Introduction of variational bias correction technique into the JMA global data assimilation system

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Variational bias correction technique (VarBC), which was originally developed at NCEP (Derber and Wu 1998), has been introduced into the JMA global data assimilation (DA) system in May 2006. The technique is an adaptive bias correction technique. In the DA system with VarBC, observation operators and control variables are extended to include bias correction procedures. The bias correction coefficients are optimized as control variables in the each analysis.

The formulation of the VarBC is based on Dee (2004). The extended control variable $\mathbf{z}$ is defined as $\mathbf{z}^{\mathrm{T}} = [\mathbf{x}^{\mathrm{T}}, \boldsymbol{\beta}^{\mathrm{T}}]$, where $\mathbf{x}$ means the control variables and $\boldsymbol{\beta}$ the bias correction coefficients. Extended cost function J is defined as follows:

$$J(\mathbf{z}) = \frac{1}{2}\left(\mathbf{x}-\mathbf{x}^{\mathrm{b}}\right)^{\mathrm{T}}\mathbf{B}^{-1}\left(\mathbf{x}-\mathbf{x}^{\mathrm{b}}\right) + \frac{1}{2}\left(\boldsymbol{\beta}-\boldsymbol{\beta}^{\mathrm{b}}\right)^{\mathrm{T}}\mathbf{B}_{\beta}^{-1}\left(\boldsymbol{\beta}-\boldsymbol{\beta}^{\mathrm{b}}\right) + \frac{1}{2}\left(\tilde{H}\left(M(\mathbf{x})\right)-\mathbf{y}^{\mathrm{o}}\right)^{\mathrm{T}}\mathbf{R}^{-1}\left(\tilde{H}\left(M(\mathbf{x})\right)-\mathbf{y}^{\mathrm{o}}\right)$$

$$\tilde{H}\left(M(\mathbf{x})\right) = H\left(M(\mathbf{x})\right) + \sum_{i=1}^{n}\beta_i\, p_i\left(M\left(\mathbf{x}^{\mathrm{b}}\right)\right)$$

where superscript b denotes background, $\mathbf{y}^{\mathrm{o}}$ the observations, $\mathbf{B}$ the error covariance matrix for $\mathbf{x}$, $\mathbf{B}_{\beta}$ the matrix for $\boldsymbol{\beta}$, $\mathbf{R}$ the matrix for $\mathbf{y}^{\mathrm{o}}$, M the time progress operator for the observation time of $\mathbf{y}^{\mathrm{o}}$, $\tilde{H}$ the extended observation operator to include the bias correction term, H the original observation operator, p the operator for bias correction predictors, and n the number of bias correction predictors. The optimized $\mathbf{z}$ can be obtained by minimizing J. In this implementation, $\mathbf{B}_{\beta}$ is defined as follows:

$$\mathbf{B}_{\beta} = diag\left(\sigma_{\beta 1}{}^2, \sigma_{\beta 2}{}^2, \cdots, \sigma_{\beta n}{}^2\right), \quad \sigma_{\beta}{}^2 = \begin{cases} \sigma_{obs}{}^2 / N_{MIN} & N < N_{MIN} \\ \sigma_{obs}{}^2 / \left(N / \left(\log_{10}\left(N/N_{MIN}\right)+1\right)\right) & N \geq N_{MIN} \end{cases}, \quad N_{MIN} = 400$$

where σ_{β} denotes the background error for bias correction coefficients, σ_{obs} the observation error, and N the number of the assimilated data. N_{MIN} means a reference observation number, which was empirically defined. With this formulation, $\boldsymbol{\beta}$ changes rapidly (slowly) when N is larger (smaller) than N_{MIN}.

The technique is applied to the operationally assimilated satellite radiance data, which are NOAA/AMSU-A, NOAA/AMSU-B, Aqua/AMSU-A, DMSP/SSM/I, TRMM/TMI and Aqua/AMSR-E. The bias correction predictors for those instruments as of January 2007 are summarized in table 1.

A long term cycle analysis experiment with VarBC (TEST) was performed from April 2005 to March 2006 and compared with routine analysis before introducing VarBC (RTN). Mean error (ME) and root mean square error (RMSE) of brightness temperature (TB) departure from first-guess of AMSU-A channel 6 aboard NOAA 15 were increased from February 2006 to the beginning of March 2006 on RTN (Gray thin lines in Fig. 1). In contrast, the ME and RMSE are quite stable on TEST (Black thick lines in Fig. 1). Figure 2 shows time sequence of the bias correction coefficient on surface temperature for the TB data during the same period. The change shows the similar tendency to RMSE on RTN with several days behind. It means the VarBC effectively corrected the bias of the radiance by changing the bias correction coefficients.

Table 1. Bias correction predictors for each sensor

Instrument	Predictors
AMSU-A	Integrated weighted lapse rate, Surface temp., Total cloud liquid water, sec(SZA*), Const.
AMSU-B	Integrated weighted lapse rate, Surface temp., sec(SZA*), Const.
SSM/I	Precipitable water, SST, SST^2, Surface Wind Speed , sec(SZA*), Const.
TMI	Precipitable water, SST, SST^2, Surface Wind Speed , sec(SZA*), Const.
AMSR-E	Precipitable water, SST, SST^2, Surface Wind Speed , sec(SZA*), Const.

*SZA: satellite zenith angle

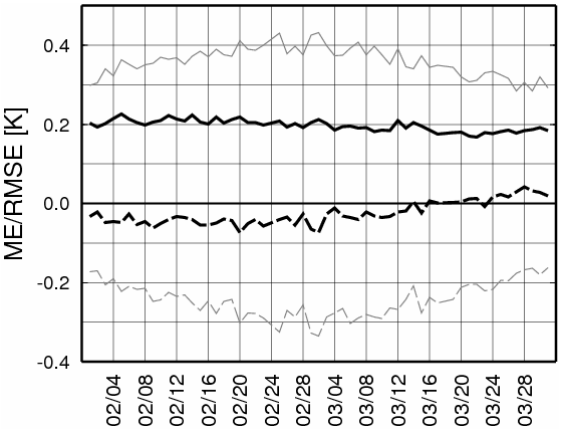

Figure 1. Time sequence of ME and RMSE of TB on channel 6 of AMSU-A aboard NOAA15 against first guess from Feb 2006 to Mar 2006. Dashed lines show ME and solid lines RMSE, gray thin lines show RTN and black thick lines TEST.

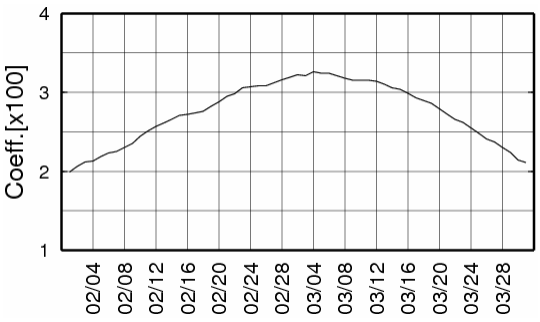

Figure 2. Time sequence of a bias correction coefficient in TEST for the same period as Figure 1.

References:

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