Recent results with TOVS data in the new CMC 3D-Var-analysis system: the combined and separate impact of microwave radiance observations with aircraft wind data

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1. INTRODUCTION

In June 2000, the CMC introduced a new 3D-Variational (3D-Var-\( \eta \)) analysis system formulated on the model’s vertical coordinate that produces analyses directly on 28 \( \eta \) levels. Most Numerical Weather Prediction (NWP) centers have been using their model's vertical geometry in the analysis step for some time and have gained experience on technical details related to the use of a model's vertical coordinate. For the Canadian data assimilation group, this experience was acquired with the development of the 3D-Var-\( \eta \), and was the first major update to the 3D-Var system implemented in June 1997 (Gauthier et al. 1998).

In 3D-Var-\( \eta \), there is an attempt to assimilate observations in their raw or unprocessed form with the use of so-called “observation operators” thereby avoiding interpolating data on a fixed pressure grid prior to their assimilation such as in the previous 3D-Var. In September 2000, the use of satellite sounding data was updated to directly assimilate so-called level-1d TOVS radiances (Reale and Chelfant, 1999) as a replacement for NESDIS-retrieved SATEM thickness. The direct use of radiances with the help of a radiance transfer model (RTM) has always been the long-term objective of our group and the main motivation for developing the 3D-Var-analysis system. Following the launch of NOAA-15, it was evident that a new source of data had emerged that would alter the approach used at most NWP Centres in satellite data assimilation. The new AMSU-A microwave produced data of exceptional quality and appeared relatively easier to use than the IR data in all sky conditions. In this study, only the microwave data of NOAA-14 and 15 are used.

In recent years, a very important source of wind data has become available in the form of automated aircraft wind reports (ACARS/AMDA). The impact of these winds when added to the current operational AIRREP data has been shown to be marginally negative in the 16-pressure level 3D-Var system and consequently was never implemented even though monitoring indicates the data is of very good quality. Because the correlation structures of the 3D-Var-\( \eta \) system are much improved, and because of its’ improved vertical resolution, it was felt that the impact of the additional aircraft data would result in positive impacts particularly if accompanied by TOVS data. As it will be shown, in 3D-Var-\( \eta \), both the TOVS radiances and ACARS/AMDA winds either separately or together, have lead to significant improvements downstream of data void areas such as Western NA and in the SH.
2. PREPARATION OF THE TOVS DATA: QUALITY CONTROL, CHANNEL SELECTION, AND THINNING

The radiances data used in this study are of two types: the so-called revised TOVS (RTOVS) from NOAA-14 and the advanced TOVS (ATOVs) from NOAA-15. Only a subset of AMSU-A channels from ATOVS and 3 of the 4 MSU channels from the RTOVS system are used in this study as listed in Table 1. Typical data coverage from the two satellites in a +/- 3-h time window is shown in Figure 1. RTOVS data are radiances that have undergone some adjustments (Paris, 1997), including a statistically based limb adjustment. These data are also cloud-classified as clear or cloudy. For ATOVS data, there are no limb adjustments but they are cloud classified. The simualted radiances used in the preparation of the innovations i.e. observed minus simulated were calculated using RTTOV-5 (Saunders et al., 1999) radiative transfer model and a 6-hour forecast model state.

All data used are quality controlled for the monitoring and assimilation steps as described in Chouinard and Hallé (1997, 1999). A first series of checks involves validating the radiances data and its accompanying information, i.e. finding coding errors in the scan position, scan angle, cloud classification, inconsistency between the scan position and scan angle, radiance data out of physical range, etc. A second series of tests, which use the innovations, consist in detecting cloud classification errors, which are detected as large cold biases in the HIRS channels 8 (low-level clouds) and 12 (cirrus clouds). A rogue check is performed to eliminate any residuals larger than 4 standard deviations from an a-priori estimate. As a final step before the assimilation step, the data is thinned to a uniform resolution of 250 km.

The biases of the innovations in each channel are monitored so as to ensure that, over large ensembles (space and time, monthly global), they are very small, ideally zero. In some channels, the biases can be as large as -1 to -2 K and often as large as and even larger than the random error. These large biases have to be removed or accounted for if any success is to be obtained in assimilating radiances data. The biases in the radiance innovations are believed to originate from two sources assuming the instrument is unbiased. First, because the RTOVS MSU radiances data are limb-corrected by NESDIS, there is a residual limb effect that remains. It is visible strictly for the limb-corrected radiances even though some of the innovation scan angle dependency are also due to inaccuracies in RTM as evidenced by scan dependent biases in the ATOVS data. Secondly, there is a significant bias that is air mass dependent and this is related to inaccuracies in RTTOV-5 modeling.

The bias correction procedure described in the ITSC X proceedings (Chouinard and Hallé, 1999) has been updated to a two-step approach. In a first step, a global scan correction as obtained from prior monitoring is applied to the data; this removes most of the scan angle dependency. In a second step, the air mass dependent bias correction procedure using a set of regression equations for each radiance is applied. In order to remove only air mass biases due to the RTM, only the innovation data over ocean and in proximity to radiosondes are used in developing the regression equations. Note that in this two step approach, there are no positional predictors to remove scan-dependent biases.

Because the instruments of NOAA-14 and 15 are very different, the choice of predictors used differs for RTOVS and ATOVS data as listed in Table 1. Most NWP centers now recognize, that the removal of the scan and air mass bias is probably the most critical step in the final preparation of the satellite radiance data prior to the assimilation step.
CHOUINARD, HALLÉ, AND SARRAZIN: Recent results with TOVS data in the new CMC

<table>
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<tr>
<th>RTOVS predictors</th>
<th>ATOVS predictors</th>
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<tr>
<td>MSU: 3, 4</td>
<td>AMSU-A: 6, 7, 8, 9, 10, 11, 12, 13</td>
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<td>SSU 1, 2, 3</td>
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Table 1. Predictors used to correct the RTOVS and ATOVS radiance biases. The channels in bold characters are the ones assimilated in this study. Note that the SSU channels 1, 2, 3 and AMSU 12, 13 are used for bias correction only and are not assimilated.

3. PREPARATION OF THE AIRCRAFT DATA: QUALITY CONTROL, SELECTION RULES AND THINNING

CMC currently receives 4 different types of aircraft meteorological reports: AIREP, ACARS, AMDAR. International AIREP, ACARS and AMDAR reports are received at CMC on the GTS from the Washington link. In a 24-hour period, CMC receives approximately 45,000 ACARS, (US airlines data gathered by ARINC) 3,500 AIREP 20,000 AMDAR. A typical coverage chart of the aircraft data in a +/- 1.5 h time window is presented in Fig. 2.

Prior to their use in the analysis, the aircraft data are quality controlled. The first step is the basic quality control. At first, latitude, longitude, time of observation and the aircraft identifier is check for coding errors. For the wind, directions outside physical limits (0-360) are flagged as in error. For the wind speed, a climatological test is performed. A separate quality control program is used for the basic quality assurance, "TrackQC". TrackQC programs groups the reports according to the aircraft identifier and sort the observations chronologically and according to pressure level. The program does a quality control one aircraft at a time.

A background quality check is applied to remove the observations with gross errors before the data assimilation step. The decision to reject or not an observation is based on the square of the normalized background departure. An observation is rejected if it exceeds a predefined multiple of the expected variance. For the wind, the quality control is done simultaneously for both the wind components.

Finally, a data selection procedure reduces the density of the data while trying to make the best use of all the information available. At first, a 3-hour time window centered on the analysis time is used instead of 6 hours. Then, for each type of data, AIREP, ACARS and AMDAR, a thinning procedure is applied where a single observations is chosen in a 1.5 X 1.5 ° box on 16 pressure layers (1000, 950, 900, 850, 800, 750, 700, 600, 500, 400, 300, 275, 250, 225, 200, 150). When more than one observation of a given type is available, the one closest to the analysis time is retained. After the thinning, only one observation of the 3 types is kept prioritizing in the following order: ACARS (1), AMDAR (2), and AIREP (3). This order is used simply because innovation statistics show that ACARS and AMDAR automated reports are on average of a better quality than the AIREP reports.

4. RESULTS

The positive impact of infrared radiances from the NOAA-11 and 14 HIRS instrument was clearly demonstrated in the previous 3D-Var pressure system as reported at the ITSC-X in Boulder (Chouinard and Hallé, 1999). Preliminary tests at our Centre and at other Centres (McNally et al., 1999) indicated very positive results with microwave only channels (AMSU-A and MSU), and the results from our parallel suite as presented in Fig 3 are indeed very positive. The 6-h trial field
(left panel) are very much improved and this improvement persists throughout the first 4 days and beyond (not shown).

Because the results of our parallel suite included the use of additional aircraft wind data (ACARS, AMDAR), we wanted to demonstrate, in a separate suite, whether the impact was due to aircraft or satellite sounding data. Following the implementation of 3D-Var-η on the 27 September 2001, a parallel suite denied of aircraft data was run during three months. The results presented in Fig 4 indicate without a doubt that the aircraft wind data has a very positive impact on the winds at 6h, 48h and 96h. Only the wind and not the temperature observations from ACARS and AMDAR are currently used, and even so, their impact on the mass field via the multivariate balance constraint is significant throughout the first 4 days.

Finally, an evaluation of medium-range forecasts was prepared for the parallel suite during the month of August 2000. In Fig 5, the monthly-mean rms error of the 500-hPa geopotential is compared against the then operational system at CMC as well as to other major NWP Centres around the world. The gains in predictability of the new system are very large as and persistent throughout 10-day forecasts and now very competitive with forecasts from the other Centres.

5. CONCLUSIONS

When TOVS/ATOVS microwave data are assimilated with aircraft wind data (ACARS/AMDR) in the new CMC 3D-Var-η system, the two types of data support each other producing significantly better results then when either is assimilated separately. This was not the case in the previous pressure system where aircraft winds produced marginally negative results. This can only be attributed to the excellent quality of each data type and the improved 3D-Var-η data assimilation system.

In preparation for the assimilation of satellite data from future platforms (NOAA-16, AIRS, IASI), we have started testing with level 1b TOVS radiances from current NOAA polar orbiters. The processing of radiances prior to the data assimilation step, including a revised bias correction algorithm based on NWP model air mass predictors, will be completely redesigned. Further, in the next analysis system, temperature and surface pressure will replace geopotential observations and a variational quality control will be introduced within the minimization loop.

6. REFERENCES

Chouinard C. And J. Hallé: The variational assimilation of TOVS radiance observations: formulation and evaluation in 1D and 3D mode. ITSC-IX proceedings, Innsbruck Austria, February 1997, p.65-75.


Fig. 1. Typical coverage from the NOAA-14 (red) and NOAA-15 (blue). This is the full level-1d dataset as received at CMC, the actual data assimilated would be thinned to a uniform resolution of 200 km.

Fig. 2. Typical coverage of aircraft wind data from ACARS (green), AMDAR (blue), and AIREP (red). This is the actual dataset used by the analysis, it has been thinned to an equivalent resolution of 1.5 degree resolution. Typically there are about 1000 ACARS, 600 AMDAR and 300 AIREP used.