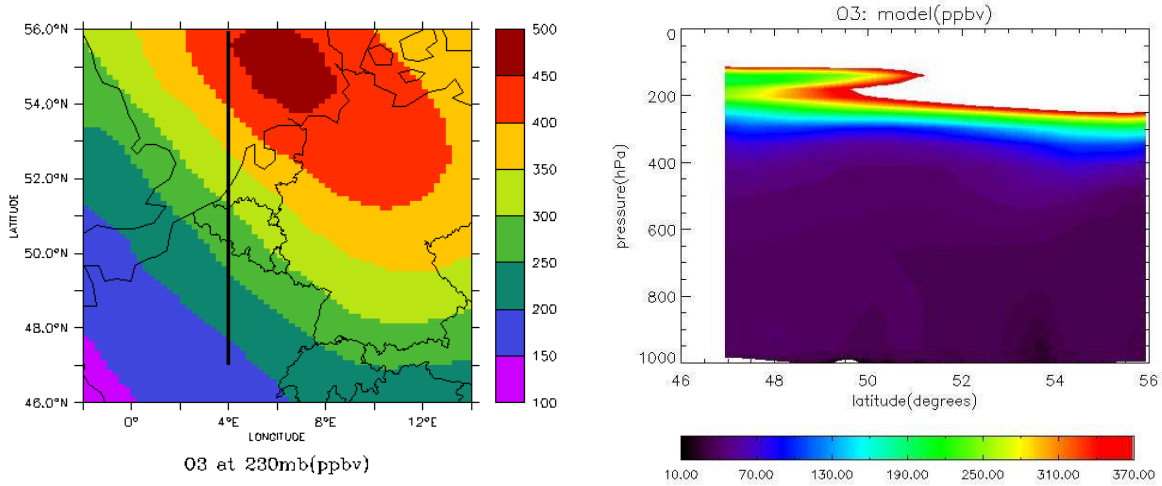

Figure 2 : Plots of O_3 (ppbv) simulated with the KNMI/CHIMERE models. Left figure: distribution of O_3 at 230mb for January 7, 2008 at 22H UTC. The solid line corresponds to the vertical cross section that indicates the 73 profiles for which the inversions are done in Phase III. Right figure: vertical cross section for O_3 corresponding to the location indicated by the black line in the figure on the left.

For the scenarios 1, 3 and 4 and below about 300 hPa, the mean retrieval bias for temperature and water vapour is small. Above 300 hPa, the bias increases and it reflects the lower sensitivity of the MTG-IRS spectra in this region and also the difficulty to retrieve the high vertical gradients present near the tropopause region. The retrieval error is also considerably smaller than the *a priori* error for both T and H_2O in the 900-400 hPa region. The reduction is much weaker near the surface and above 300hPa. For Scenario 2 the results are not satisfactory, which shows the necessity of including appropriate O_3 error covariance matrix.

The theoretical analysis presented in Phase II predicted that the impact of O_3 for scenarios 3 and 4 should be weak; however, the analysis indicated as well that the error reduction should be stronger for the sequential case. The results obtained in the current evaluation phase confirm a small impact of O_3 for both retrieval scenarios (3 and 4), however, contrary to what was expected, without significant improvement for the sequential retrieval. This is the case despite the relatively good performances of the O_3 retrieval.

5. Conclusions and Recommendations

Our results show that if the *a priori* error on CO and O3 is properly taken into account, the impact of CO and O_3 on T/H_2O retrieval performance from MTG/IRS spectra is weak. In particular, the impact is smaller than that of other effects such as errors on surface emissivity and choice of T/H_2O *a priori*. However, in case of underestimating of the CO and O_3 errors in the retrieval scheme, the impact of O_3/CO knowledge error on the quality of the retrieval can be considerable. Appropriate characterisation of the O_3/CO *a priori* errors, and their proper use in the retrieval scheme, is thus a key point for the overall quality of the T/H_2O retrieval.

Moreover, the inclusion of trace gas retrievals, within or before the main retrieval should be considered, in order to ensure a constant quality of the derived moisture and temperature information. This is true for the current state-of-the-art estimates of CO/O_3 *a priori* information which are based on climatologies. If trace gas retrievals were not performed, a bias in the moisture and temperature profiles might be present for cases with large departures from climatological tracer profiles, departures that are not well represented by the *a priori* error statistics.

Two methods are proposed for the retrieval of CO/O_3 in addition to T/H_2O: the combined and sequential approaches. With the current characterisation of the *a priori* matrices, we recommend the sequential approach. This method allows mitigating the stochastic errors due to trace gases, while in the combined retrieval, this mitigation is not achieved without *a priori* information on the cross correlation terms between CO/O_3 and T/H_2O. The characterisation of these terms is not consolidated in the current state-of-the-art information on the *a priori* error covariance matrices. Future work on the characterisation of the error covariance matrices, which include specification of the cross correlation terms, should increase the interest of using the combined method.

Results obtained in Phase III with the sequential retrieval for retrievals from synthetic spectra (in contrast to the information content analysis performed in Phase II) do not show expected mitigation of the O_3 impact, with respect to the "default" scenario (only transport of the climatological O_3 error). We presume that vertical correlations in the O_3 retrieval between stratosphere and troposphere, which is due to the poor vertical resolution of O_3 retrieval, can impact temperature and H_2O retrievals. To verify this, we recommend in future consolidation work, investigating the sensitivity of the T/H2O retrievals to the posterior O_3 error covariance matrix as well as to adequate channel selection.