NEW DEVELOPMENTS FOR THE USE OF MICROPHYSICAL VARIABLES FOR THE ASSIMILATION OF IASI RADIANCES IN CONVECTIVE SCALE MODELS.

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1. Introduction

Nowadays, most data assimilated in numerical weather prediction come from satellite observations. However, the exploitation of satellite data is still sub-optimal with only 10 to 15% of these data assimilated operationally. Keeping in mind that about 80% of infrared data are affected by clouds, it is a priority to develop the assimilation of cloud-affected satellite data. The hyperspectral infrared sounder IASI has already contributed to the improvement of weather forecasts thanks to its far better spectral resolution and information content compared to previous instruments (Hilton et al 2011). Currently, very few cloudy observations from the hyperspectral sounder IASI are assimilated over sea. A simple approach assuming single layers of opaque clouds defined by two cloud parameters (cloud top pressure and effective cloud fraction) is often used in the operations (Pavelin et al, 2008 McNally, 2009, Guidard et al, 2011). The context of this study is the HyMeX campaign (Ducrocq, et al 2013) aiming at a better understanding of the hydrological cycle over the Mediterranean Sea. We propose to use microphysical variables (liquid water content LWC, ice water content IWC) provided by the convective scale model AROME (2.5 km) to improve the assimilation of IASI cloudy radiances. The advanced interface RTTOV-CLD (Hocking 2010), included in RTTOV, using cloud microphysical properties (LWC, IWC and cloud fraction) from the model forecast has been evaluated in a previous study (Martinet et al, 2013). The use of such radiative transfer model is necessary with the view of adding the cloud variables into the state vector of the variational assimilation system.

In this paper, the potential benefit of an additional IASI channel subset to be exploited under cloudy conditions has been studied. The impact of the initialisation of cloud parameters on the forecast in a simplified model is shown before a short concluding summary.

2. New IASI channel selection for clouds

A new IASI channel selection IASI has been chosen from 366 channels used operationally at ECMWF (Collard and McNally, 2009). This selection of 134 channels aims at improving the retrieval of LWC and IWC. After the comparison of different channel selections (Martinet et al 2014), the chosen methodology is based on the highest sensitivity of the brightness temperature to LWC and IWC similarly to the study by Gambacorta and Barnet (2011) and to the lowest one to the other atmospheric constituents or parameters (Fig. 1). This method was called the physical method.

It was noticed that the channels selected by the physical approach span evenly the infrared window regions better than the other methods and complete the already existing IASI channel selection well (Fig. 2). The physical approach selects window channels on weak water-vapour absorption lines, which are also known to be informative for the derivation of cloud emissivity and cloud-top pressure. The non-selection of water-vapour channels by the physically based channel selection was expected, as this approach discards water-vapour channels by minimizing the interference between cloud variables and humidity.

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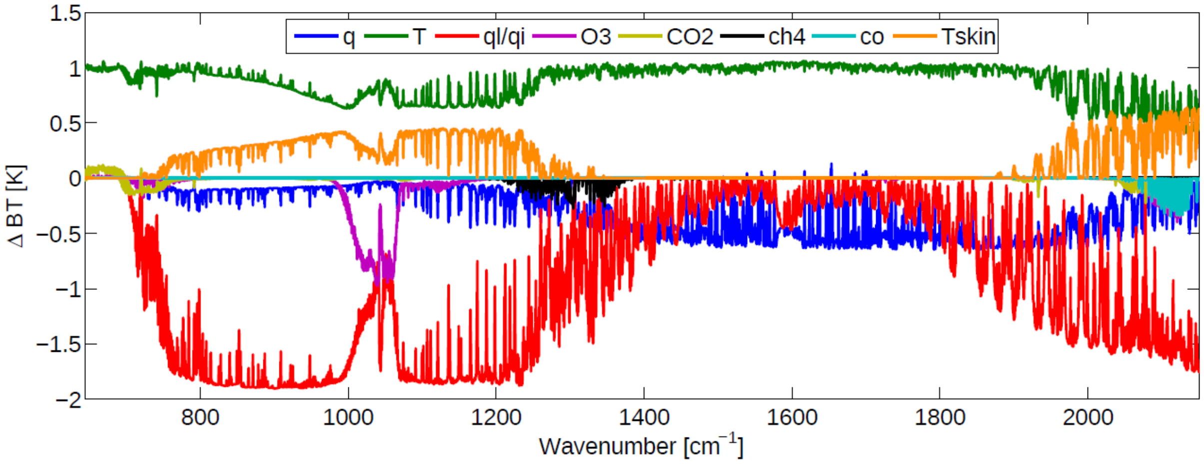

Figure 1: Sensitivity response of the brightness temperature to the perturbation of each atmospheric component independently. Blue curve: humidity perturbation. Green curve: temperature perturbation. Red curve: ql and qi perturbation, Cyan curve: CO. Dark purple: O3, Orange curve: skin temperature. Light green: CO2. Black curve: CH4.

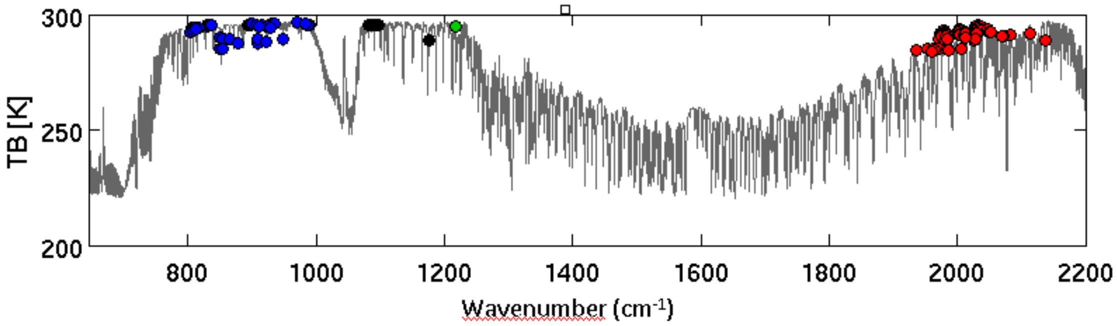

Figure 2: Iasi spectrum and location of the 134 selected channels with the physical channel selection method.

This channel selection has been then evaluated through Observing System Simulation Experiment and 1 dimensional variational assimilation. Cloud variables have been added to the control vector of the 1D-Var algorithm and a subset of 480 IASI channels (channels in the short wave being removed) were used to optimise the retrieval of cloud properties (Martinet et al., 2014a). Profiles of temperature, humidity, liquid water content and ice water content are retrieved on each of the 60 AROME levels simultaneously. Figures 3 and 4 present the vertical profiles of root-mean-square errors of background and analysis with this 480 IASI channel selection for cloud parameters, humidity and temperature. It was found that the analysis of ice water content and liquid water content was improved with the reduction of the RMSE with a maximum of 8% for opaque clouds and 7% for low clouds (Fig. 3). However it was difficult to gain new information in the case of semi-transparent clouds. The cloud fraction is improved over the whole troposphere. The temperature and the humidity are well retrieved with semi-transparent and low clouds (Fig. 4).

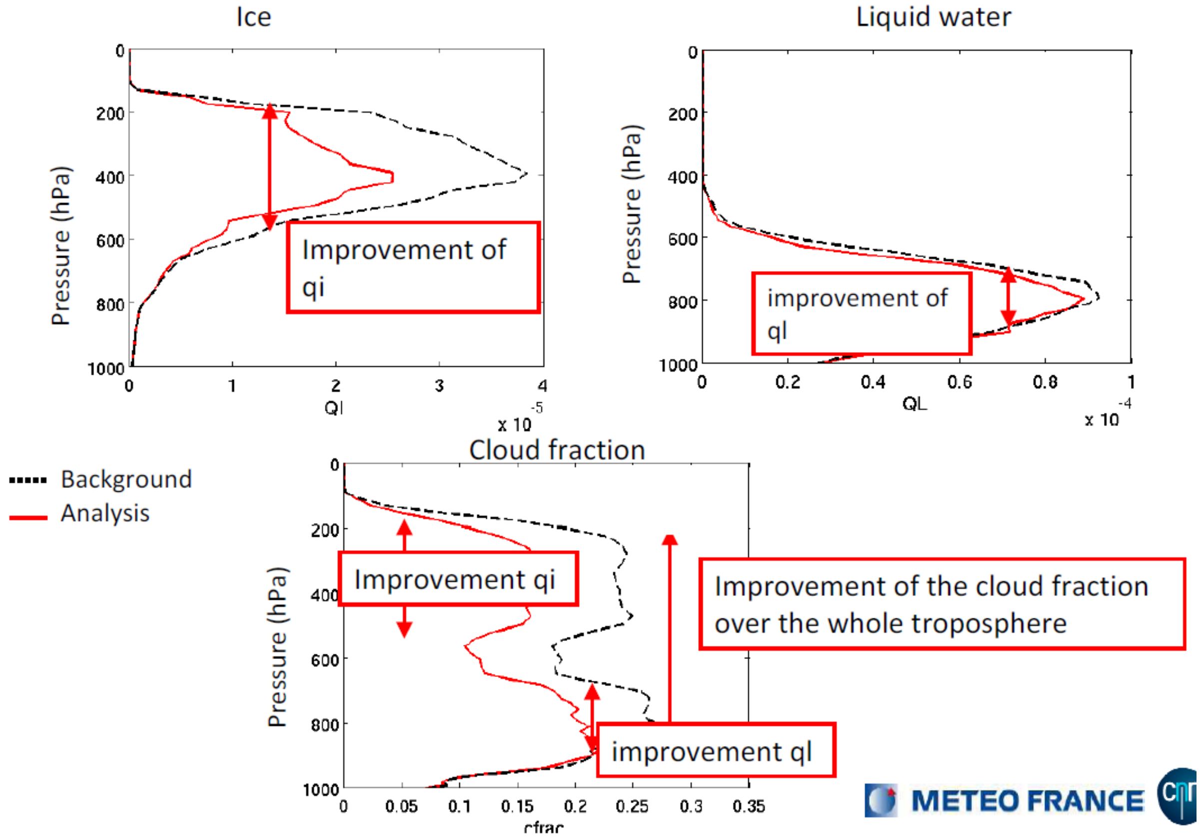

Figure 3: Vertical profiles of root-mean-square errors of the background against the 'truth' (black dotted line) and the analysis against the 'true' AROME profiles with the new channel selection (red line) for the ice profile, the liquid water content and the cloud fraction and for low-level clouds.

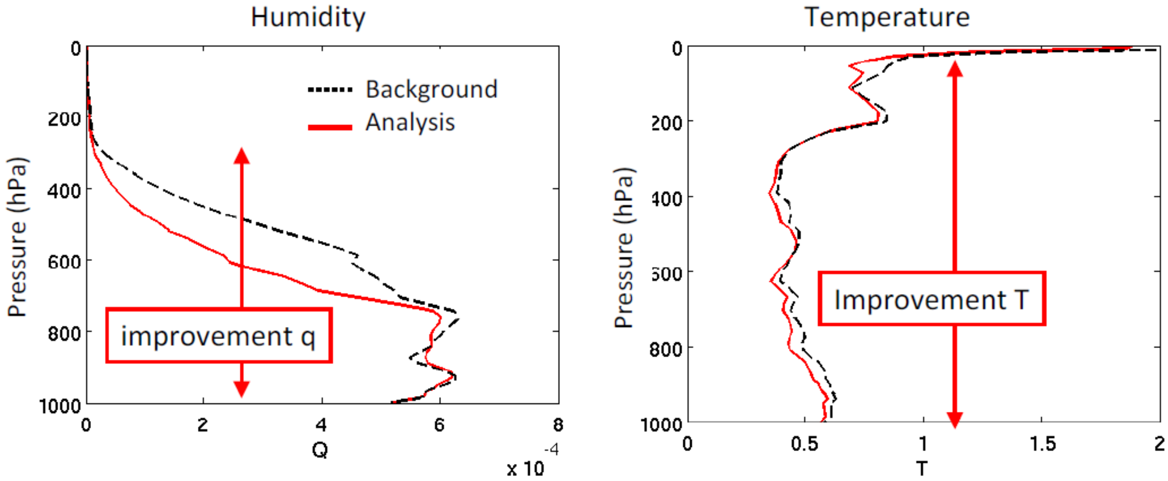

Figure 3: Vertical profiles of root-mean-square errors of the background against the 'truth' (black dotted line) and the analysis against the 'true' AROME profiles with the new channel selection (red line) for the humidity and the temperature and for low-level clouds.

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3. Study of the Impact of cloudy IASI radiances on short-range 1D forecasts (OSSE)

The persistence of the cloudy increment provided by the 1D-Var in the numerical weather prediction (NWP) model has then been studied (Martinet et al 2014b). A simplified one-dimensional version of the AROME model was used to run three-hour forecasts from the 1D-Var analysed profiles in order to study the capability of the convective scale model AROME to keep the cloudy increments. The evolution of the total cloud water content is compared when the AROME forecast is initialized with the analysis resulting from the 1D-Var or with the initial background.

-Time series of the integrated cloud water content gives an indication on the maintenance of the cloudy increment in the NWP model and its adjustment by quick grid-scale parameterized physics. The 'true' AROME profile is used to produce a 3-hour forecast which is considered as the 'reference'. The analyzed profiles are used to initialize another 3-hour forecast for comparison with the 'reference'. Either only temperature and humidity are initialized by the analysis or liquid water content and ice water content are also initialized in addition to temperature and humidity.

The criterion for the evaluation is the time series of the forecast error reduction (ER):

ER=1- RMSE(analysis)/RMSE(background)

where RMSE (analysis) is the root-mean-square errors of the retrieved profiles with respect to the truth and RMSE(background) the root-mean square errors of the background with respect to the truth. This criterion is displayed in Figure 6.

The average forecast error reduction reaches 15 to 20% for IWC in the case of semi-transparent clouds, 3% for liquid water content in the case of low clouds and 9 % for the ice water content of opaque clouds. The initialization of cloud variables in addition to temperature and humidity reduces the IWC forecast error with an average of 3% for opaque clouds and 10% for semi-transparent clouds (neutral impact for liquid water content).

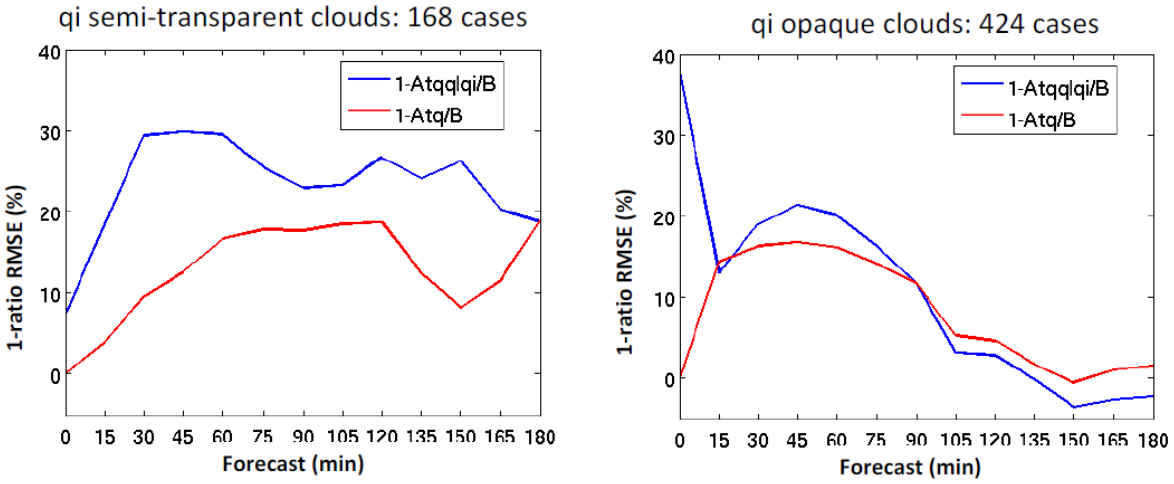

Figure 5: Forecast error reduction of ice water content brought by the initialization of temperature and humidity by the 1D-Var analysis (red line) or the initialization of liquid water content and ice water content in addition to temperature and humidity (blue line) for semi-transparent cloud (left panel) and opaque clouds (right panel).

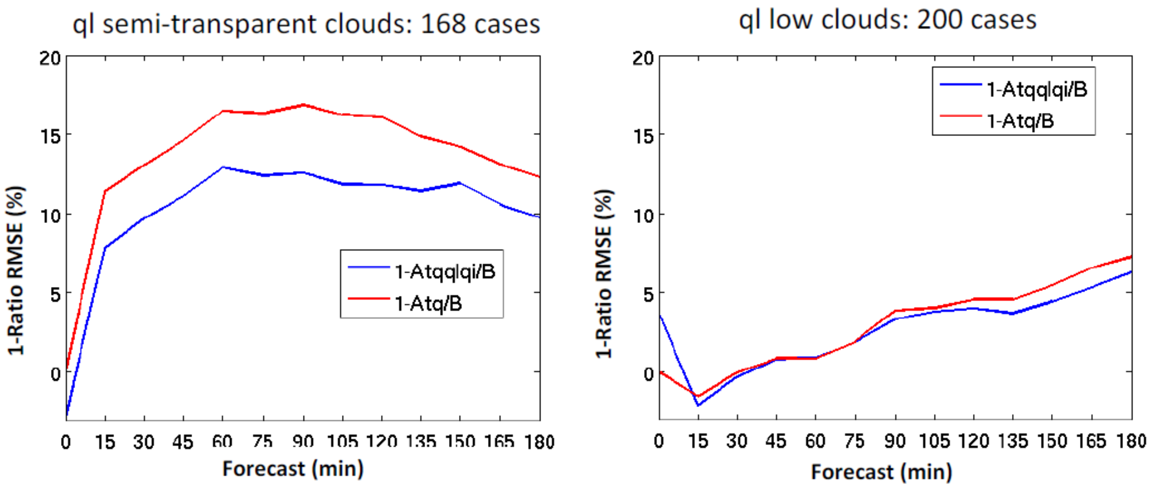

Figure 6: Forecast error reduction of ice liquid content brought by the initialization of temperature and humidity by the 1D-Var analysis (red line) or the initialization of liquid water content and ice water content in addition to temperature and humidity (blue line) for semi-transparent cloud (left panel) and low clouds (right panel).

These promising results have shown a good maintenance of the analysis increment during more than one hour and a half of forecast and up to 3 hours. The liquid water content and ice water content forecast errors are thus well reduced when they are analysed. The initialisation of cloud variables improves the forecast of ice water contents

4. Summary

We have obtained good 1D-Var retrievals of microphysical variables (LWC, IWC) after the addition of 134 IASI channels sensitive to cloud microphysical variables. 1D-Var retrievals have been used to initialize 3-h forecasts performed with the one-dimensional model AROME 1D. The cloudy increment in the NWP model is maintained during approximately 3 hours with a significant improvement of the forecast of cloud variables. The results of this study show that the NWP model successfully retains information when cloud variables are included in the control vector of the assimilation. A significant reduction of the forecast error of liquid water content, ice water content, temperature and humidity is observed.

Unfortunately, there is still a large distance between our experiments in an idealized framework and the assimilation of real cloudy radiances into an operational forecast model. AROME 1D is a very simplified version of the AROME model as no large scale processes are taken into account. However, clouds are dominated by parameterised processes and this simplified framework is relevant for a first evaluation of the impact of the assimilation of cloudy IASI data into a convective scale model before a future inclusion of the cloud variables in the control vector of the AROME 3D model. The future operational assimilation of cloudy infrared radiances will also have to be carried out carefully to avoid the degradations that can appear in a full system and that might not be represented in our experiments (Geer and Bauer, 2011). However, in regard to these encouraging results, a positive impact on nearcasting applications and forecasts of heavy rainfall events, which are highly coupled to cloud variables, can be expected.

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