Preliminary results of soil moisture data assimilation into JMA Global Analysis

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1. Introduction

The Japan Meteorological Agency (JMA) uses climatological monthly mean soil moisture data to provide initial conditions for the land model of its Global Spectral Model (GSM). However, this configuration could potentially degrade forecast results, especially for the lower atmosphere, because the data do not represent day-to-day variations in initial soil moisture. To improve the quality of such moisture and lower-atmosphere conditions, a simplified Extended Kalman Filter (SEKF; Drusch et al., 2009, de Rosnay et al., 2013) has been tested with JMA Global Analysis (GA). A numerical weather prediction (NWP)-type experiment and related evaluation against in-situ observation have also been executed to assess the impacts of the soil moisture analysis cycle.

2. Assimilation method

In the SEKF, the analyzed state vector $\boldsymbol{x_a}$ is computed at time t_i for each grid point as

$$\boldsymbol{x_a}(t_i) = \boldsymbol{x_b}(t_i) + \boldsymbol{K_i}[\boldsymbol{y_o}(t_i) - H_i(\boldsymbol{x_b})]$$

where $\boldsymbol{x_b}$ is a first-guess state vector, $\boldsymbol{y_o}$ is an observation state vector and H_i is a nonlinear observation operator. The Kalman gain matrix $\boldsymbol{K_i}$ is computed as

$$\boldsymbol{K_i} = \left[\boldsymbol{B^{-1}} + \boldsymbol{H_i^T R^{-1} H_i}\right]^{-1} \boldsymbol{H_i^T R^{-1}}$$

where $\boldsymbol{B}$ is a background-error covariance matrix and $\boldsymbol{R}$ is an observation-error covariance matrix. Following de Rosnay et al. (2013), these are static and diagonal matrices composed of error variances. $\boldsymbol{H_i}$ is a linearized observation operator approximated from finite differences using individual perturbations of the model state vector.

Analysis-based screen-level parameters and an ASCAT surface soil moisture product (Bartalis et al., 2007) are assimilated in the SEKF. The former are calculated via optimal interpolation using 2-m temperature (T_{2m}) and relative humidity (RH_{2m}) data as reported in SYNOP observations, while the latter is matched to the soil moisture climatology of the JMA land model using cumulative distribution function (CDF) matching before SEKF application.

3. Experimental settings

Figure 1 shows the specifications of the NWP-type experiments, all of which were based on the operational GA and GSM as of Nov. 2019 except for the SEKF used in the TEST experiment. In the JMA land model, soil is discretized into seven layers with thicknesses of Δz = 0.02, 0.05, 0.12, 0.3, 0.5, 1.0 and 1.5-m. To prevent unrealistic soil moisture drift during long-term integration, initial soil moisture between the fourth and seventh layers was set as climatological values in the TEST experiment. Such configuration can be rationally applied to deeper layers in consideration of low sensitivity among the Jacobians of T_{2m} and RH_{2m}.

4. Verification results

Figure 1 shows that initial conditions of soil moisture determined from the SEKF cycle (TEST experiment) can be used to represent day-to-day variations. SEKF introduction improved the RMSEs of temperature at 850 hPa verified against ECMWF and UKMO analysis for land areas (e.g., Central Asia, Australia, North America and South America; Figure 2). Figure 3 shows normalized changes in the standard deviation of the first-guess departure for radiosonde observations on temperature and relative humidity. SEKF application improved statistics in the lower atmosphere, especially in the Northern Hemisphere. Forecast skill for lower temperature and humidity in the short range were also improved by 4% in the Northern Hemisphere (Figure 4).

5. Summary and future works

The quality of lower-atmosphere initial conditions was improved by introducing the SEKF to the JMA GA. The improved initial soil moisture and lower-atmosphere conditions produced better forecast skill for the near-surface atmosphere. Based on these results, the SEKF is planned to be introduced as part of near-future GA upgrades.

As no clear improvement is currently seen on sub-seasonal to seasonal timescales, future focus needs to be placed on enhancement with extended-range forecasts.

Table 1: Specifications of each NWP-type experiment.

	CNTL (operational version)	TEST
Forecast model	☐ GSM 1705 (JMA, 2019) ☐ TL959L100 (approx. 20km, 100 vertical levels up to 0.01hPa)	
Initial conditions of atmosphere	☐ 4D-Var global objective analysis	
Initial conditions of land model	☐ **Soil moisture content: climatological values using offline model forced by GSWP3(Kim, 2017)**	☐ **Soil moisture content: Soil analysis (SEKF)** ☐ **Observations: SYNOP (T_{2m}, RH_{2m}), Metop-A,B (ASCAT soil moisture)**
	☐ Snow water equivalent: Snow analysis (2D-OI) ☐ Other variables: forecast guess	
Period	☐ Jun. 10, 2017 to Oct. 11, 2017	

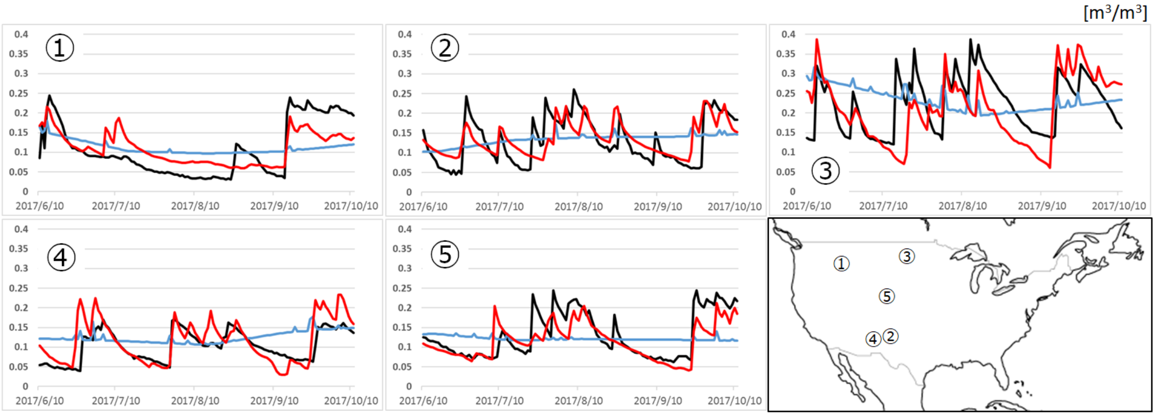

Figure 1: Comparison of soil moisture analysis in the second layer with USDA SCAN observations (at a depth of 5 cm) for five sites from July to September 2017. Black: USDA SCAN; blue: CNTL; red: TEST.

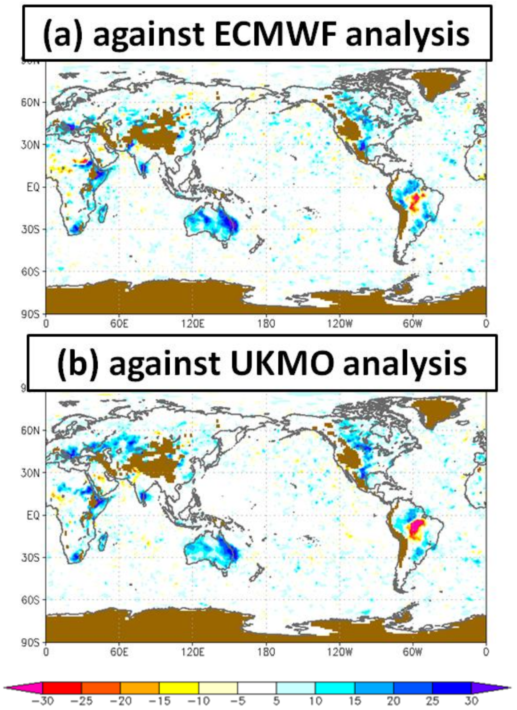

Figure 2: Percentage of relative improvement in root mean square error for 24-hour forecasts of temperature at 850 hPa verified against (a) ECMWF and (b) UKMO operational analysis.

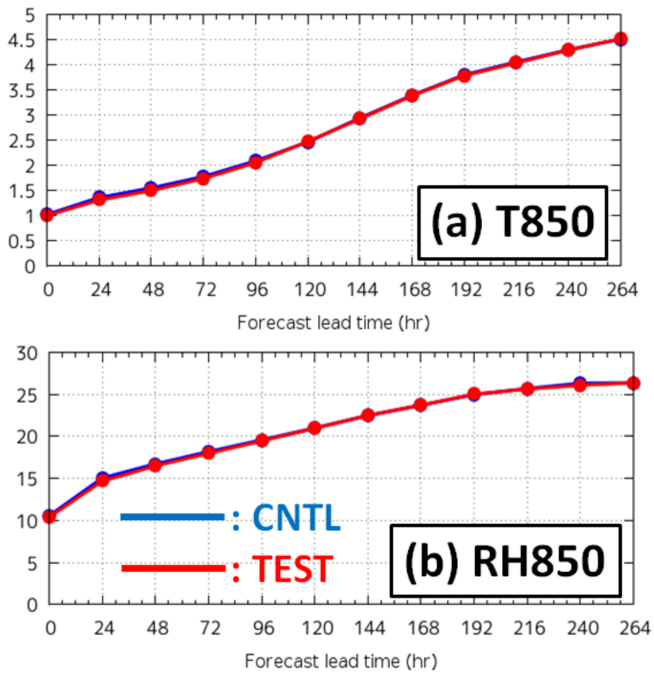

Figure 4: Root mean square error of (a) temperature at 850 hPa (b) relative humidity at 850 hPa against radiosondes in the Northern Hemisphere (20 – 90°N) for July to September 2017.

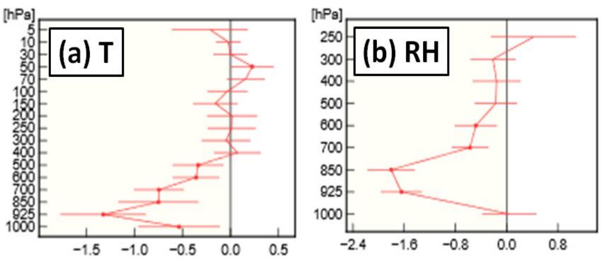

Figure 3: Normalized changes in the standard deviation of first-guess departures for radiosondes in the Northern Hemisphere (20 – 90°N): (a) temperature (b) relative humidity. Error bars: 95% confidence intervals.

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