Assimilation of WV-CSRs from Five Geostationary Satellites in the JMA Global 4D-Var System

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1. Introduction

The Japan Meteorological Agency (JMA) has been using clear sky radiances from the water vapor channels (WV-CSRs) of five geostationary satellites (MTSAT-1R, GOES-11 and 12, and Meteosat-7 and 9) since August 2008 in the JMA global four-dimensional variational (4D-Var) data assimilation system (DAS). WV-CSRs are generated by averaging the radiances of cloud-free pixels among several hundred pixels, such as in 16 x 16 blocks (60 km x 60 km at the nadir) in the case of MTSAT-1R. The size of the averaging area is in the same order as the horizontal resolution of the operational global forecast model. Since the original radiance data resolution is about 4 km x 4 km, the data averaging processes may reduce representativeness errors and improve the Gaussian distribution characteristics of observation error statistics through processes described by the central limit theorem (Fig. 1). WV-CSRs are sensitive to humidity in the middle to upper troposphere where there are very few observations of humidity. In general, forecast model errors of humidity are larger than those of other dynamic variables such as temperature and wind because humidity is largely dependent on moist physical sub-grid processes, which are modeled with less credibility than resolvable dry dynamics. WV-CSRs therefore provide important information in this data-sparse area.

2. Quality control of WV-CSRs

Several quality control procedures are applied to WV-CSR data in advance of 4D-Var assimilation. The data are thinned to every 2.0 degrees horizontally and every 2 hours temporally to avoid taking into account the observation error correlation, which is not considered in the JMA global 4D-Var. Those with a low percentage of clear pixels and a large standard deviation of brightness temperature are excluded because they offer low representativeness of the area. Large departure (observation minus first-guess) data are also excluded to avoid contamination from data with a non-Gaussian error statistics and to maintain tangent linearity of the observation operator. For Meteosat-7, data from near local midnight are also excluded to avoid contamination from data affected by solar stray light (Munro, 2004). The variational bias correction scheme, VarBC (Dee, 2004; Sato, 2006; Ishibashi, 2009), is applied in the 4D-Var system. The predictors of VarBC for WV-CSRs are the first-guess of brightness temperature, near-jet-level wind speed and a constant. No empirical tuning is applied to the bias correction parameters and the observation error settings.

3. Assimilation of WV-CSRs

Observing system experiments were carried out to estimate the impacts of WV-CSR data on both analysis and forecast quality for the two one-month periods of August 2007 and January 2008. Adding WV-CSRs from the five geostationary satellites reduced the dry bias of analysis and first-guess with respect to radiosondes in the mid-troposphere of the summer hemisphere (Fig. 2). The root mean square errors (RMSEs) of forecasts were significantly reduced by assimilating WV-CSRs for several variables and levels (Fig. 3). The RMSE reductions of dynamic variables such as temperature, geo-potential height and wind are interesting because the Jacobians (here defined as partial derivatives of the observation operator – the Jacobian matrix – rather than the determinant of the matrix – the Jacobian determinant) of the observation operator for WV-CSRs, RTTOV (Saunders, 2002), have major sensitivity to humidity, minor sensitivity to temperature and no sensitivity to wind. In the 4D-Var system, however, extended observation operators which include a forecast model as a time evolution operator are sensitive to these variables. The RMSE reduction of dynamic variables is due to the extended observation operators and the forward integration of the outer model. The RMSE reduction by forward integration is also explained by the sensitivity of dynamic variables to humidity in the model.

References

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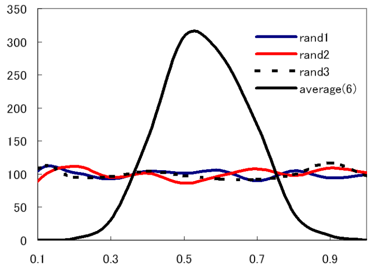

Fig. 1 Central limit theorem. The red line, blue line and black dotted line show the frequencies of random numbers generated in the range from 0 to 1. The black solid line shows the frequencies of averaged random numbers.

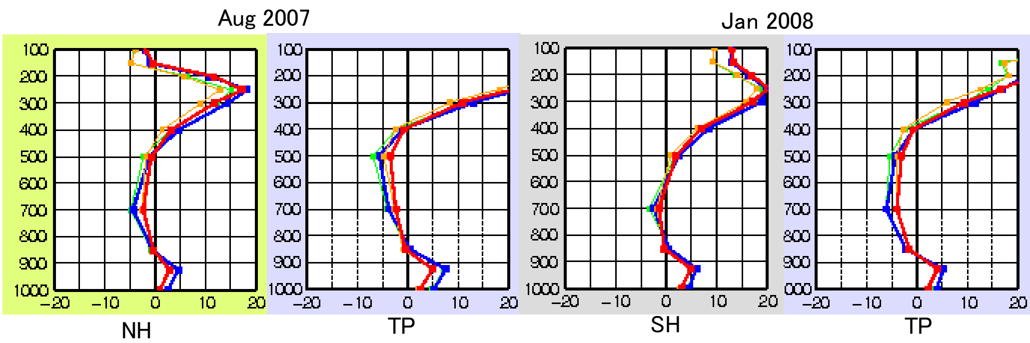

Fig. 2 The humidity biases of first guess and analysis against radiosonde observations for each experiment in the tropics and summer hemisphere. The red lines show TEST analysis, the blue lines show the TEST first guess, the orange lines show CNTL analysis and the green lines show the CNTL first guess, where TEST is the experiment with WV-CSRs and CNTL is without WV-CSRs.

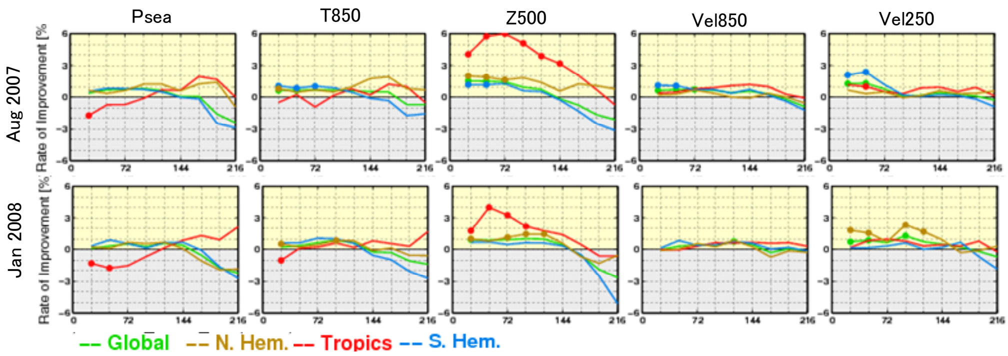

Fig. 3 Rate of improvement in the RMSE of forecast errors for sea level pressure, 850 hPa temperature, 500 hPa geopotential height, 850 hPa and 250 hPa wind velocity. The improvement rate is defined as (CNTL-TEST)/CNTL, where CNTL and TEST are the RMSE of the cycle experiment without WV-CSRs and with WV-CSRs, respectively. The dots on the score lines represent statistical significance.