Cloudy radiance assimilation

with extension of control variables in 4D-Var

Toshiyuki Ishibashi
Meteorological Research Institute, Japan Meteorological Agency
E-mail: ishibasi@mri-jma.go.jp

1. Introduction

Direct assimilation of clear sky radiance data from satellites with four-dimensional variational (4D-Var) data assimilation systems (DASs) is one of the main factors in improvements of analysis and forecast accuracy. While, we know atmospheric disturbances often accompany clouds. Therefore, we can guess the radiance data in cloudy regions have ability to detect fast growing components of background errors, and reduce forecast errors significantly. However, the direct assimilation of radiances in cloudy regions (cloudy radiances) is difficult because, in the cloudy regions, the accuracy of first guesses is worse than that of clear sky radiances, and strong nonlinearity of the physical process concerned with water substances is exist.

In this letter, we describe the development of the direct assimilation of the cloudy radiances with extension of control variables in 4D-Var.

2. Extension of control variables in 4D-Var

We extend control variables of 4D-Var to include total cloud water content (TCW, the sum of cloud water content and cloud ice content) for the direct assimilation of cloudy radiances. Here, we use the Japan Meteorological Agency (JMA) global 4D-Var DAS.

First, we briefly describe the cloud processes of the global numerical weather prediction (NWP) model of JMA (JMA, 2007). The forecast variables of the model include TCW. The cloud scheme of the model is constructed from the probabilistic cloud scheme (Smith, 1990) and the Arakawa-Shubert scheme, and the scheme determines TCW and cloud cover simultaneously. TCW is divided into cloud ice and cloud water by the linear diagnostic function of temperature. The inner models of 4D-Var, the tangent linear model and the adjoint model, also include corresponding cloud schemes, however, in the routine system, initial values of perturbations and forcing of TCW are set to zero. Therefore, if we give the initial values and the forcing, these inner models can construct the time evolution part of the observation operators for cloudy radiances, and there is no need to construct new diagnostic operators which calculate cloud quantities from ordinary control variables.

Figure 1 shows scatter plots of linear and nonlinear time evolution of perturbations of TCW, cloud cover, and specific humidity. We can find explicit linearity

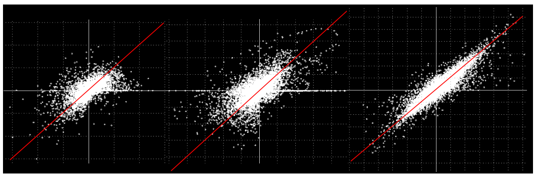

Figure 1. The tangent linearity of NWP model for TCW (left), cloud cover (center), and specific humidity (right). The red lines denotes the perfect tangent linearity.

for specific humidity and weaker but still explicit linearity for TCW and cloud cover.

To give adequate error covariance matrix for TCW is not an easy problem. Here, we take simple way as a first step. The background error covariance matrix of TCW is given as the same space correlation structure as that of specific humidity and variance is rescaled by one scalar coefficient. In following sections, this scalar coefficient is given as 10^{-3}.

3. Experimental Design

Here, we describe the experimental design to evaluate the extended 4D-Var for cloudy radiance assimilation, which is described previous section. We assimilate cloud affected AMSU-A radiances, channel 4 to 6, as cloudy radiance data. These data have information of clouds, however, not used in the JMA operational system. To see averaging property of these channels, Figure 2 shows Jacobian of averaged radiances in these channels. We find the main sensitivity altitudes for temperature, specific humidity, and cloud water are about 300hPa, 300hPa and 900hPa, and 900hPa, respectively. The sensitivity to cloud ice content for these channels can be ignored, since it is very small (figures not shown).

Analyses with three DASs (CNTL, CNTL-CLD, and TEST) are executed at 00UTC 20 Jul 2009. CNTL assimilates the original observation data with the original 4D-Var, CNTL-CLD assimilates the original data and cloudy radiances with the original 4D-Var, and TEST assimilates the original data and cloudy radiances with the extended 4D-Var. Three day forecasts from the three analysis fields are calculated and forecast accuracy are compared.

4. Experimental Results

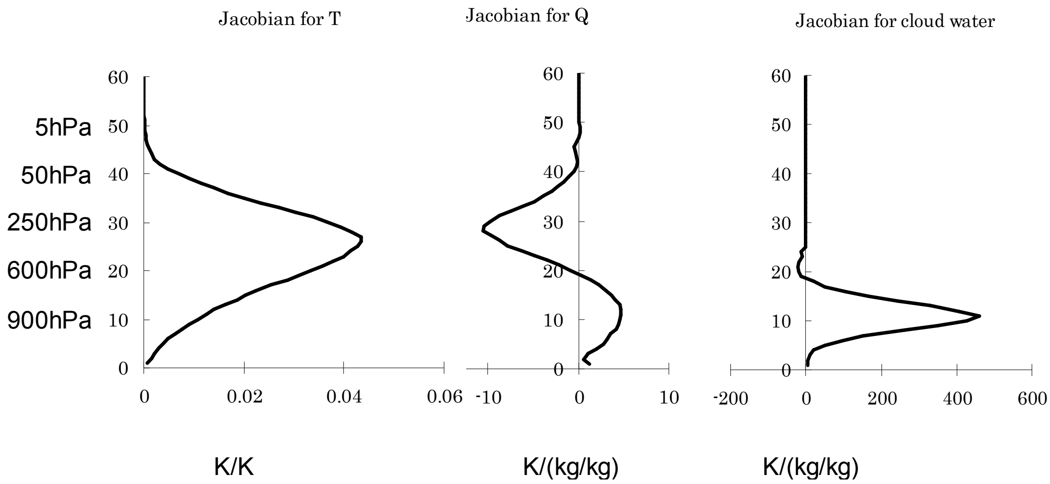

Figure 2. The averaged Jacobian of AMSU-A for channel 4, 5, 6. The left panel is Jacobian for temperature, the center is for specific humidity, and the right is for cloud water content.

Figure 3 shows the improvement rate of forecast RMSEs of CNTL-CLD and TEST from CNTL. Here, analyses generated by the original 4D-Var (CNTL) are used for truth. The figure shows TEST changes forecast accuracy from CNTL in mainly near 300hPa and 700hPa. These levels correspond to the sensitivity altitude of cloudy radiances (Figure 2). We find wide improvement area in the figure, although, error increases are found before 24 hours and after 60 hours at low levels. We can guess the error increases before 24 hours are not important because in this time analysis errors are not enough small compared with forecast errors differences. The figure also shows CNTL-CLD changes forecast accuracy from CNTL in near 300hPa and the low levels. We find wide improvement area above 700hPa in the figure, although, error increases are found after 24 hours at the low levels (mainly blow 900hPa).

The main difference of the forecast accuracy changes are the error increases in CNTL-CLD and the error decreases in TEST at the low levels. These altitudes correspond to the sensitivity levels of cloud water content, and we can guess the improvement of TEST is due to the adequate treatment of cloud water content sensitivity.

5. Future plans

In this letter, we have described the extension of 4D-Var for cloudy radiance assimilation. Future plans are as follows; First, one month long OSEs for statistically significant evaluation are needed. Secondly, the processes of the forecast accuracy changes caused by the cloudy radiance assimilation should be understood. Thirdly, the error covariance matrix of TCW should be set more adequately. Finally, more strong cloud affected or rain affected radiances (microwave imagers and infrared sensors) will be tested.

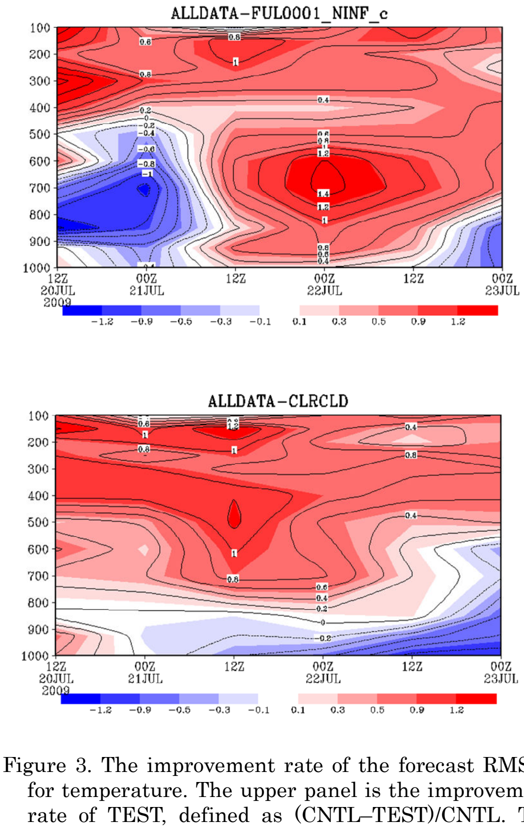

Figure 3. The improvement rate of the forecast RMSEs for temperature. The upper panel is the improvement rate of TEST, defined as (CNTL–TEST)/CNTL. The bottom panel is the improvement rate of CNTL-CLD, (CNTL–CNTL-CLD)/CNTL. The vertical axis is the pressure altitudes, and the horizontal axis is the forecast days (three days).