AN APPLICATION OF WRF 3-D VAR RADIANCE ASSIMILATION TO A BAIU FRONTAL TORRENTIAL RAINFALL CASE USING TMI DATA

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1. INTRODUCTION

A Baiu front is one of the most significant circulation systems in East Asia. During the Baiu season, a quasi-stationary front extends from southern China to Japan. Intense rainfall events are associated with mesoscale convective systems (MCSs) along the Baiu front. The initiation and the organization of MCSs often occur over the ocean, which makes precipitation forecasting of Baiu frontal precipitation difficult in Japan due to limited effects of assimilating ground-based observations. The success of assimilation is crucial for space-borne radiance measurements.

The purpose of this study is to evaluate applicability of WRF 3-D Var radiance assimilation to short-range quantitative precipitation forecasting (QPF) of Baiu frontal rainfall. Impact of assimilating ground-based observations is also investigated. Especially, an observation operator for radiance assimilation is based on Chen et al. (2004). Differences between this study and their work are in a mesoscale model and in the background error. That is, this study is based on the WRF model, and the background error statistics are not climatological.

2. NOTES IN THE USE OF THE WRF 3-D VAR

General descriptions of the WRF 3-D Var can be referred to as Barker et al. (2004) and Skamarock et al. (2005). Just a few notes are given for understanding.

Control Variables

Control variable (cv) transformation is an important procedure for computationally efficient minimization of a cost function. This study chooses cv option 5 with modifications associated in using the total water mixing ratio q_t as a moisture control variable. The inclusion of q_t is intended to assimilate radar reflectivity data (Sugimoto (2007)).

Radiative Transfer Model

A radiative transfer model (RTM) in the current version of the WRF-Var is based on Petty's algorithm (Petty and Katsaros (1992)). The Petty's approach, however, does not account for scattering effects and contaminations by the land surface emissivity, so that it can deal with radiance data only in non-rainy regions plus over the ocean. Linearization of the nonlinear observation operator is evaluated by Chen et al. (2004). Effects of absorption/emission are frequency-dependent, so that the RTE in the WRF-Var is tuned for SSM/I (Special Sensor Microwave/Imager) data.

3. SET-UP AND CONFIGURATIONS

Baiu Frontal Rainfall Case to be Applied

A framework of assimilation will be applied to a frontal rainfall event associated with a Baiu front. Infrared image from Japan Meteorological Agency (JMA) GMS is depicted in Fig. 1 together with a weather map. Severe convections embedded in the Baiu frontal region cause torrential rainfall in and around Kyushu Island, and eventually terrible disasters by debris flow occurred at several locations in a day.

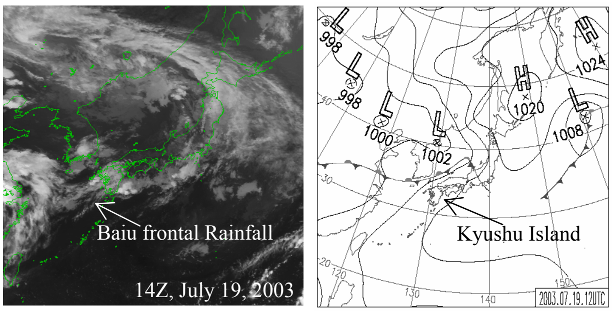

Fig. 1: IR image and weather map.

Description of Observations

Brightness temperature data from TRMM 1B11 product (version 6) are assimilated. TRMM Microwave Imager (TMI) has five comprehensive frequencies compared with SSM/I, which enables the use of Petty's

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*Corresponding author: Soichiro Sugimoto, Central Research Institute of Electric Power Industry, 1646 Abiko, Abiko, Chiba 270-1194, Japan; E-mail: soichiro@criepi.denken.or.jp radiative transfer model and its Jacobian.

Sites of ground-based observations are plotted in Fig. 2. Observations are performed operationally by JMA for radars and profilers and by Geographical Survey Institute for GPS. Because JMA radars are conventional, radar reflectivity data are assimilated. GPS precipitable water (PW) data are produced by analysis using RT-NET software.

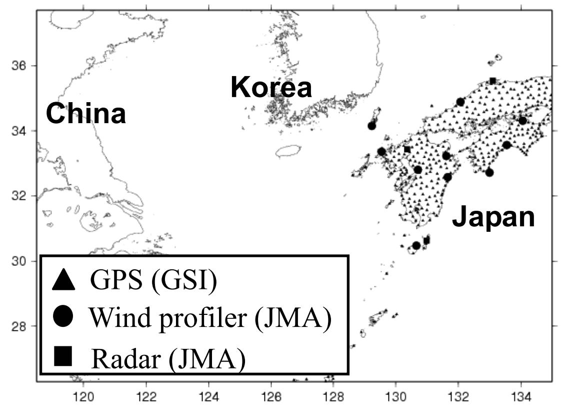

Fig. 2: Sites of ground-based observations.

The standard deviations of error for TMI observations are assigned as 5 K (19.35 GHz), 6 K (21.3 GHz), 7 K (37.0 GHz), and 9 K (85.5 GHz), considering the representative error of the observation operator and the imperfect correspondence of channel frequencies with SSM/I. Height-dependent errors are assigned for profiler data in 3DVAR OBSPROC. Error variances of GPS-PW is the constant value of (1.5 mm)^2. Random errors with the standard deviation of 1 dBZ are used for radar reflectivity.

Configurations of the WRF model and the 3-D Var

Table 1 shows a configuration of the WRF model. NCEP final analysis (FNL) data, which are provided at the interval of 6 hours, are used for the initial and the boundary conditions.

The domain-averaged background error statistics for control variables are estimated by the NMC method with past records of 24-hr and 12-hr forecasts. Regression coefficients, eigenvalues/eigenvectors, and length scales estimated are used with tuning in the 3-D Var. The "outer-loop" is used to remove observations from which the background has large departure.

Fig. 3 illustrates the time-line in case studies. Data assimilation is performed in a cycling mode with the 4-hr assimilation window from 1400Z. After the end of assimilation window at 1800Z, a 12-hr forecast run with 3-D Var analysis is performed for each case.

Table 1: Configuration of the WRF model.

		Description
	Model version	Version 2.1
	Horizontal resolution	4 km
	Number of grids	330 × 280 (H) × 36(V)
	Pressure on a top level	50 hPa
	Time step	15 seconds
	Data source for IC & BC	NCEP Final Analysis (GDAS)
Physics Options	Cumulus Parameterization	None
	Microphysics	WRF Single-Moment scheme 6
	Planetary boundary layer	YSU scheme
	Surface layer scheme	Monin-Obukov similarity theory
	Land/Surface model	Noah
	Diffusion scheme	2nd order, 2-D Smagorinsky
	Radiation	Dudhia (Short), RRTM(Long)

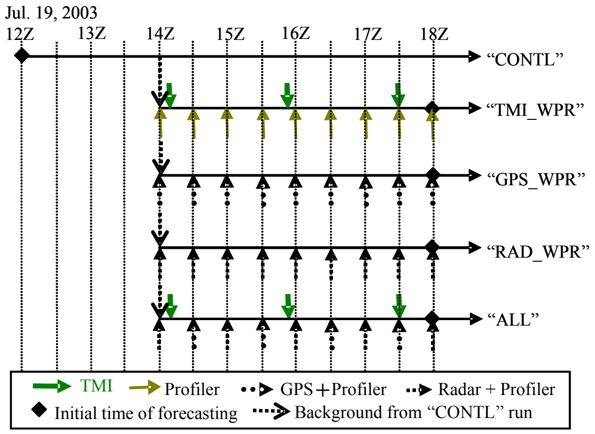

Fig. 3: Time-line in case studies.

4. RESULTS

Increments after a Cycling 3-D Var

Distribution of columnar water vapor at the end of assimilation cycle is plotted in Fig. 4 with one in the

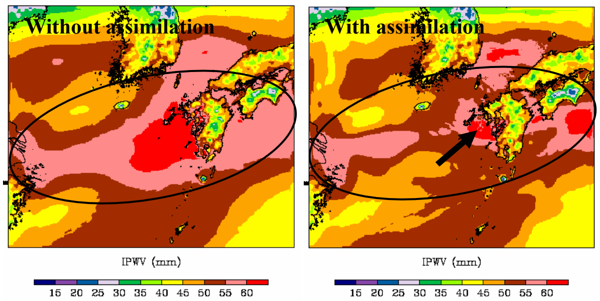

Fig 4: Water vapor fields with and without assimilation.

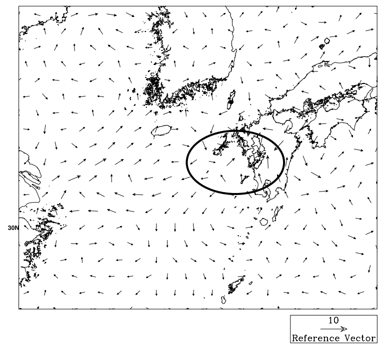

Fig. 5: Increments of horizontal winds [m s^{-1}].

control run. Water vapor field over the ocean is modified mainly by assimilation of TMI data, while assimilation of GPS-PW data contributes to modify water vapor field over the land. In the southern side of the Baiu front (circle), overall negative increments are analyzed. A particularly humid region is concentrated just in the upwind side of a heavy rainfall area (arrow). The convergence of horizontal winds is enhanced by assimilation of profiler data (Fig. 5, circled).

Evaluation of the Performance in Terms of QPF

Fig. 6 shows analysis and forecasts in terms of 1-hr accumulated precipitation. Note that the forecast for the case "GPS_WPR" is not shown. First of all, a spin-up problem is prominent up to 2000Z, July 19 in a control run. The control run has another problem that a heavy rainfall area over Kyushu Island is forecasted northwards. In all cases with assimilation, problems mentioned above are mitigated.

Meanwhile, the most critical shortcoming in the control run is that a pattern of torrential rainfall occurred around the west coast of Kyushu Island cannot be reproduced. Inflow of very humid air over the East China Sea (Fig. 4) leads to forecasts of inaccurate and excessive precipitation (circle). Radiance assimilation (cases "ALL" and "TMI_WPR") improves the situation significantly, although precipitation amount forecasted tends to be a little excessive. This suggests that the modification of water vapor field in Fig. 4 is reasonable.

Fig. 7 plots the root mean square error (RMSE), bias, and a threat score (a threshold of 1 mm/hr). Considering all scores, a case of "ALL" indicates the best performance. Remarkable impact of radiance assimilation is found in the lead times over 6 hours. Positive impact is found up to 5- or 6-hr ahead in assimilation of ground-based observations. Radar reflectivity is useful to improve the quantitative skill, but the benefit does not keep so long (Sugimoto (2007)).

5. SUMMARY

A framework for assimilation of various kinds of observations is applied to a severe torrential rainfall case caused by a Baiu front. The framework is based on the WRF 3-D Var with some modifications, and observations within an assimilation window are assimilated in a cycling mode.

Results indicate that the framework works well in improving QPF. As a notable benefit, a spin-up problem is significantly mitigated by assimilation in each case study. The use of all kinds of dataset for assimilation shows the best performance. The powerful performance of radiance assimilation is remarkable in that the capability of forecasting the intermittent arrival of convections from the ocean is increased. Positive impact is found in the lead times over 6 hours, while impact of assimilating ground-based observations does not keep so long.

Basically, the reliability of the radiative transfer model in the WRF-Var is limited over the ocean plus non-rainy regions. Moreover, assimilation of TMI data seems to cause excessive amount of precipitation forecasting in spite of endeavors of tuning 3-D Var. Therefore, an important issue to be studied is to sophisticate the model so that it can account for scattering effects. Case studies are also required for various types of rainfall and regions, along with researches on the background error.

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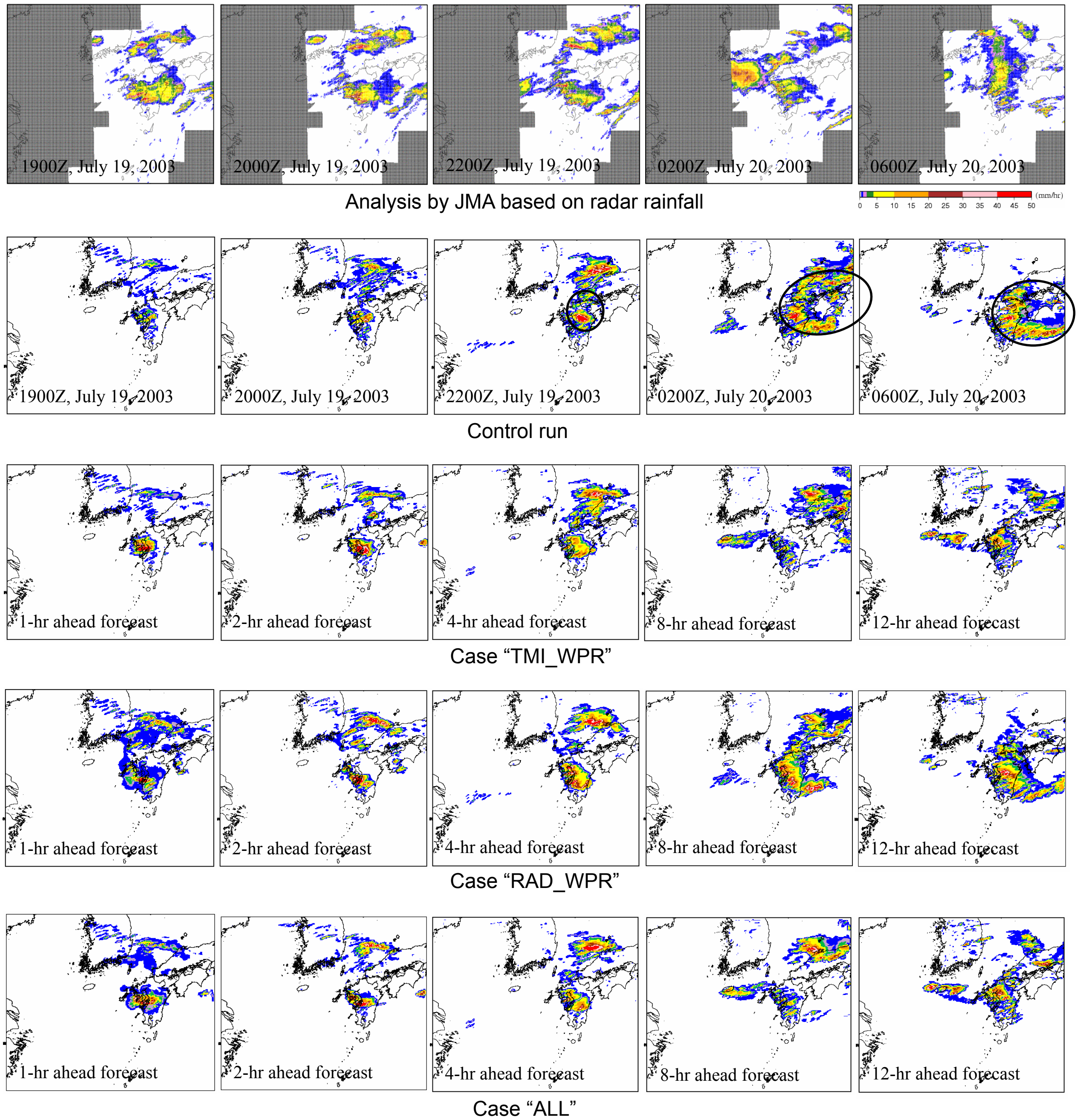

Fig. 6: Distributions of 1-hr accumulated precipitation for analysis and forecasts.

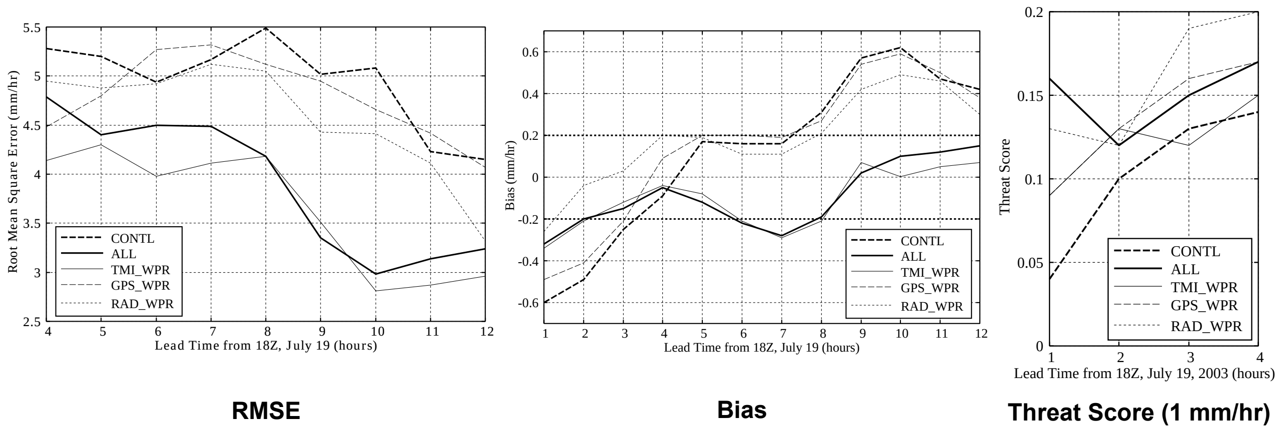

Fig. 7: Skill scores for 1-hr accumulated precipitation forecasting.