

Recent Development of ATOVS usage in Korea Meteorological Administration

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Abstract

The ATOVS radiance data has been assimilated operationally at the Korea Meteorological Administration since December 2004. The 1dVar is applied as a quality control before the radiance assimilation. The bias correction is done in 1dVar and bias corrected innovation is passed to the 3dVar. The scan angle and air mass bias correction is performed. The predictors for the air mass bias correction is AMSU A 5,7, and 9 channels and SST. The observation error is not fixed but computed from the innovation and background error covariance in radiance space at every soundings. The observation error helps to present the details of atmospheric situation. The analysed ozone profile is used for the radiative transfer model. The impact is small yet but it can be important to assimilate ozone channels in future. The forecast results of direct assimilation are verified. The impact is significant most of the area including the Northern Hemisphere. Typhoon track is well predicted and it is assumed that strength and location of the north pacific high pressure is precisely analysed with the help of ATOVS data.

1. Introduction

Many operational centers adapt variational method as a numerical weather prediction (NWP) analysis scheme. The variational analysis method is global minimization and can get more balanced analysis than the traditional optimal interpolation method, which is local minimization in getting the analysis. Another advantage of the variational analysis is that it can assimilate asynoptic data such as satellite radiation effectively by using observation operator, while the traditional optimal interpolation is difficult to assimilate asynoptic data (Coutier et al., 1998; Deber and Bouttier, 1999; Lorenc et al., 2000; Rabier et al. 1998). The Korean Meteorological Administration (KMA) has replaced the traditional statistical interpolation method at the end of 2003 in order to get a better analysis over the ocean by assimilating satellite radiance data directly.

In this study, the direct assimilation of ATOVS data is developed and the method is described in Section 2. The analysis and forecast results with the direct assimilation are compared with that of the operational one at KMA in Section 3. The summary and discussion is in Section 4.

2. Method

a) 3dVar

The 3 dimensional data assimilation method is originated from the Japan Meteorological Agency (Takeuchi and Tsuyuki, 1999). The analysis variables are vorticity, unbalanced divergence, unbalanced surface pressure and temperature, and logarithm of specific humidity on hybrid sigma level and in spectral space. The incremental method is adapted with the resolution of inner loop of T63 and outer loop of T213.

The background error covariance is a block diagonal matrix. It is assumed that the horizontal error correlation is uncorrelated by using the spectral coefficient under the condition with the homogeneity and isotropy. The error correlation between variables is removed by using the unbalanced part of the variables. The linear balance equation is used to remove the balance component between mass and wind field and the constraints of the balance vary depending on the latitude (Daley, 1996). However the vertical correlation is explicitly considered to make the background error covariance block-diagonal. The latitudinal dependency of the vertical error correlation is considered.

For operational use, the typhoon bogus technique is applied to the background before the analysis depending on the Fujita formulation (Fujita, 1952). The global model at KMA is spectral model of which truncation is T213 and therefore the background of the analysis is spectral coefficient and the analysis increment in spectral space is directly used as an initial field of the global model.

b) Direct Assimilation

For the satellite data assimilation, the ATOVS level-1d radiance data is used directly in the 3DVAR system. As the 3dVar in KMA has no outer loop, all the radiance data passed to the analysis is used in the minimization, and therefore the quality control of the radiance data is extremely important. The 1dVar is processed before the direct assimilation as a quality control. The bias corrected radiance innovations which is successfully minimized in the 1dVar can be passed to the 3dVar for the direct use of radiance. In 1dVar, the innovation of HIRS 1-8, 10-15 and AMSUA 4-11 are calculated only over the ocean and cloud information retrieved from the NESDIS is used to calculate the cloudy radiance. If the bias corrected departure of window channel (HIRS 8 is used) exceeds 1.5 degree, the cloud information is assumed to be wrong and the data is rejected. If the calculated radiance exceeds 350K or less than 150K, the data is rejected. The number of innovations of which absolute values are less than 4 degree are less than 4 channels the sounding is rejected.

The bias correction is based on the method proposed by Eyre (1992) and the channel predictors of the air mass bias are HIRS 1 AMUS-A 5, 7, and 9. Scan angle bias correction coefficients depend on the 6 binned satellite zenith angles (0-5degree, 5-15, 15-25, 25-35, 35-45, 45-above) and the direction is ignored. The control variables in 1dVar are temperature, specific humidity on the standard pressure levels up to 10hPa, surface pressure, and horizontal winds over the sea surface. The other data necessary for the radiative transfer model (RTTOV version 7 is used in this study) is from climatology(i.e. ozone profile), from NESDIS retrieved profile(i.e. temperature above model top and humidity above 300hPa), and from NOAA surface analysis(i.e. SST).

The background error of 1dVar is independently calculated from the 3dVar background error. The

3dVar background errors are calculated from the difference between 24 and 48 hours forecasts of spectral coefficient on model's hybrid sigma level using the NMC method. However, the 1dVar background errors are calculated from 24 and 48 hour forecasts difference of physical variables converted into physical space of standard pressure level and the Gaussian grid.

The observation error of the radiance is calculated for each radiance observation. The observation error is calculated by using the relationship between innovation and background error in the radiance space. This method can help to get the objective value of the observation error and can be directly related to the current situation of the weather. The details are in Joo and Lee(2002).

The 3dVar formulation and flow charts are in Figure 1. In figure 1, J_{inc} is the cost function, η stands for the control variables, D means innovations, H is tangent linear of observation operators and it is radiative transfer model for radiance observation. δx is control variables multiplied by the background error, and the superscript T and -1 mean matrix transpose and inversion respectively. B means background error covariance matrix, R is observation error, x_b means background, y is observation, H is observation operator.

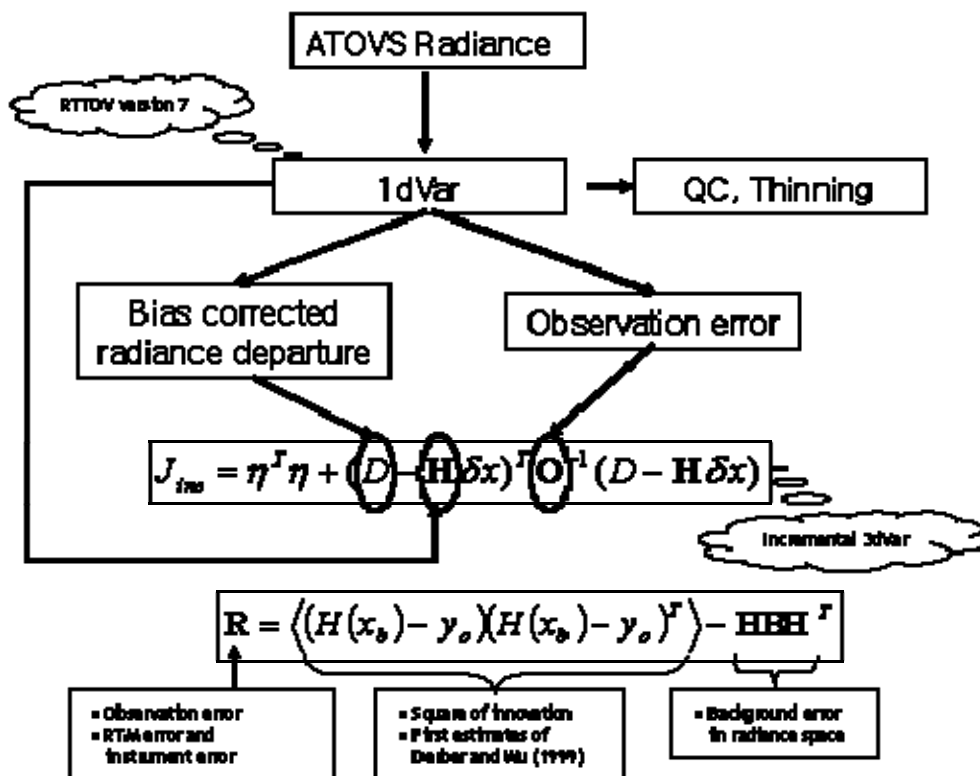


Figure 1. Schematic diagram of direct assimilation in KMA. The symbols are explained in the text.

c) Basic state update

The basic state of tangent linear operator is not fixed during the minimization and it is necessary to update the basic state at every iteration. However, it requires lots of computing time and most of the centers do not update the basic state of the tangent linear operator. The radiative processes are highly non-linear compared to the other transforms in observation operator and it is necessary to check the validity of

the fixed basic state during the minimization. For simplicity, the 1dVar is used instead of 3dVar. The 1dVar analysis results from a fixed basic state are compared with that of updated one. The correlations of the results are shown in table 1. Except the upper level humidity retrievals, most of the results show high correlation coefficient and even in the radiative processes are highly non-linear, it might be reasonable to use the fixed basic state during the minimization. With this results, the basic state is fixed during the minimization in this study.

Table 1. The correlation and linear regression coefficient between the 1dVar analysis with updating the basic state of observation operator and that of fixed basic state.

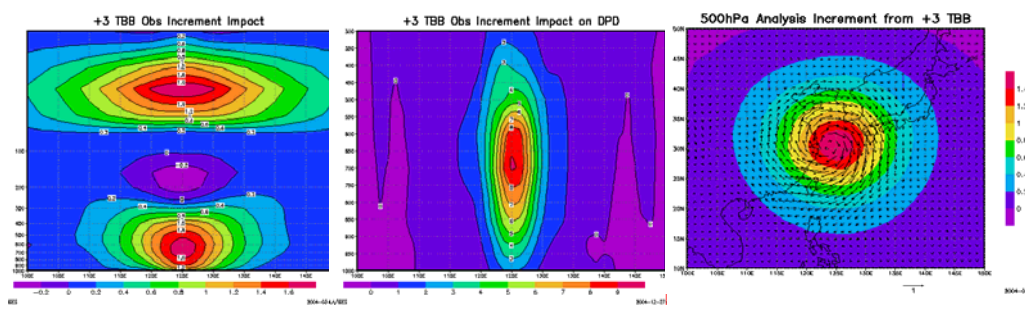
Variable	Corr Coef	Reg Coef		Variable	Corr Coef	Reg Coef	
		Intercept	Slope			Intercept	Slope
SFC T	1	0.481	0.998	SFC q	1	0.022	0.998
1000 T	1	0.624	0.998	1000 q	1	0.027	0.997
925 T	1	0.569	0.998	925 q	1	0.035	0.993
850 T	1	0.315	0.999	850 q	0.999	0.033	0.987
700 T	1	0.003	1	700 q	0.999	0.049	0.983
600 T	1	-0.31	1.001	600 q	0.999	0.06	0.985
500 T	1	-0.837	1.003	500 q	0.998	0.069	0.985
400 T	1	-1.426	1.005	400 q	0.992	0.06	0.982
300 T	0.998	-1.384	1.005	300 q	0.993	0.017	0.987
250 T	0.999	-0.274	1.001	MSLP	1	0.683	0.999
200 T	1	0.395	0.998	SFC U	1	-0.032	1.001
150 T	1	-0.445	1.002	SFC V	1	-0.007	1.001
100 T	1	0.086	1				
70 T	1	0.141	0.999				
50 T	1	0.103	1				
30 T	1	0.033	1				
20 T	1	0.011	1				
10 T	1	-0.005	1				

d) One point observation experiments

At 125E and 30N, a radiance innovation of which departure is +3 degree is assimilated to verify the spread of information. The temperature and humidity increments are shown in figure 3. Most of the levels, analysis increment of temperature is positive as expected. However, there are negative increments near the tropopause. The reason is assumed to be caused by the negative error correlation structure in 3dVar. The temperature error correlation structures are shown in figure 3. The humidity is dew point depression and positive value means decrease of humidity in the atmosphere. The positive innovation in humidity

channel means less humidity in the observation and analysis becomes drier than the background. The results are the same as we expected and direct assimilation is working properly.

Figure 3. Analysis increment of temperature(left), dew point depression(center), and wind vector and geopotential height(right) caused by the one point radiance observation located at 125E/30N.



3. Results

a) RAOB fits

Analysis results are verified against collocated radiosonde observation from 14 December 2003 to 28 December 2003 (Fig. 4).

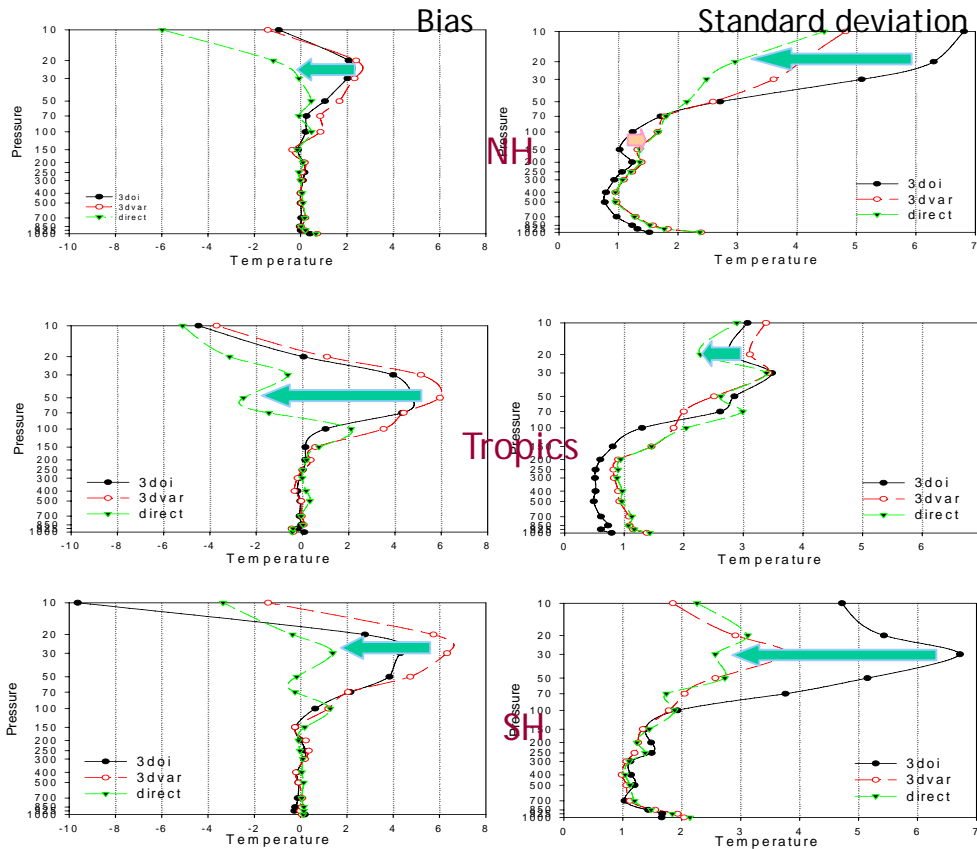


Figure 4. Averaged analysis verification against RAOBs from 14 December 2003 to 28 December 2003. 3dOi, 3dVar and direct stand for the verification of 3dimensional optimal interpolation, 3dVar without direct assimilation of ATOVS data, and 3dVar with direct assimilation respectively.

As a reference, the analysis results of 3dOI are also shown. The bias is much reduced with the direct assimilation especially over the stratosphere, while there is no improvement in the troposphere. It means that the satellite data is more effective in the stratosphere than in the troposphere as the in-suit observation is limited in the stratosphere. In the northern hemisphere and the tropics, the bias is increased at the model top. The reason is not clear yet and need more investigation on this problem. The standard deviation is improved mainly over the stratosphere like bias and it is most distinctive over the northern hemisphere. In the troposphere, the standard deviation is smallest in the 3dOI case. The initialized filed is also verified to find out the reason of better fit of 3dOI. The RAOB fit of background, analysis, and initialized filed are shown in Fig. 5. The 3dOI analysis fit well to the RAOB, however, the initialized filed move away from the RAOB and come close to the background. It means the 3dOI analysis is done locally and fit well to the nearby RAOB but the analysis field is not well balanced. Therefore during the initialization process, the analysis moves away from the RAOB to keep the balance. On the contrary, the 3dVar shows no changes between analysis and initialized filed. It means the 3dVar analysis is already well balanced and can get more optimal solution than the 3dOI.

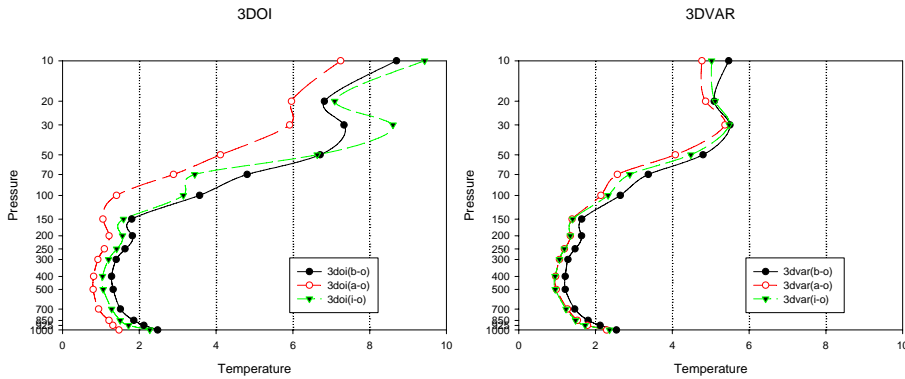


Figure 5. Averaged RAOB fits of background, analysis and initialized filed against RAOBs from 14 December 2003 to 28 December 2003. The 3dOI, 3dVar stand for the verification of 3dimensional optimal interpolation, 3dVar respectively.

b) Forecast verification

The global 10 day forecasts are produced with assimilating the ATOVS radiances. The radiances are assimilated 6 hourly in the global numerical weather system in Korea Meteorological Administration and 10 day forecast is produced at every 12 UTC. The experiment period is from 24 December 2003 to 7 January 2004 for the winter season and from 4 April to 31 July 2004 for the spring and summer season. The experiment is referred as DG3V hereafter. Another experiment named G3VR is performed which is identical to the DG3V except assimilating the ATOVS data in retrieved form instead of radiance itself. The 10 day forecast of both experiments are verified against it own analysis. Figure 6 shows the results for the 500hPa geopotential height in the northern hemisphere, the tropics and the southern hemisphere.

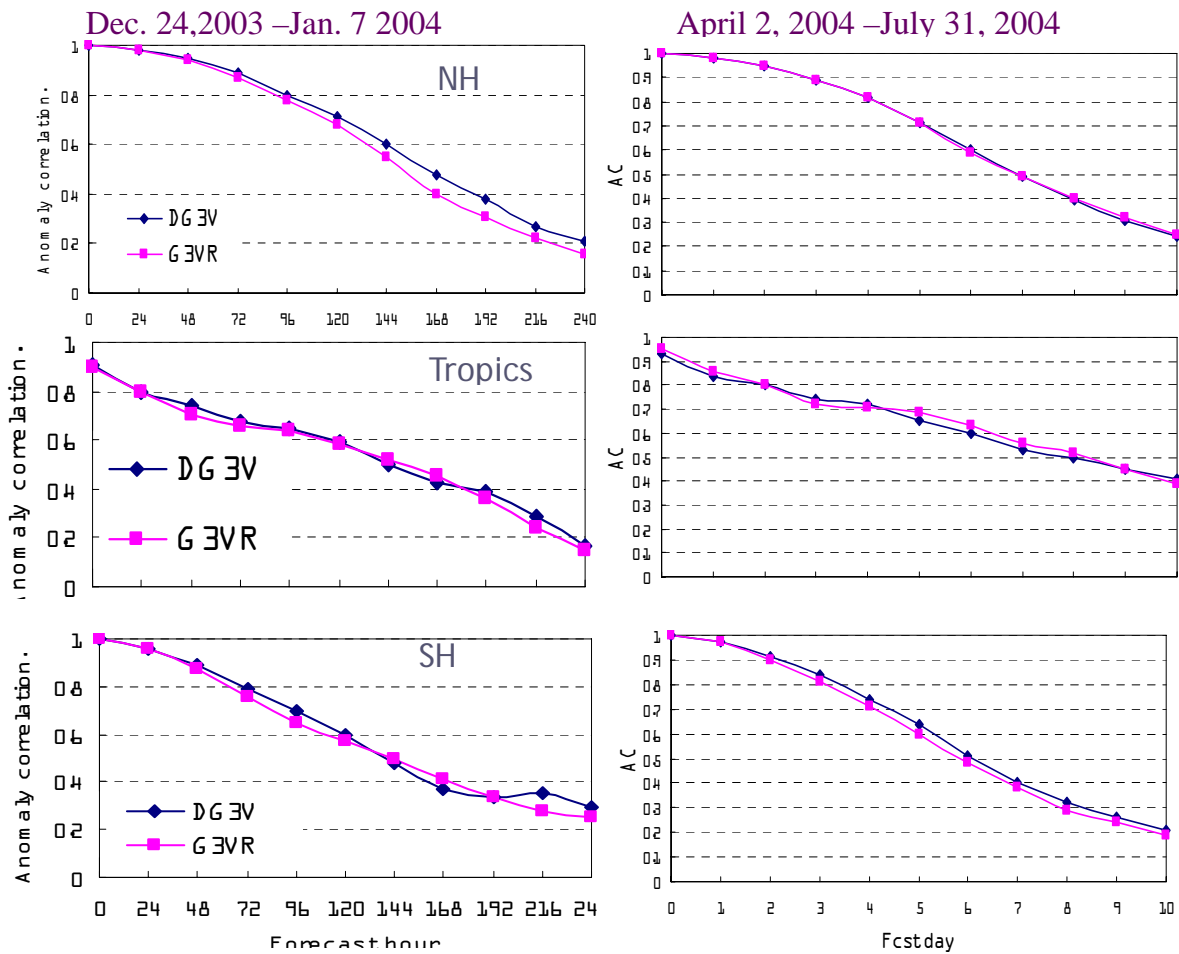


Figure 6. Anomaly correlation of 500hPa geopotential height forecast for the DG3V and G3VR experiments. Left panel is for the winter case and right panel is for the spring and winter case. Top, middle and bottom is for the Northern Hemisphere, Tropics, and the Southern Hemisphere, respectively.

In the winter case, the impact of radiances is positive all the area and most significant in the Northern Hemisphere and the positive impact become stronger after 5 day forecast. For the spring and summer case, the impact is almost neutral in the Northern Hemisphere and in the Tropics, and positive impact is shown in the Southern Hemisphere.

c) Typhoon Track Forecast

The radiances are assimilated only over the ocean in this study as the surface emissivity over a land is very difficult to calculate accurately. The typhoon track is strongly affected by the surrounding air flow over the ocean and the accuracy of typhoon track forecast can be used to estimate the quality of analysis over the ocean. Therefore the error of typhoon track forecast is verified to evaluate the analysis over the ocean by assimilating the ATOVS data. All the typhoons which come near the Korean peninsula during the experimental period are used to calculate the track error and the averaged errors are shown in Fig. 7.

The typhoon track errors are much reduced with the help of radiance assimilation. The typhoon track error is reduced about 200km at 72 hour forecast and the peak error reduction is about 450 km at 168 hour forecast.

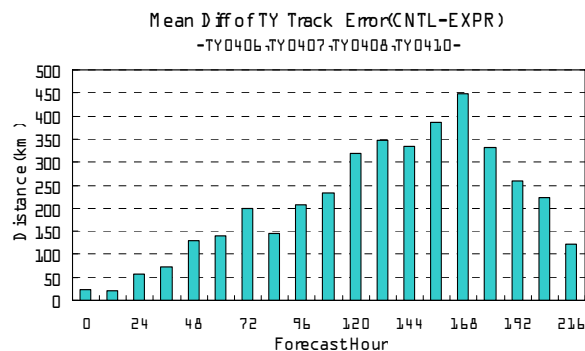


Figure 7. Difference of mean track errors of Typhoon forecasts in 2004(G3VR-DG3V).

4. Discussion

The impact of radiance assimilation in the Korea Meteorological Administration's global numerical weather forecast is evaluated. The general performance showed positive impact in analysis and forecast. Especially, the typhoon track forecasts are quite much improved.

However, after long term parallel experiment, it shows a drift of upper level temperature forecast in the tropics. The fit of background to the radiance observation was increasing especially at the stratospheric channels (Fig. 8).

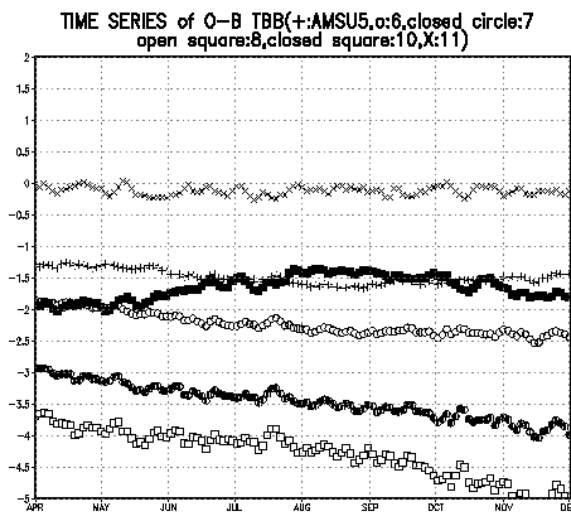


Figure 8. Time series of radiance innovation from 2 April to 31 December 2004 for AMSUA channel 5, 6, 7, 8, 10, and 11.

It resulted in a degrade of forecast skill in the tropics. With extensive investigations, it was found that the increasing innovation was caused by the bias correction method applied in radiance assimilation. The bias correction in this study based on the Eyre(1992)'s method and therefore the bias correction moves

observation to the average value of background. If the model forecast has strong bias, the bias cannot be corrected by the radiance assimilation if the bias correction is applied. In KMA, there is a strong warm bias at the stratosphere (see Fig. 8). The bias correction is only applied at the tropospheric channel radiances to correct the warm model bias at the stratosphere. No bias correction at the stratospheric channels can help to reduce warm bias at the stratosphere temperature forecast. However, it makes the forecast temperature warmer below the tropopause (Fig. 9), and is found to be caused by a negative temperature background error correlation between stratosphere and upper troposphere.

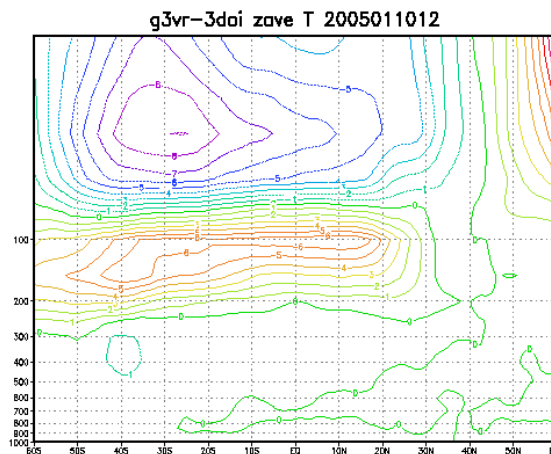


Figure 9. Difference of zonal mean temperature between DG3V and G3OI (The DG3V and G3OI is explained in the text).

The bias correction is applied not only for the tropospheric channels but also for the stratospheric channels and the same cycle experiments as DG3V are done (This new experiment is named BIAS). The results show no model drift and forecast results are better than the DG3V experiment (Fig. 10), but the warm model bias at the stratosphere remains. It is necessary to find a way to remove warm model bias at the troposphere in the future.

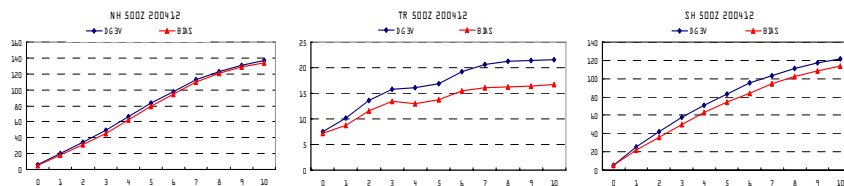


Figure 10. One month averaged root mean square error of 500hPa geopotential height forecast for the DG3V and BIAS experiments (DG3V and BIAS is explained in the text). Left, middle, and right panels are for Northern Hemisphere, Tropics, and the Southern Hemisphere, respectively.

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