

Comparison of the CMC analysed fields of Integrated Water Vapour with those retrieved from the SSM/I

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Abstract

On June 19th, 2003 the Canadian Meteorological Centre (CMC) began assimilating Advanced Microwave Sounding Unit-B (AMSU-B) clear-sky brightness temperatures and Geostationary Observing Earth Satellite (GOES) radiances in its 3D-Var global data assimilation system (Chouinard and Hallé 2003). These new satellite data join the AMSU-A level-1b clear-sky brightness temperatures that are already assimilated (channels 3-10 over oceans, 6-10 over land) at CMC since June 7th, 2001 (Chouinard et al. 2002). To prepare for the assimilation of Special Sensor Microwave Imager (SSM/I) brightness temperatures, the CMC analysed integrated water vapor (IWV) fields are evaluated over open oceans by comparing them with SSM/I retrieved IWV. Two comparisons are performed. Firstly, SSM/I IWV fields are compared against analysed fields to measure the impact of assimilating AMSU-A channel 3 (50.3 GHz) which has a non-negligible humidity dependence. Analyses prior to the addition of AMSU-B and GOES data are used for this purpose. Two assimilation cycles are executed: one assimilating AMSU-A channels 3-10 and the other channels 4-10. Secondly, SSM/I IWV is compared with analysed fields of IWV that are derived with and without the additional AMSU-B and GOES data over the same period. Results show that with respect to moisture the impact of assimilating AMSU-A channel 3 is small, but the benefit of assimilating AMSU-B and GOES data is substantial.

Introduction

At the Meteorological Service of Canada recent efforts have aimed to improve the global analyses produced by the Canadian Meteorological Centre's (CMC) operational analysis system by increasing the volume of quality satellite-borne observations that are assimilated. For example, clear-sky brightness temperatures measured by the Advanced TIROS¹ Operational Vertical Sounder (ATOVS) instrument package aboard NOAA's polar orbiting satellites have been introduced to the assimilation cycle over the past 2½ years. Advanced Microwave Sounding Unit-A (AMSU-A) level-1b observations from NOAA 15 and NOAA 16 were added on June 7th, 2001, and from NOAA 17 on December 11th, 2002. AMSU-B data from the three NOAA satellites was added more recently on June 19th, 2003. Also at that time, the assimilation of radiances from the water vapour channel of the GOES-W satellite replaced that of GOES retrievals of dewpoint depression (DPD) that had been included since 1993 (Garand 1993; Garand and Hallé 1997).

Preliminary work is now under way to assimilate Special Sensor Microwave Imager (SSM/I) brightness temperatures in the global cycle. In preparation for the inclusion of this new data source, two sensitivity experiments were conducted using the CMC's 3D-Var assimilation scheme. The aim of the first experiment was to measure the impact of assimilating channel 3 (50.3 GHz) of the AMSU-A instrument, prior to the introduction of the AMSU-B and GOES data. As with the 7 imaging channels of the SSM/I instrument (at frequencies/polarizations of 19.35 V,H, 22.235 V, 37.0 V,H, and 85.5 V,H GHz), channel 3 is sensitive to atmospheric moisture. The objective of the second experiment was to determine how the recent addition of AMSU-B data and the change in the type of GOES data that is assimilated have affected the analysed moisture fields.

Experimental Setup

To evaluate the experiments, retrievals of integrated water vapour (IWV) were employed. These retrievals were derived from open-water, non-precipitating SSM/I observations using a regression algorithm (Alishouse et al. 1990; Petty 1990). SSM/I brightness temperatures from the Defense Meteorological Satellite Program's (DMSP) polar orbiting satellites (DMSP 13, DMSP 14, and

¹ Television Infrared Observation Satellite (TIROS) was the name given to the original polar orbiting satellites in the 1960s, which have since evolved into the NOAA satellite series.

DMSP 15) were applied independently in this exercise, since intercalibration coefficients were not available. For each of the two experiments, there was a CONTROL run and a TEST run. Analysed IWV fields were computed by vertically integrating specific humidity, output by the assimilation cycle in CONTROL or TEST mode, over the 28 CMC global model terrain-following coordinates. These were then interpolated to the SSM/I observation locations for each 6-hr period over the length of the experiment. Mean IWV fields representing the observed values and analysed values were computed on a global 1° x 1° grid using a straightforward binning and averaging technique over the period of the experiment. Finally, the mean analysed IWV fields were compared against the mean SSM/I IWV fields to formulate our conclusions. The results shown below are with respect to the DMSP 15 satellite only, although the DMSP 13 and DMSP 14 results are very similar.

Experiment #1

For the first experiment, the CONTROL configuration (labelled CH3) consisted of the assimilation of AMSU-A data from channels 3 through 10 over a 3 week period in March, 2003 (see Table 1 for a summary of the ATOVS channel parameters). In the TEST configuration (labelled NOCH3), AMSU-A data from channels 4 through 10 were assimilated over the same period. In both cases, humidity profiles from GOES-W and GOES-E were also assimilated. To allow for a period of stabilization after the removal of channel 3 in the NOCH3 simulation, only the last two weeks of data were analysed (i.e. March 8th to March 21st). Additionally, statistics were calculated for grid boxes that contained a minimum of 50 SSM/I observations. This represents 9-10% of the observations that would normally occur during a 2 week period within a 1° x 1° sized box (no filtering).

Table 1: ATOVS Channel Parameters

ATOVS Channel No.	AMSU-A Channel No.	Frequency (GHz)	Polarization
1	1	23.8	V
2	2	31.4	V
3	3	50.3	V
4	4	52.8	V
5	5	53.596	H
6	6	54.4	H
7	7	54.94	V
8	8	55.5	H
9	9	57.29	H
10	10	57.29	H
11	11	57.29	H
12	12	57.29	H
13	13	57.29	H
14	14	57.29	H
15	15	89.0	V
	AMSU-B Channel No.		
16	1	89.0	H
17	2	150.0	H
18	3	183.31	H
19	4	183.31	H
20	5	183.31	H

Experiment #1 Results

In Figure 1a the difference between the mean observed IWV field and the mean analysed IWV field for CH3 is given. Generally, it can be concluded that the model has underestimated the amount of atmospheric moisture over tropical regions, particularly over the Indian Ocean. A very large surplus of moisture in the analyses is evident over the southern Pacific Ocean, just off the west coast of South America. It has been noted by Deblonde (1999) that this positive bias is attributed to an overestimation of humidity by the GOES DPD retrievals as a consequence of persistent marine stratocumulus clouds. In contrast, the dry bias evident west of South America along the equator is attributed to clear skies. Neither area is handled well by the procedure used to derive vertical humidity profiles from GOES radiances since radiosonde observations required to calibrate the retrievals are

not available. The cloud distribution described above was verified over the period of the experiment by cloud liquid water charts produced by Remote Sensing Systems (RSS) Inc.² (not shown).

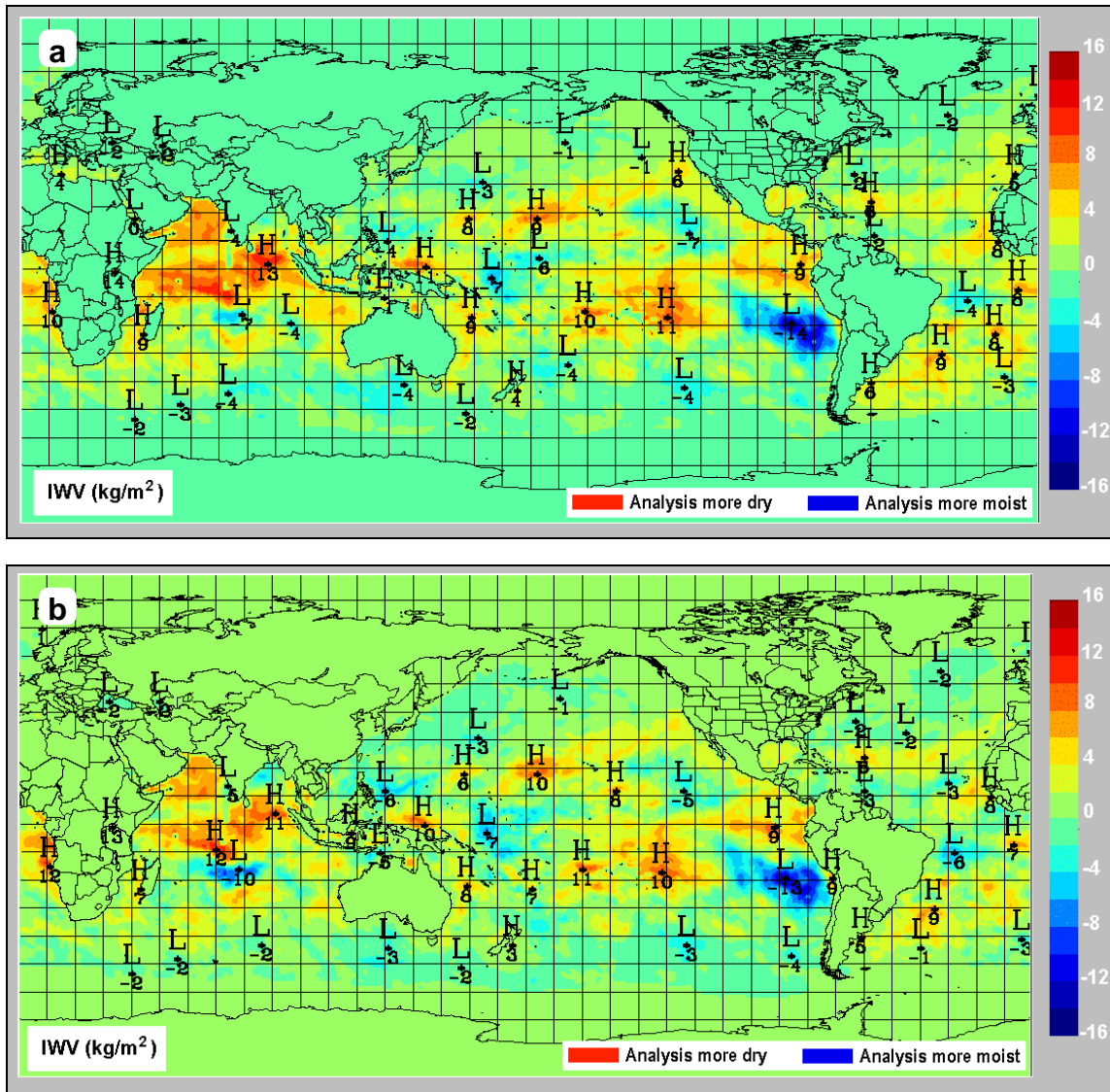


Fig. 1: Observed IWV (kg m^{-2}) minus analysed IWV for CH3 run (a) and for NOCH3 run (b) of Experiment #1.

From the high degree of similarity between Figure 1a and Figure 1b, it is evident that the exclusion of AMSU-A channel 3 from the assimilation process does not result in any obvious positive or negative impact on the analyses, with respect to moisture. As expected, the strong positive anomaly off the west coast of South America is not affected by the absence of channel 3 data in NOCH3.

Statistics for the two runs are summarized in Figure 2. Generally, the analysed IWV field correlates equally well with the observed field, regardless if channel 3 is assimilated or not. However, the biases show an improvement in most regions, except between 20°S to 60°S , when channel 3 observations are excluded. A large reduction in positive bias in the tropics primarily reflects an increase in moisture over the Indian Ocean. The changes to standard deviation are negligible. A plot of the zonally averaged difference in analysed IWV between CH3 and NOCH3 over the entire globe (Figure 3) further demonstrates the moistening that has occurred over tropical and northern mid-latitude regions. As well, drying is observed over a narrow southern middle-latitude band as a result of the removal of AMSU-A channel 3.

² available at www.ssmi.com.

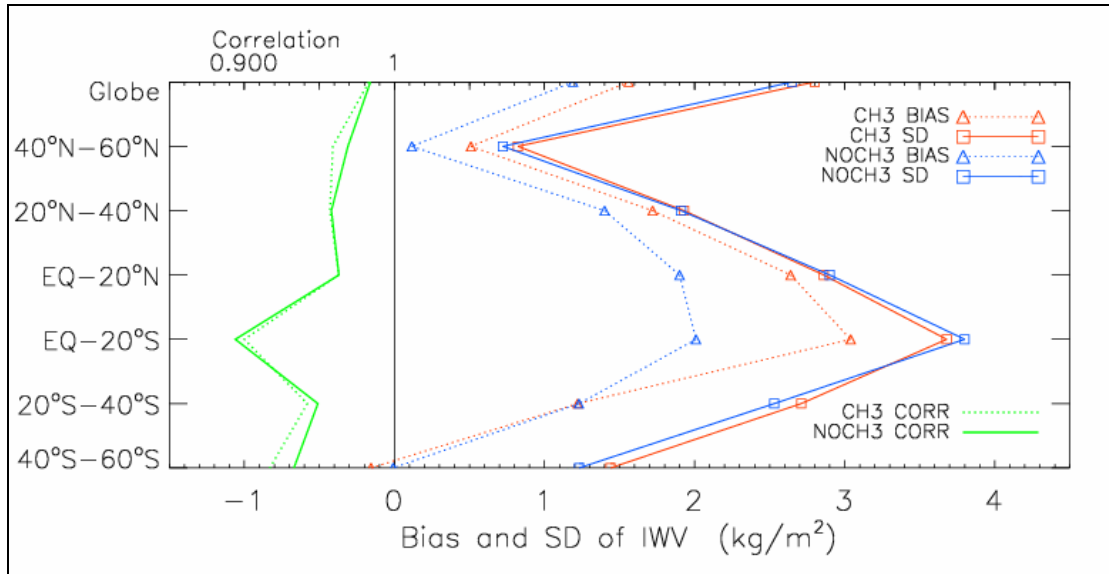


Fig. 2: Bias (dashed blue/red lines), standard deviation (solid blue/red lines), and correlation (green lines) statistics for CH3 and NOCH3 runs of Experiment #1 with respect to DMSP 15 observations. Statistics are computed over 6 latitude bands between 60°S and 60°N, and for the globe (top of chart).

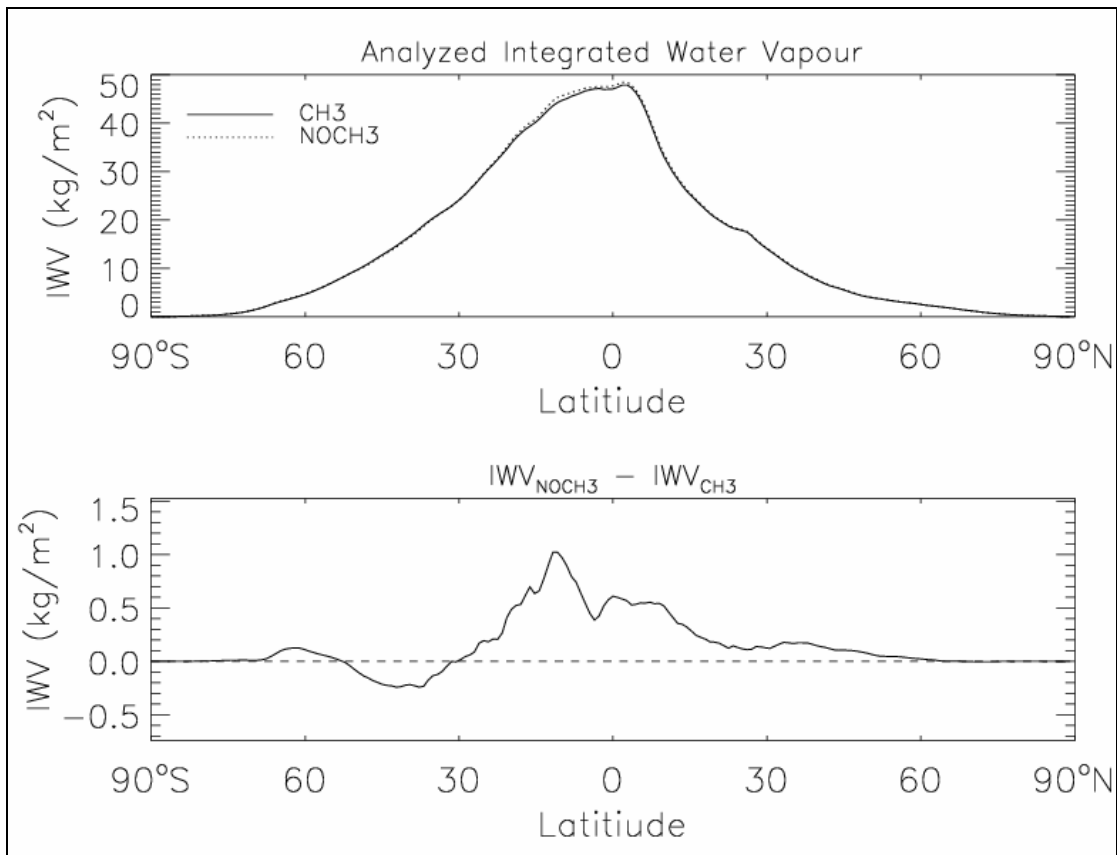


Fig. 3: Zonally averaged analysed IWV (kg m^{-2}) for CH3 and NOCH3 runs of Experiment #1; absolute values (top) and difference field (bottom).

Experiment #2

For the second experiment, the CONTROL simulation (labelled NOAMSUB) assumed the CMC's operational configuration of the assimilation process during the month of May, 2003. In this

arrangement, AMSU-A clear-sky observations (channels 3-10) from NOAA 15, NOAA 16, and NOAA 17 and vertical humidity retrievals from the GOES-W satellite were assimilated (GOES-E data was unavailable for the month of May). The experimental configuration (labelled AMSUB) assumed the CMC's parallel configuration during the same period. In this arrangement, AMSU-A (channels 3-10) and AMSU-B (channels 2-5) clear-sky brightness temperatures from the NOAA 15, NOAA 16, and NOAA 17 polar orbiting satellites were assimilated. As well, direct assimilation of radiance observations from the water vapour channel of GOES-W replaced the assimilation of GOES retrievals of DPD. Statistics were calculated for grid boxes that contained a minimum of 100 SSM/I observations. Again, this represents 9-10% of the observations that would normally occur during a 31 day period within a $1^\circ \times 1^\circ$ sized box.

Experiment #2 Results

Similar to Figure 1a, the difference between the mean observed IWV and the mean analysed IWV for NOAMSUB for the month of May shows a model that underestimates the amount of atmospheric moisture in tropical areas and slightly overestimates it over the southern latitude oceans and the northern Pacific ocean (see Figure 4a). However, the large moisture surplus noted off the west coast of South America in Figure 1a is negligible in the May plot. The monthly mean cloud liquid water map produced by RSS for May confirms that there was much less marine stratocumulus in the area over the period. Nonetheless, significant moisture deficits and surpluses in the analyses remain in the NOAMSUB simulation over the northwestern and far eastern Indian Ocean, the far western Pacific Ocean, the northern equatorial Pacific, and much of the Atlantic Ocean. Large differences in moisture over the Atlantic Ocean between the NOAMSUB run and the CH3 run of Experiment #1 are due to the absence of GOES-E data in the former simulation.

The mean difference field produced when AMSU-B data and GOES radiances are assimilated is given in Figure 4b. It is clear that the additional data is providing valuable information to bring the analysed moisture fields much closer to the SSM/I moisture fields. In particular, the amplitudes of the significant dry biased regions have been reduced by a factor of at least two. Two prominent moisture surplus regions previously noted over the equatorial Pacific Ocean have also been brought inline with DMSP 15 observations by the AMSUB simulation.

Computing the difference between the mean analysed IWV fields that were produced by the NOAMSUB and AMSUB runs illustrates the intense, localized changes to the global humidity levels that have occurred (Figure 5). It is interesting that these changes are specifically targeting the most problematic areas identified in the NOAMSUB simulation.

A summary of statistics similar to that produced for Experiment #1 is provided in Figure 6. From this information, it is easy to conclude that the assimilation of the new data has a remarkable positive impact on the analyses. In all regions, the mean AMSUB IWV values correlate much better with SSM/I observations - between 60°S and 60°N the correlation has increased from 0.932 to 0.977. A global moistening of the analyses in the AMSUB cycle is evident by comparing the bias statistics. In the zone bounded by 40°S and 60°S there is a small deterioration in the analysed humidity as regions where the moisture is already overestimated become more humid. Between 40°N and 60°N the additional data has a neutral effect as the bias changes from slightly positive to slightly negative. In the tropical and extratropical areas in between, however, the increase in moisture is beneficial as it reduces a dry bias. In all regions the additional data gives a notable decrease in the standard deviation of IWV with respect to SSM/I observations. The largest gains are made in the tropics, where the standard deviation actually becomes smaller in magnitude than the bias. Hence, there are still improvements to be made, which perhaps could be realised by the assimilation of SSM/I data.

Incidentally, one of the more weakly correlated regions in the NOAMSUB run is the band EQ to 20°N , which may be due to areas of intense convection associated with the Inter-Tropical Convergence Zone (ITCZ). This hypothesis is supported by Figure 2 which shows that in the March experiment the most weakly correlated band was EQ to 20°S , where portions of the ITCZ would have resided at a time of the year closer to Southern Hemispheric summer.

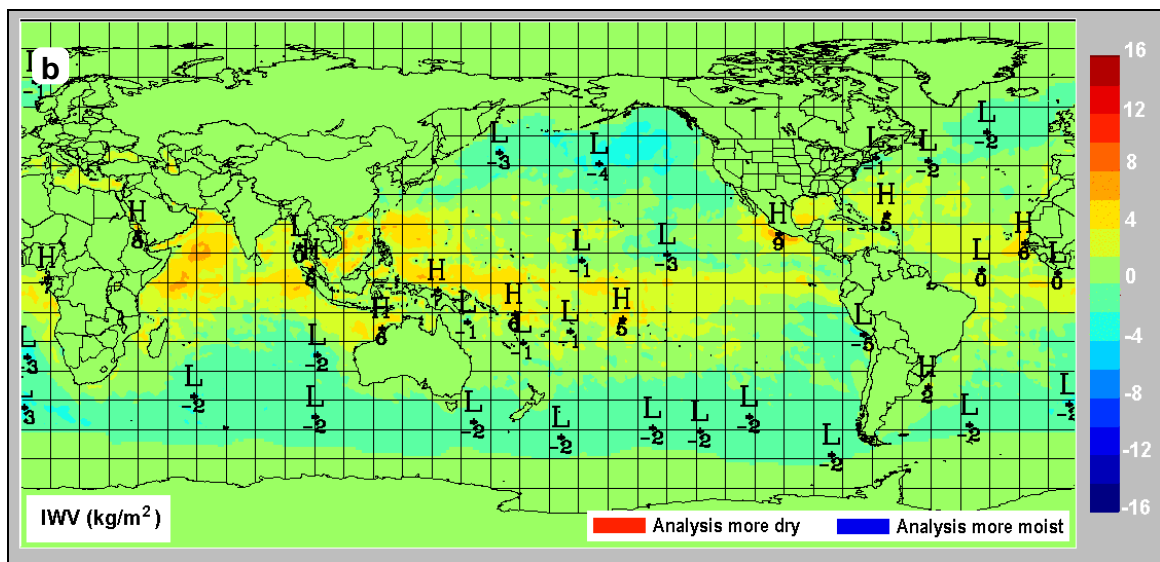
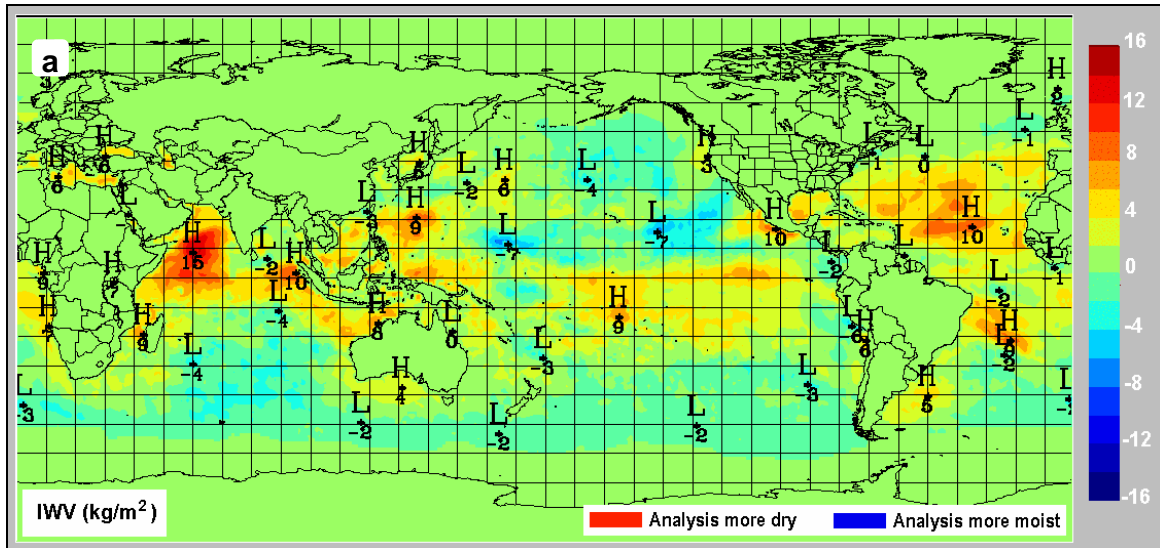


Fig. 4: Observed IWV (kg m^{-2}) minus analysed IWV for NOAMSUB run (a) and for AMSUB run (b) of Experiment #2.

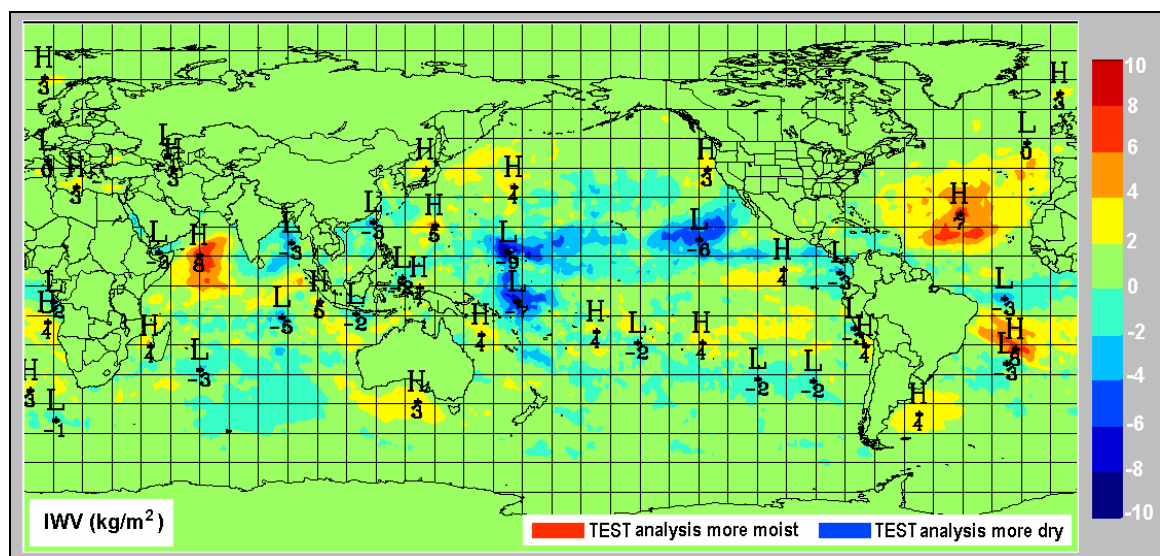


Fig. 5: Analysed IWV (kg m^{-2}) for AMSUB run minus that for NOAMSUB run of Experiment #2.

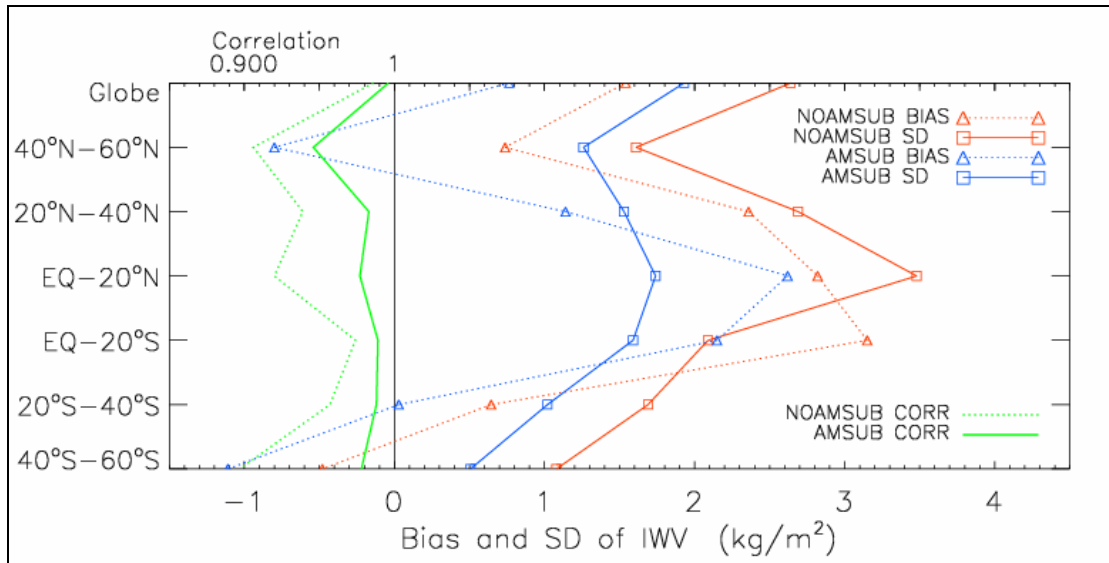


Fig. 6: Same as in Fig.2 except for NOAMSUB and AMSUB runs of Experiment #2.

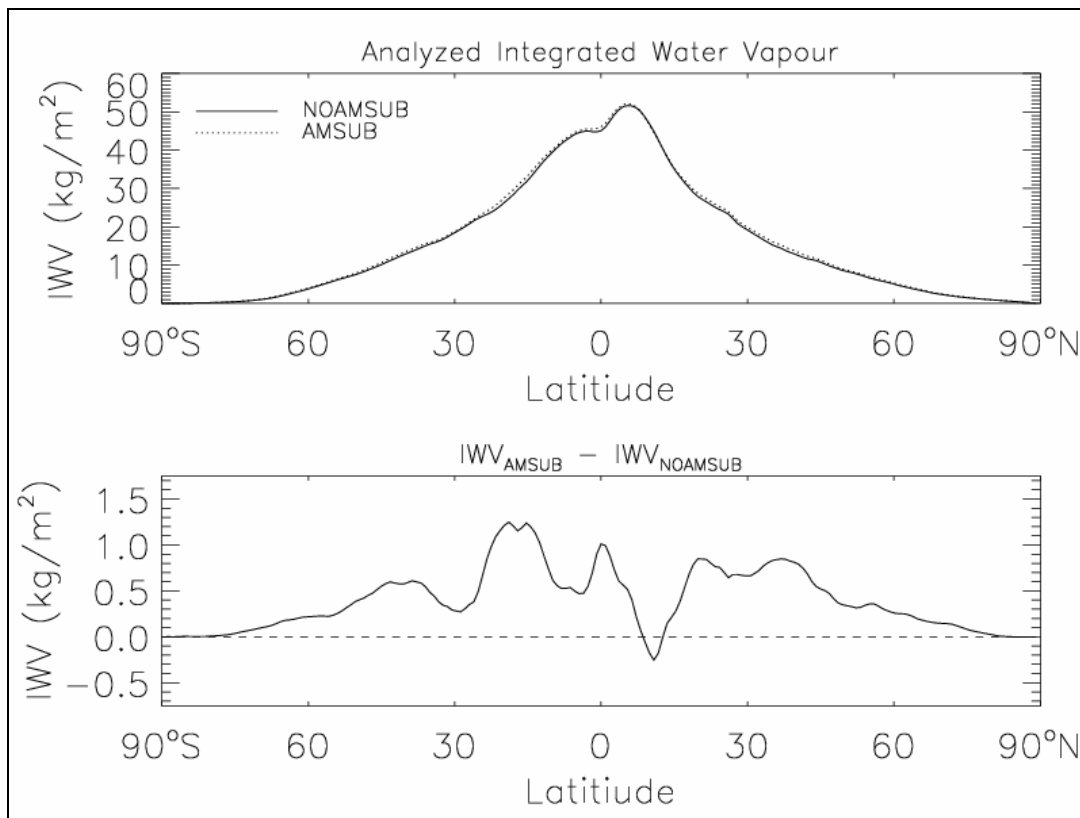


Fig. 7: Same as in Fig. 3 except for NOAMSUB and AMSUB runs of Experiment #2.

Zonally averaged changes to the mean analysed IWV field brought about by the new assimilation setup are illustrated in Figure 7. This chart verifies that the additional data works to increase the amount of moisture in the analyses almost everywhere on the globe. The exception is a small amount of drying which occurs in the subsidence band located just north of the ITCZ. Figure 8 depicts the vertical structure of changes to the mean specific humidity field. From the bottom panel it is evident that the drying near 10-12°N occurs in the lowest 100-200 hPa of the atmosphere. Otherwise, the most significant relative increases in moisture occur between 15°S and 55°S at 850 hPa (max. of 13.0%), and directly over the equator at 500 hPa (11.0%). This is not surprising since the AMSU-B channels peak at higher altitudes in a tropical air mass and at lower altitudes in a cooler, extratropical air mass.

As well, satellite data plays a larger role in the Southern Hemisphere due to more data being assimilated over open waters and fewer land-based observations. Changes to the humidity field between 60° latitude and the poles are considered insignificant due to the lack of absolute moisture in these regions.

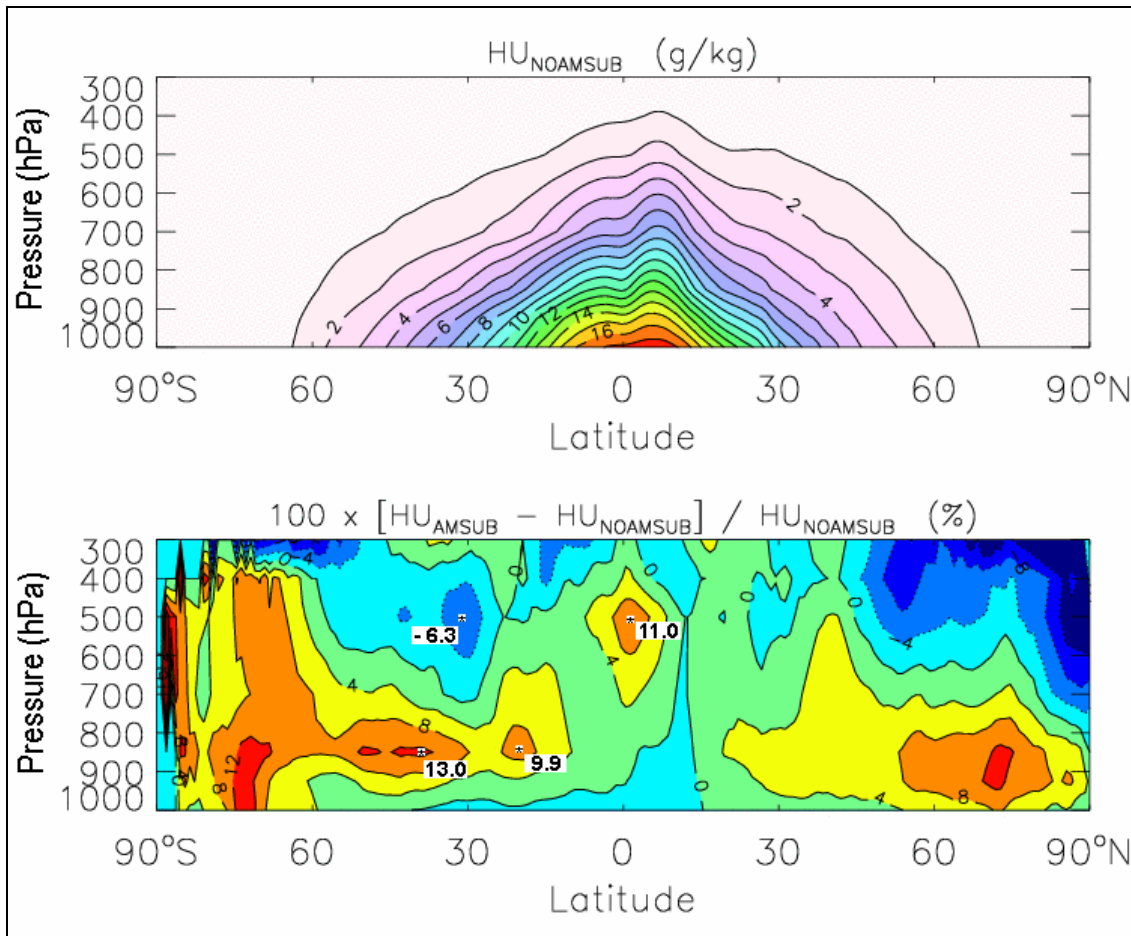


Fig. 8: Zonal averages of the mean analysed specific humidity (g kg^{-1}) for NOAMSUB and AMSUB runs of Experiment #2; absolute value for NOAMSUB (top) and relative change (bottom).

Conclusions

Two assimilation experiments were conducted in an effort to answer the following questions:

- 1) What is the significance of assimilating AMSU-A channel 3 brightness temperatures (over open oceans) in the production of CMC analyses?
- 2) How has the addition of AMSU-B brightness temperatures and the replacement of GOES DPD retrievals by GOES water vapour channel radiances affected the analyses?

To address the first question, two assimilation cycles were studied over a three week period in March of 2003. In one simulation, observations from AMSU-A channels 3 through 10 were assimilated. In the second, only observations from AMSU-A channels 4 through 10 included. Mean IWV fields were calculated from the analyses output over the final two weeks of each cycle, and compared against mean IWV fields calculated from SSM/I observations. Differences in the global distribution of moisture indicated that the inclusion of channel 3 radiances produces a less humid atmosphere over the tropics and northern latitudes, and a mildly more humid atmosphere over the southern mid-latitudes. Drying of the atmosphere over much of the globe when channel 3 is included slightly deteriorates the analyses when compared against SSM/I observations. Standard deviation and correlation statistics remain largely unaffected whether channel 3 is assimilated or not. Thus, the

impact with respect to moisture of including channel 3 in CMC's global assimilation cycle is concluded to be small. Note, AMSU-A channel 3 is also sensitive to temperature. However, its effect on analysed temperature fields was not explored in this study.

In response to the second question, operational analyses were extracted from CMC archives for the month of May, 2003. These analyses were produced with the assimilation of AMSU-A channels 3-10 brightness temperatures and GOES DPD retrievals. During the same period, a parallel run was executed at CMC whereby the GOES humidity profiles were removed from the assimilation process, and measurements from AMSU-B channels 2-5 and the GOES water vapour channel were added.

Differences between the monthly mean IWV fields computed from operational (NOAMSUB) and parallel (AMSUB) analyses with that derived using SSM/I observations show a significant improvement in the parallel configuration. More specifically, the inclusion of AMSU-B brightness temperatures results in more humidity being captured in the analyses, which for areas bounded between 40°S and 40°N reduces a prominent dry bias. Between 40°N and 60°N, the dry bias becomes a wet bias, and between 40°S and 60°S a wet bias becomes slightly larger in magnitude. In all regions, but especially the tropics, a notable reduction in standard deviation is observed. The newer moisture fields correlate much more strongly with SSM/I than in the previous design. An analysis of 2-D global plots of mean IWV from NOAMSUB and AMSUB shows that the largest differences with SSM/I are greatly reduced. The effect of assimilating the GOES-W water vapour channel cannot be determined in this study since this channel peaks at higher, less humid altitudes which were not a focus of the plots and statistics shown. The parallel version of the assimilation scheme became operational at CMC on June 19th of 2003.

In the coming months work will be performed to examine the effect of assimilating SSM/I brightness temperatures in the AMSUB configuration of Experiment #2, to see if the moisture fields can be improved even more.

References

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