Operational status and recent developments on cloud and precipitation assimilation at JMA

Masahiro Kazumori, Takashi Kadowaki, Takuya Komori, Hidenori Nishihata and Kozo Okamoto

Japan Meteorological Agency

Abstract

This paper describes operational status and recent developments on cloud and precipitation assimilation at the Japan Meteorological Agency (JMA). JMA operates Global Spectral Model (GSM) and Meso-scale Model (MSM). An incremental four dimensional variational method is employed as those data assimilation systems. In the Meso-scale Analysis, precipitation data derived from ground based radar and microwave imager are assimilated operationally. In the Global Analysis, satellite radiance data in clear sky conditions are assimilated and all-sky microwave radiance assimilation scheme is under development. Toward infrared cloudy radiance assimilation, linearity on a combined observation operator of a cloud diagnostic scheme and a radiative transfer model was investigated with 1D-Var approach.

1. Introduction

Accurate forecasts on severe weather and heavy precipitation are essential information for disaster prevention and reduction. Japan Meteorological Agency (JMA) operates two Numerical Weather Prediction (NWP) models.

The one is Global Spectral Model (GSM). The target of GSM is short and medium range forecast up to nine days ahead to cover the entire globe. The horizontal resolution is about 20km (TL959L60) and the model top is 0.1hPa. The model is being operated four times a day to produce the forecasts. GSM output is used not only for weather forecast guidance but also for other various applications such as driving force for ocean wave forecast model, volcanic ash tracer model, etc.

The other NWP model is Meso-scale Model (MSM). The target of MSM is to provide guidance for issuing warnings or making very short-range forecasts of precipitation to cover Japan and its surrounding areas. The horizontal resolution is 5km and the model top is 21,800m. The model is being operated eight times a day to produce the forecasts up to 33 hours.

An incremental four dimensional variational (4D-Var) method is employed for the data assimilation system in both models. The 4D-Var for the GSM has been in operation since 2005. Global analysis is performed at 00, 06, 12 and 18 UTC. An early analysis with a short cut-off time is performed to prepare initial conditions for operational forecasting, and a cycle analysis with a long cut-off time is performed to maintain the quality of the global data assimilation system. And the 4D-Var for the MSM has been in operation since 2002. In April 2009, a new 4D-Var based on the JMA non-hydrostatic model, which is a current MSM forecast model replaced a 4D-Var based on a hydrostatic spectral model that used to be a forecast model of the JMA MSM [Honda and Sawada, 2009].

Satellite observation data such as raw radiance and retrieved products have been used in the JMA data assimilation system. Those data have made major contributions to accurate weather forecasting. So far, the data under clear sky condition are mainly used in the current system. In order to achieve further improvements of weather forecast accuracy, utilization of satellite data under cloudy and rainy condition is necessary. In this paper, we describe the operational status and recent developments on cloud and precipitation assimilation in JMA's Global and Meso-scale NWP system.

2. Precipitation assimilation in MSM

Since 2002, hourly precipitation data derived from ground based radar observation over Japan have been assimilated operationally in Meso-scale Analysis. Rain gauge data are employed to calibrate the radar data and to produce the analyzed hourly precipitation data. The analyzed precipitation data are averaged and smoothed to fit coarse resolution of MSM 4D-Var inner model (15km) and to avoid failure of minimization in the variational data assimilation. A devised cost function of precipitation is employed [Koizumi et al., 2005] in the minimization process in MSM 4D-Var. Improvement of spin-up issues of rainfall forecast was confirmed by the assimilation of analyzed hourly precipitation data.

In addition to the analyzed hourly precipitation data, precipitation data derived from satellite microwave imager's brightness temperature such as SSMI and TMI were incorporated in 2003. And AMSR-E precipitation data were also added in 2004. Total precipitable water amount from microwave imager is assimilated in clear sky condition and microwave imager's precipitation is utilized in rainy condition, which means that measurements of microwave imager are assimilated under all weather condition. It was found that assimilation of microwave imager data under all weather condition produces realistic atmospheric moisture field and that leads to better rainfall forecast in JMA MSM. For instance, an assimilation experiment demonstrated that in a heavy rain event at Fukui prefecture in Japan in 2004, a band of strong rainfall was well forecasted in the MSM and fake rains in the model forecast were disappeared by the assimilation of AMSR-E total precipitable water and precipitation [Tauchi et al, 2004].

3. Radiance assimilation in GSM

In JMA Global Analysis, satellite radiance data under clear sky condition are assimilated operationally since 2003. Microwave sounding radiance from AMSU-A (NOAA-15,16,18,19, Metop and Aqua), AMSU-B/MHS (NOAA-15,16,17,18,19,Metop) and SSMIS on DMSP F-16, microwave imager radiance from AMSR-E on Aqua, TMI on TRMM, SSMIS DMSP F16, F17 and CSR from geostationary satellites (MTSAT-1R, GOES-12,13, Meteosat 7 and 9) are used operationally.

As a radiative transfer model for the satellite data assimilation, RTTOV-9.3 [Saunders, 2008] is utilized for forward model calculation and Jacobian (K-matrix) calculation [Kazumori, 2009]. A data thinning to reduce horizontal correlation and to save computational resource is applied for the satellite radiance data in a pre-process step of the analysis. A gross error check for O-B (Observed – background brightness temperature) departure and inflations of observation errors are also applied in the pre-process step. It should be pointed that relatively large observation errors are assigned for moisture sensitive channels such as microwave imager AMSR-E, TMI and SSMIS radiance to avoid excessive rainfall in early stage of forecast range (spin-down issues of rainfall forecast) in JMA Global Analysis. As satellite radiance bias correction, a variational bias correction scheme has been used for all satellite radiance data. In a minimization process of cost function in 4D-Var, seventy times iterations are performed. Low resolution dry model (T159L60) is used for the former thirty-five iterations and the low resolution model including moist physics is used for the latter thirty-five iterations.

4. Development of all sky microwave radiance assimilation

Cloud and rain often appear in meteorologically sensitive area for weather forecast accuracy. Therefore cloud and rain affected radiance assimilation is inevitable to improve initial condition of NWP model. A fast radiative transfer model including scattering process to calculate satellite radiance in microwave region is required for the rain affected microwave radiance assimilation.

In order to study the performance of the radiative transfer model RTTOV-SCATT [Bauer et al., 2006] in JMA Global Analysis system, atmospheric profiles that are used as inputs for the radiative transfer calculation were compared between JMA and ECMWF. Large differences of characteristics of cloud and rain profiles were identified. It is thought that the differences are originated from different moist physics parameterization between JMA and ECMWF. Especially, JMA's cloud cover is lacking in the middle level of troposphere compared with ECMWF profiles. The difference may cause some troubles for the use of RTTOV-SCATT in JMA Global Analysis. Moist physics parameterization of JMA global model needs to be evaluated and improved, if necessary to produce realistic atmospheric profile as first guess for the data assimilation.

Calculated brightness temperatures were compared between RTTOV and RTTOV-SCATT. RTTOV calculates the brightness temperatures in clear sky condition. In RTTOV-SATT calculation, in addition to temperature, specific humidity and ozone profiles, cloud liquid, cloud ice, cloud cover and rain profiles are provided as input parameters. O-B (observed – background) distribution of RTTOV-SCATT became much close to Gaussian distribution compared with that of RTTOV.

One single assimilation experiment was performed to confirm successful implementation of RTTOV-SCATT in JMA global 4D-Var system. In a test run, cloud water, cloud ice, cloud cover and rain profiles produced from nonlinear inner low resolution GSM in JMA Global 4D-Var were used as input profiles for the radiative transfer calculation for microwave imager. The cloud and rain related variables were not perturbed in 4D-Var in this initial experiment. In the pre-process (quality control and data thinning) of microwave imager's brightness temperature, cloud screening step was removed but strongly rain affected radiance data were not assimilated in this experiment. The result showed increases of available microwave imager data for the assimilation and total precipitable water increment in the analysis was also increased. It is necessary to confirm whether the increment makes the analyzed moisture field more realistic and produce better forecast. Also observation error setting and bias correction should be modified to work for all sky microwave radiance data in future experiment.

5. Early study for cloudy IR radiance assimilation with 1D-Var method

Toward assimilation of cloud affected infrared radiance, an early study with 1D-Var approach was started in JMA. Infrared radiance observations have high sensitivity to cloud and it is thought that there is a nonlinear behavior in the observation operator. However, in variational data assimilation scheme, observation operator is expected to have a linear sensitivity to perturbations of the input parameters. In order to understand the behavior of the observation operator for cloud affected infrared radiance, linearity test was performed by comparing the output of the tangent linear model with those from finite difference calculations using the forward model operator. The observation operator used in this 1D-Var study was a combined moist physics parameterization (large condensation process of ECMWF diagnostic scheme [Tompkins and Janiskova, 2004]) and the radiative transfer model RTTOV 9.3. Hyperspectral sounder radiance data were used as the observation. Profiles of cloud contents (cloud water and cloud ice) and fraction were estimated by using the diagnostic scheme from

GSM temperature and specific humidity profiles. Profiles were optimized with 1D-Var and analyzed profiles were obtained. Nonlinear forward model was used to calculate the radiance. For the case of fixed cloud water and cloud cover profiles (only temperature and humidity were perturbed), better linearity was found. However, once cloud water and/or cloud cover profiles were perturbed, strong nonlinearity appeared. When the profiles have 100% relative humidity condition before or after the 1D-Var process, in other words, in which there is a cloud, those showed the strong nonlinearity. The result suggests that the treatment of water vapor saturation and cloud generation in the variational data assimilation are difficult and current system can accept only weakly cloud affected infrared radiance for the assimilation and the data number is extremely limited.

6. Summary

Improving the forecast accuracy of severe weather and heavy precipitation is one of the most important issues in operational NWP centers. Current satellite data utilization is focused on mainly clear sky atmosphere. Cloudy and rainy area is meteorologically sensitive and the assimilation of satellite data in cloud and rain condition can lead further improvement of forecast accuracy.

In Meso-scale Analysis, analyzed hourly precipitation and precipitation from Microwave imager have been assimilated operationally. The precipitation assimilation reduced the model spin-up issue in rainfall forecast and the analyzed moisture field produced better rainfall forecast.

In Global Analysis, radiance data in clear sky condition have been assimilated and are making major contribution in the global forecast accuracy. All sky microwave radiance data assimilation in Global Analysis is under development. As the radiative transfer model including scattering process in microwave region, RTTOV-SCATT can be used in JMA global 4D-Var system. Different characteristic in background atmospheric profiles was identified in the comparison between JMA and ECMWF profiles. Especially, cloud and rain related variables have large difference. The performance of moist physics parameterization and its simplified model for tangent linear and adjoint model is an important factor for successful data assimilation in cloudy and rainy condition. And forecast model spin up /down (e.g. excessive rainfall in early forecast stage) need to be reduced to make smooth connection between analyzed field and forecast field in the data assimilation cycle.

Early study with 1D-Var method toward assimilation on cloudy infrared radiance showed the nonlinearity behavior of observation operator in perturbed cloud contents cases. It indicates the difficulty of treatment of water vapor saturation or cloud generation and it limits the available data number of infrared radiance in cloudy condition. Use of several outer loops in 4D-Var makes the trajectory updates possible and it may help the handling of weak nonlinearity behavior in observation operator.

Collaborations among the observation, modeling, and data assimilation experts are necessary to understand the difficulties. And sharing experience and knowledge on cloud and rain assimilation among NWP centers will accelerate the development of cloud and rain assimilation scheme.

References

Bauer, P. Moreau E., Chevallier F. and O’Keeffe U., 2006: Multiple-scattering microwave radiative transfer for data assimilation applications. *Quart. J. Roy. Meteorol. Soc*. **132**: 1259-1281.

Honda, Y. and K. Sawada, 2009: Upgrade of the Operational Mesoscale 4D-Var at the Japan Meteorological Agency. *CAS/JSC WGNE Res. Activ. Atmos. Oceanic Modell.*, **39**, 1.11–1.12.

Kazumori, M., 2009: Impact Study of the RTTOV-9 Fast Radiative Transfer Model in the JMA Global 4D-Var Data Assimilation System. *CAS/JSC WGNE Res. Activ. Atmos. Oceanic Modell.*, **39**, 1.21–1.22.

Koizumi, K., Y. Ishikawa and T. Tsuyuki, 2005: Assimilation of precipitation data to JMA mesoscale model with a four-dimensional variational method and its impact on precipitation forecasts. *Sci. Online Letts. Atmos.*, **1**, 45-48.

Saunders R., 2008: RTTOV-9 science and validation report. NWP-SAF report. NWPSAF-MO-TV-020, available from http://www.metoffice.gov.uk after requesting a password.

Tauchi, T., Y. Takeuchi, Y. Sato, Assimilation of the Aqua/AMSR-E data to numerical weather predictions, Geoscience and Remote Sensing Symposium, *IGARSS '04. Proceedings, IEEE International*, Volume **5**, Page(s):3199 - 3202, 2004.

Tompkins A.M. and Janiskova M. 2004. A cloud scheme for data assimilation: Description and initial test. *Quart. J. Roy. Meteorol. Soc*. **130**: 2495-2517.