MODIFICATIONS IN THE OPERATIONAL USE OF SATELLITE ATMOSPHERIC MOTION WINDS AT CMC

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ABSTRACT

In December 2001, the Canadian Meteorological Centre implemented modifications to its operational 3D-Var analysis and to the number and type of observations assimilated. Among these modifications was a new selection of satellite winds which contributed to improvement in the quality of the forecasts. GOES satellite observations from NESDIS BUFR coded bulletins were added. SATOB format METEOSAT observations from EUMETSAT were replaced by a selection from the expanded low-resolution BUFR bulletins. The quality indicators, MPEF QI and NESDIS RFF, are used in the screening and thinning procedures. Quality thresholds were determined from observation minus background statistics. The quality control of the observations was improved with the introduction of variational quality control and the addition of an asymmetric test for satellite winds. Also, the weight given to the satwinds was increased by lowering the observation error from 7.5 to 5.0 m/s at high levels. Impact trials for July 2001 and November 2001 confirm that the new selection contributes to improvement in forecast quality when compared to the results obtained with the old selection of satellite winds. Experiments with no satellite winds also confirm the usefulness of these observations in the CMC global assimilation and forecast system.

1. Introduction

Following the implementation of the 3D-Var analysis system (Gauthier et al. 1999), the CMC operational global data assimilation system has undergone several major revisions. In June 2000, the 3D-Var analysis program was converted from a 16-level pressure coordinate system to a 28-level η (terrain-following) coordinate system (Chouinard et al. 2001). The observations are assimilated in their raw or unprocessed form with the use of observation operators, avoiding the interpolation of the observations to fixed pressure levels. The innovations are computed in observation space using the full resolution (0.9º grid) background state provided by the 6-hour forecasts of the GEM model (Coté et al. 1998) while the analysis increments are calculated at a lower T108 spectral resolution. The June 2000 implementation also included a revision of the background and observation errors. The background error covariance statistics were redesigned following the approach of Parrish and Derber (1992), based on an ensemble of 24 and 48-h forecasts valid at the same time.

In September 2000, the use of satellite sounding data was updated to directly assimilate TOVS radiances as a replacement for NESDIS-retrieved SATEM thickness values. The radiances are quality controlled, corrected for bias and filtered to a uniform 250-km resolution prior to the assimilation (Chouinard and Hallé 1999). The improvement to analysis and forecast quality due to the introduction of the radiances was particularly large over the Southern Hemisphere. At the same time, the automated aircraft wind observations (AMDAR/ACARS) were added to the old AIREP format reports already assimilated, providing an important improvement to the quality of short-term forecasts (Sarrazin et al. 2000). In June 2001, NOAA-15 and NOAA-16 level-1b AMSU-A radiances replaced the level-1d data used previously.

In December 2001, a number of modifications improved the quality of CMC global forecast system. A correction was made to the formulation of the gravity wave drag parameterization in the forecast model. The 3D-Var-η analysis program was modified to assimilate temperature and surface pressure instead of geopotential height. The quality control of observations, previously based on the method of optimum interpolation, was changed to a combination of a background check prior to the analysis and variational quality control during the minimization. The change of variables allowed for a more direct assimilation of surface observations. For RAOBS, in addition to the change from geopotential to temperature, the number of assimilated levels was increased from the 16 mandatory pressure levels to 27 levels. Also, aircraft temperature reports and AMSU-A channels 3,4 and 5 were added to the assimilated observations. The final modification, and the subject of the remainder of this paper, was an increase in the number of satellite winds assimilated by the 3D-Var, and the revision of the selection procedure for these winds.

2. Satellite Winds Selection

Prior to December 2001, the only satellite winds assimilated at CMC were those in SATOB format, namely from JMA, SATOBS from the GMS-5 satellite and from EUMETSAT, SATOBS from the METEOSAT-5 and 7 satellites. The observations were assimilated without any additional selection procedure done at CMC. No GOES winds had been assimilated since the introduction of the high-density system at NESDIS. Currently, BUFR bulletins from NESDIS (CD, VZ and WV), the expanded low-resolution winds (ELW) BUFR bulletins from EUMETSAT and the SATOB bulletins from JMA are included in the selection procedure. As explained below, the selection procedure consists of 3 steps: first the blacklisting of unwanted data, then a background check, and finally a spatial thinning of the remaining observations.

There are a large number of possibilities in defining the selection rules. It is expected that more fine-tuning of the rules could be done in the future. Some of the rules chosen are subjective but derived from the experience of other centers. The rules applied in the first step of the selection procedure are listed below. Some of the rules, for example the quality indicator threshold, cannot be applied to SATOB format observations since the information is not available.

<u>Blacklisting rules (to keep the data)</u>

- time window: within ±1h30 of analysis time
- derivation method: 1:infrared, 2:visible or 3:water vapor in cloudy region
- level: infrared: all levels below 50 hPa, visible: below 700 hPa, water vapor: above 400 hPa
- wind speed: above 2.5 m/s
- satellite angle: < ~55º
- quality indicator: above threshold
- land mask: over ocean, over land only south of 20ºS and above 400 hPa

It has been shown that EUMETSAT quality indicator (QI) and NESDIS recursive filter flag (RFF) can provide a means to select the higher quality satellite wind observations (Butterworth and Ingleby, 2000, Kelly and Rohn, 2000, Holmlund et al., 2001). The quality indictor thresholds were chosen from observation minus background statistics, from the CMC assimilation system, based on data from October and November 2000 and confirmed with May 2001 data.

For the METEOSAT satellite winds, a single QI threshold value of 0.85 was kept at all levels and for all channels, slightly above the 0.80 value of EUMETSAT automatic quality control for the SATOB CMW. Statistics for winds below 700 hPa, show a sharp decrease in vector RMS between 0.8 and 0.85 QI values. An example is shown in figure 1. Overall this new selection does not significantly reduce the number of METEOSAT observations from the previous approach which used only the CMW dataset valid at 1 h. before the analysis time, because two sets of observations are now used, valid 1h. before and 30 min. after analysis time. Note that no high-resolution METEOSAT observations were used; their assimilation will be examined later. Also, the QI index used in the selection is the old one, not the new version that is independent of the ECMWF background.

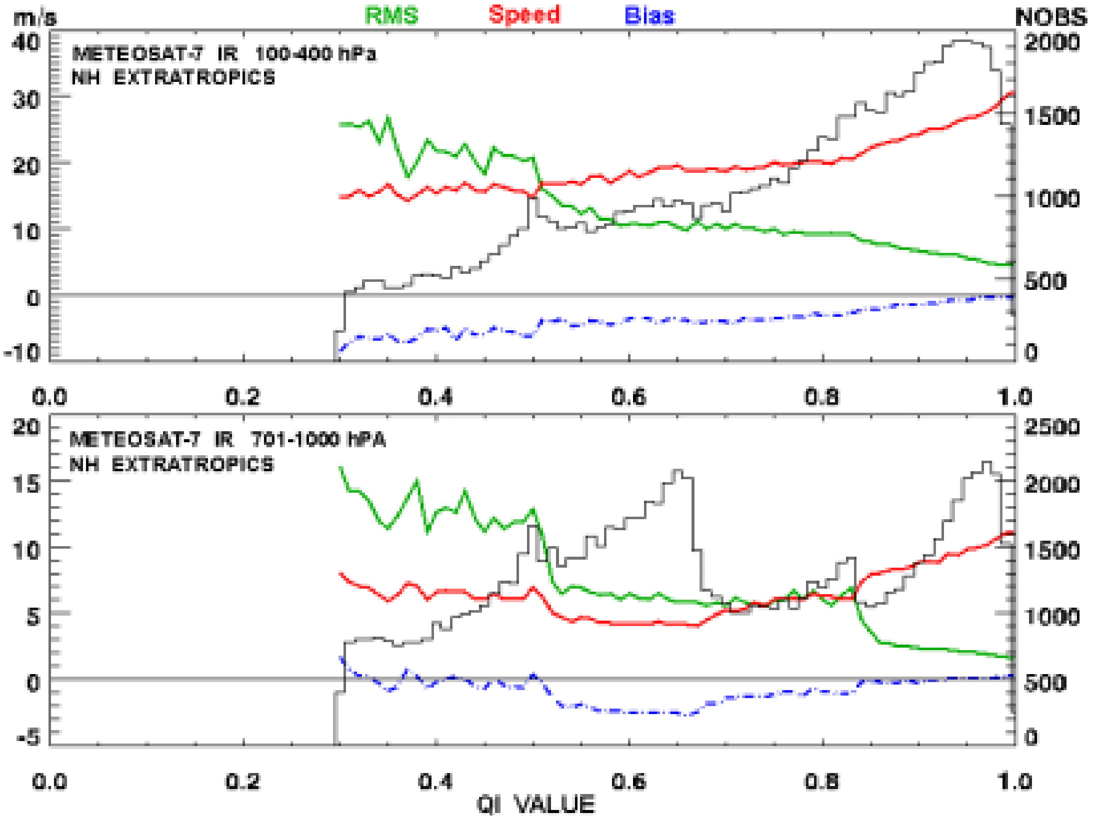

Figure 1: QI versus observation minus background statistics for METEOSAT-7 infrared cloud motion winds, vector RMS, wind speed bias, average wind speed and number of observations per 0.01 bins.

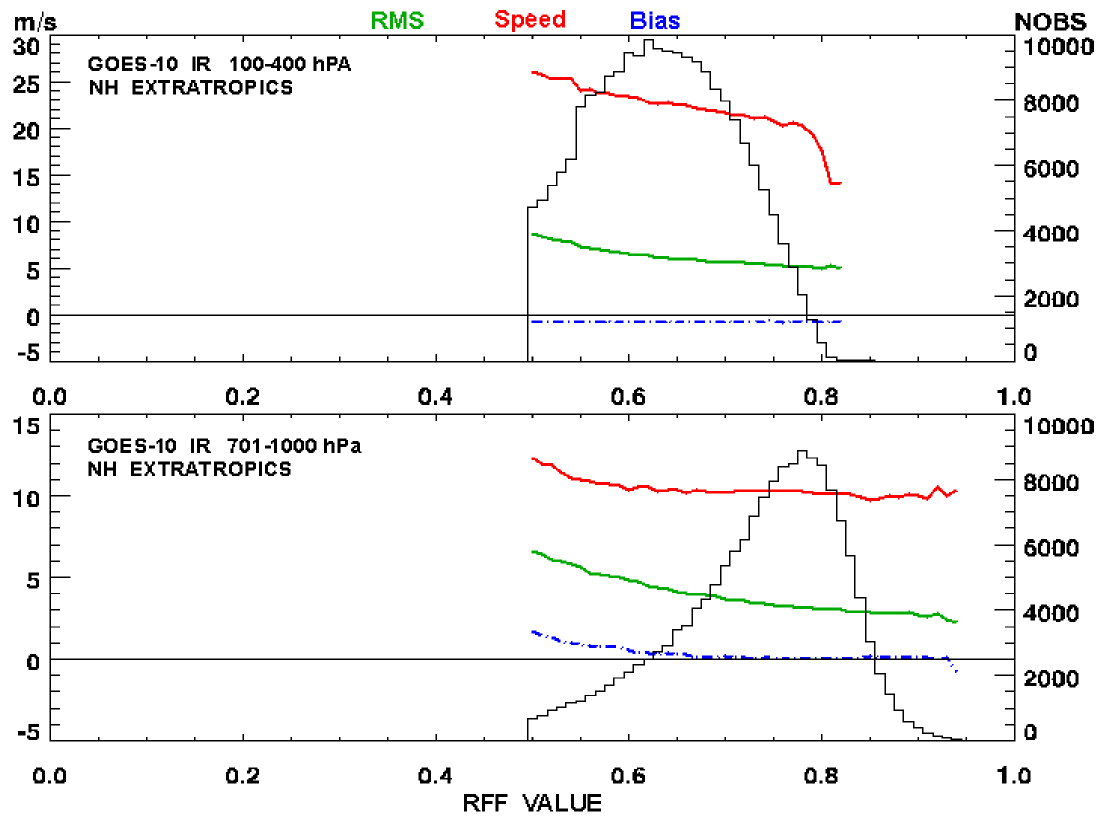

Figure 2: RFF quality indicator versus observation minus background, GOES-10 IR cloud-motion winds, vector RMS, wind speed bias, average wind speed and number of observations per 0.01 bins.

For GOES data, the RFF observation minus background statistics distributions are somewhat smoother and no obvious threshold value comes out of the statistics (see figure 2). The chosen thresholds, listed in table 1, more or less eliminate the bottom half of the distribution for all derivation methods. The number of remaining observations, after the selection is completed, is usually sufficient to give a good geographic coverage.

Table 1: RFF quality indicator threshold values per level and latitude bands

	≤ 400 hPa	**401 – 699 hPa**	**≥ 700 hPa**
extra-tropics	0.65	0.70	0.75
tropics	0.70	0.75	0.80

Thinning rules

After the blacklist step of the selection, a background check is performed on the remaining observations. This will usually eliminate only a few observations with a large departure from the background, about 0.1% of the observations. Finally, the thinning program will keep only one observation per box of 1.5x1.5° of horizontal resolution and 11 vertical layers centred on pressure levels (1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100 hPa). Within a box, the priority is given to the observation closest to the analysis time and secondly the observation with the maximum quality indicator value. Figure 3 shows an example of the spatial distribution of the remaining observations. On average, ~6,000 observations are kept compared to ~3,500 previously.

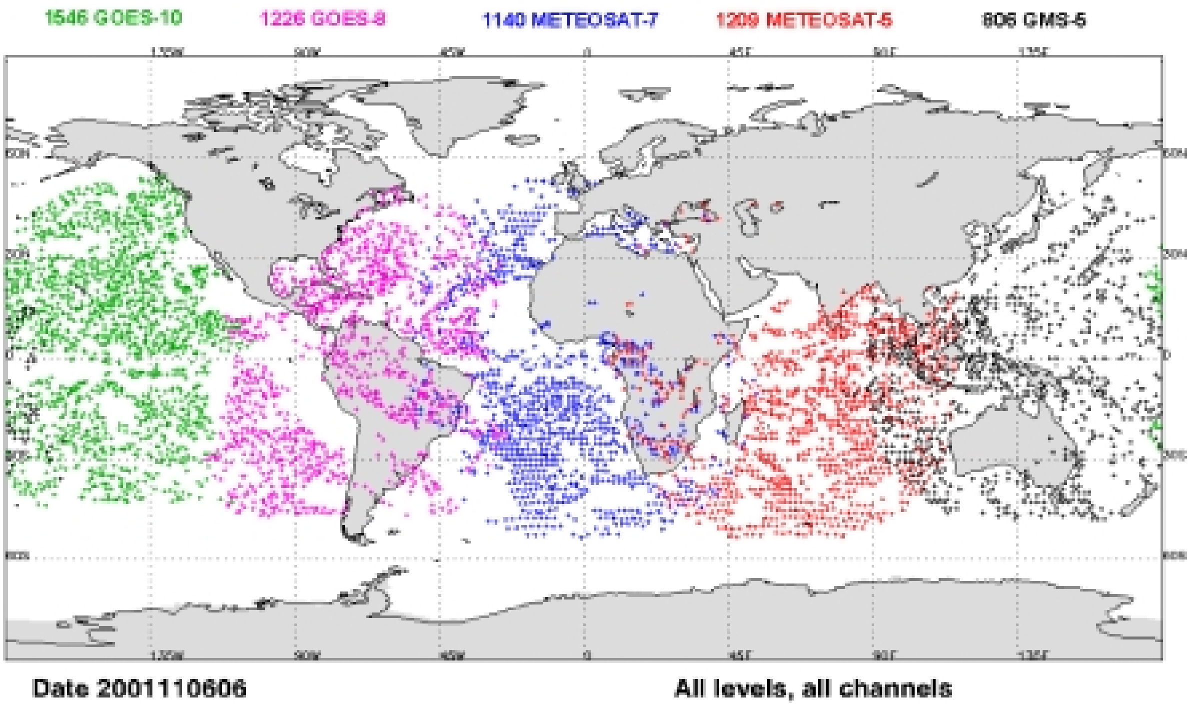

Figure 3: Remaining observations after the blacklisting, background check and thinning procedures for 6 November 2001, 06 UTC, all levels, all channels.

3. Data Assimilation

Two additional modifications to the assimilation system are important for the evaluation of the impact of the satellites winds. First, the observation errors were reduced from 7.5 to 5 m/s above the 500hPa level and from 3 to 2.5 m/s for the low levels. The observation errors had been set to values used by ECMWF many years ago and not changed since then. For this implementation, the values have been adjusted to something closer to the values currently used by other weather centres. Further tuning will likely be needed with this new CMC forecast and assimilation system.

Second, an asymmetric test for the quality control of satellite winds is included in the new variational quality control. The test essentially holds some satellite wind reports, those with wind speeds less than the background wind speed, to a higher standard of quality. The rationale is to compensate for the well-known wind speed bias due to the averaging in space and time inherent in the atmospheric motion vectors generated by tracking features (most notably clouds) with satellites. The variational quality control method (see Andersson and Järvinen, 1999) is made asymmetric by altering the specification of the prior probability of gross error, A, as follows:

$$A_{new} = k\, A_{old} \qquad \text{for } \nu_o < \nu_b$$
$$A_{new} = A_{old} \qquad \text{for } \nu_o \geq \nu_b$$

where ν_o is the observed wind speed (m/s), ν_b is the wind speed of the background at the location of the observation, and k, chosen empirically, is $0.7\nu_b$. Choosing k to be proportional to ν_b ensures that the variational quality control will be more stringent where the wind speeds are higher, i.e. near jets, where a biased wind speed report can do the most harm. Since the higher wind speed regions are our main concern, the application of the asymmetric test is limited to the extratropical upper troposphere.

The impact of the asymmetric test was examined separately in the summer trial. This assimilation cycle covers the period from 7 June to 31 July 2001. The control is an assimilation cycle with all the modifications mentioned above and the test run is a cycle with no asymmetric test in the variational quality control of the satellite winds. Figure 4 compares the quality of the 6-hr forecast used as background in the assimilation cycle against radiosonde observations for the Southern Hemisphere, for the period of June 15 to July 31. There is a significant reduction in rms forecast error with the asymmetric test. For that period, a good number of observations show an important negative bias in the Southern Hemisphere. To give an indication of the number of observations with a reduced weight in the analyses, the variational quality control flags observations with a weight reduced by more than 75%. In the control cycle, there is an additional 1.5% of satellite wind observations “rejected” by the quality control with the asymmetric test compared to the test run without the asymmetric test. However, the quality control of the satellite winds seems to need additional tuning, since in the test run only about 0.1% of the satellite winds are “rejected”.

4. Trials

Before the implementation into operations of the new selection of satellite winds and the quality control modifications, these changes were tested for two different periods. For the first period, an assimilation cycle was run from 7 June to 31 July 2001. Thirty-two global forecasts were produced at 36-hour intervals from the analyses of this assimilation run, starting on June 15. Similarly, another assimilation cycle was run for the period of 25 October to 26 November 2001. Twenty-one forecast, again at 36-hour intervals were produced during that second trial period.

For these trials, the control run included the various improvements to the CMC forecast system mentioned in the introduction but without the change to the use of the satellite winds. Two experiments were carried out. In the first, the new selection of satellite winds, the change in observation error and the asymmetric test in the variational quality control were applied. In order to evaluate the usefulness of these observations, a second experiment was done without any satellite winds. The verification scores are obtained from comparison with radiosonde observations.

Figure 5 shows the difference in the mean 250 hPa wind analyses due to the inclusion of satellite winds in the assimilation cycle of the CMC forecast system. This is a comparison between experiment 1 with the new selection and experiment 2 without satellite winds. Clearly, the Tropics are the region that responds the most to the inclusion of these observations. Of course in a case-by-case comparison, some significant impacts can also be found at higher latitudes. In the Tropics this type of observation is more predominant than it is in the northern extratropics, for example. In the Tropics the impact of the observations is more important on the wind field, while in the extratropics the temperature and geopotential heights may be significantly changed as well.

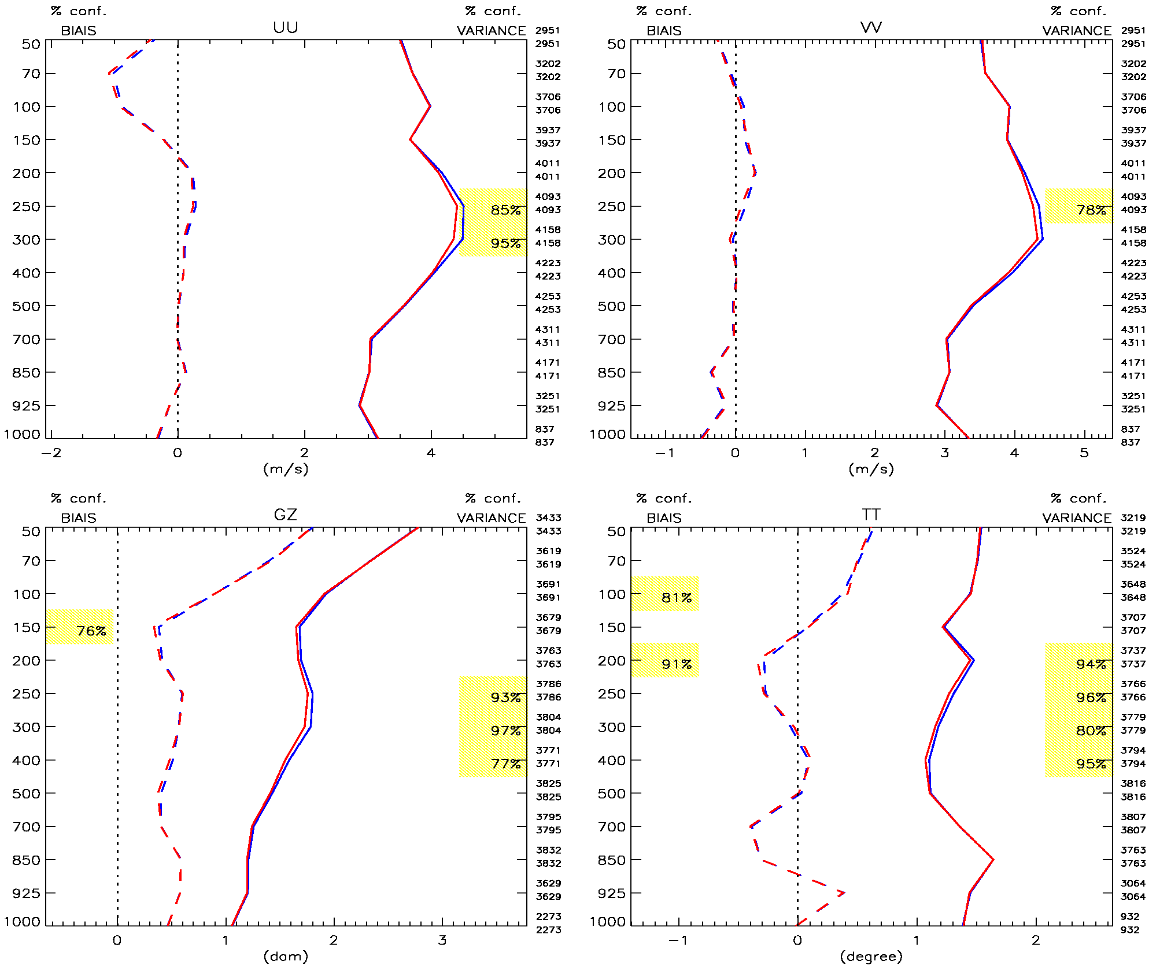

Figure 4: Verification of the quality of the background fields, against the southern hemisphere radiosonde observations. Period: 15 June 2001 to 31 July 2001 (94 cases); red lines represent results with the asymmetric test, blue lines without, solid lines are the RMS forecast error and the dash lines the bias for the wind components (UU,VV), the geopotential (GZ) and the temperature (TT).

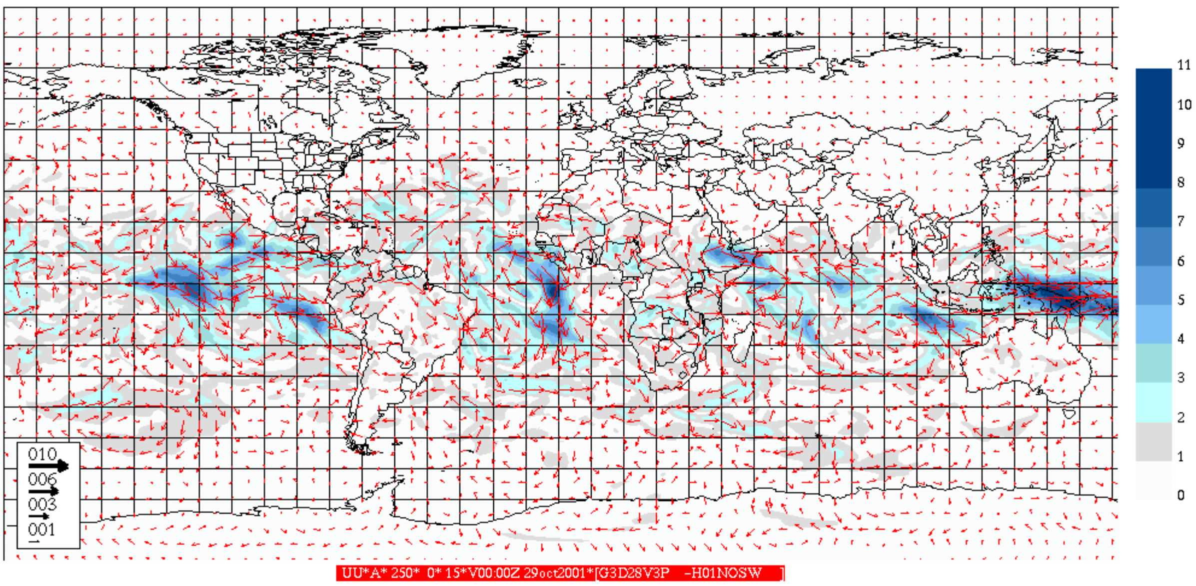

Figure 5: Differences between the mean wind (m/s) analyses at 250 hPa (00 and 12 UTC) for the period from 29 October to 5 November 2001, the run with the new selection of satellite winds minus the run without any satellite winds.

Table 2 is a summary of the scores obtained for the comparison of the control using the old selection of SATOB format observations, with experiment 1 using the new selection of satwinds. The forecast verification scores are shown in terms of percentage change of the RMS of forecast error. This is an average of the July and November results, without considering the difference in the number of forecasts of the two periods. A negative value is a reduction of the RMS and an improvement in the quality of the forecasts, when compared to the radiosonde observations. Overall the new usage of the satellite wind observations, including the change of observation error and the asymmetric test in the quality control, is an improvement on the old method. In all latitude bands there is a small reduction of the RMS of forecast error. From the results of the asymmetric test shown in the previous section, it appears that the new quality control contribute significantly to the improvement. With the addition of the GOES satellite observations, we were particularly interested in the results over North America. For both periods, the forecast quality for North America was slightly improved in the new system until day 4. Afterward, the results are more or less neutral.

Table 2: Percentage change in RMS forecast error of the new satwinds versus the old selection. Verification against radiosonde observations, for wind speed at 250 hPa (UV250), geopotential at 500 hPa (GZ500), temperature at 700 hPA (TT700) and dewpoint depression at 700 hPa (ES700). A negative value indicates an improvement in the quality of the forecast.

	Northern Extratropics			Tropics			Southern Extratropics		
	24h	72h	120h	24h	72h	120h	24h	72h	120h
UV 250	-0.2	-0.6	-0.8	-1.3	-1.8	-0.8	-1.6	-1.8	-0.4
GZ 500	-0.3	-0.7	-1.7	-1.2	0.0	-2.5	-0.3	-1.8	-0.1
TT 700	-0.4	-0.7	-1.0	-0.9	0.0	-1.7	-1.4	-3.2	-1.6
ES 700	-0.6	-0.1	+0.9	+0.4	+0.8	-1.3	-1.6	+1.5	-0.5

The observations minus background statistics show an important reduction in root-mean-square vector difference (RMSVD) for the satellite wind observations in the new system compared to the control. For example, the RMSVD goes from about 7.5 m/s to about 6 m/s for the satellite wind observations in the 100-400 hPa layer.

In the same format as table 2, table 3 is a summary of the impact of satellite winds obtained by comparing the new system, experiment 1, with a model run without any satellite winds, experiment 2. It was shown in figure 5 that the impact on the wind field at 250 hPa is more important in the Tropics. The results in table 3 also show that the most significant improvement in the quality of the forecast is obtained for the wind field in the Tropics. Despite the improvement shown in table 2 for the Southern Extratropics, overall we get mixed results for the impact of satellite winds in that region. For Northern Extratropics, the satellite wind observations contribute a small improvement in the quality of the forecast.

Table 3 : Percentage change in RMS forecast error of the new satwinds versus no satwinds trial. The verification is against radiosonde observations, for wind speed at 250 hPa (UV250), geopotential at 500 hPa (GZ500), temperature at 700 hPA (TT700) and dewpoint depression at 700 hPa (ES700). A negative value indicates an improvement in the quality of the forecast.

	Northern Extratropics			Tropics			Southern Extratropics		
	24h	72h	120h	24h	72h	120h	24h	72h	120h
UV 250	-0.4	-2.1	-1.4	-7.3	-4.6	-3.4	+0.4	+2.4	+0.2
GZ 500	-0.7	-3.7	-3.1	-3.2	-0.7	-1.9	+2.4	-4.0	-2.5
TT 700	-0.4	-1.5	-1.8	+0.5	-1.2	-1.4	-0.4	-2.1	-2.1
ES 700	-0.5	+0.3	+0.1	+0.3	-0.1	+0.1	-0.7	+2.4	+1.2

5. Conclusion

Modifications in the usage of satellite winds were implemented in the Canadian Meteorological Centre operational assimilation and forecast system on 11 December 2001. These modifications improve slightly the quality of the forecast system compared to the previous procedures. The influence of this type of observation is relatively modest in the CMC forecast system, except for the wind field in the Tropics where the improvement in the quality of the forecasts is more important. The results also indicate that further tuning might be needed. The quality control rejects only a few of the satellite wind observations when the observation speed is greater than the background and could probably be more restrictive. The high-resolution METEOSAT observations remain to be tested. Also, the observation error should be evaluated more closely in relation to the errors of other observation type and the background.

REFERENCES

Andersson, E. and H. Järvinen, 1999: Variational quality control. *Q. J. R. Meteorol. Soc.*, **125**, pp. 697-722.

Butterworth, P., N.B. Ingleby, 2000, Recent Developments in the Use of Satellite Winds at the MET. OFFICE, *Proc. Fifth International Winds Workshop,* 28 February–3 March 2000, Lorne, Australia, publ. EUMETSAT, EUM P 28, pp. 151-159.

Chouinard, C., C. Charette, J. Hallé, P. Gauthier, J. Morneau, R. Sarrazin, 2001, The Canadian 3D-VAR Analysis Scheme on Model Vertical Coordinate**,** *Proc. AMS 14th Conference on Numerical Weather Prediction,* 30 July–2 August, Fort Lauderdale, Florida, pp. 14-18.

Chouinard, C., J. Hallé, 1999, The impact of TOVS radiances in the CMC 3D-Var analysis system**,** *Proc. ITSC-X,* Boulder, Colorado, February 1999, pp. 92-98.

Côté, Jean, Sylvie Gravel, André Méthot, Alain Patoine, Michel Roch, Andrew Staniforth, 1998: The Operational CMC–MRB Global Environmental Multiscale (GEM) Model. Part I: Design Considerations and Formulation**.** *Monthly Weather Review*: 126, No. 6, pp. 1373–1395.

Gauthier P., C. Charrette, L. Fillion, P. Koclas, S. Laroche, 1999, Implementation of a 3D variational analysis at the Canadian Meteorological Centre, Part I, The global analysis, *Atmosphere-Ocean,* XXXVII, No 2, pp. 103-156.

Holmlund, Kenneth, Christopher S. Velden, Michael Rohn, 2001, Enhanced Automated Quality Control Applied to High-Density Satellite-Derived Winds. *Monthly Weather Review*: 129, pp. 517–529.

Kelly, G., M. Rohn, 2000, The Use of the MPEF Quality Indicator, *Proc. Fifth International Winds Workshop,* 28 February–3 March 2000, Lorne, Australia, publ. EUMETSAT, EUM P 28, pp. 177-185.

Parrish, D.F., J.C. Derber, 1992, The National Meteorological Center's spectral statistical interpolation analysis system, *Monthly Weather Review,* 120, pp. 1747-1763.

Sarrazin R., B. Brasnett, C. Charrette, C. Chouinard, P. Koclas and G. Verner, 2000, Impact of ACARS/AMDAR data in the new CMC 3D-Var analysis system, *34th CMOS Congress, May 2000, Victoria, BC, Canada.*