Development of a multi-species aerosol-radiation scheme in JMA's global model

Shoukichi Yabu[1], Taichu Y. Tanaka[2] and Naga Oshima[2]

1: Numerical Prediction Division, Japan Meteorological Agency, Tokyo, Japan
2: Meteorological Research Institute, Tsukuba, Ibaraki, Japan
e-mail: yabu@met.kishou.go.jp

1. Introduction

In the aerosol-radiation scheme of the Global Spectral Model (GSM) used by the Japan Meteorological Agency (JMA), the monthly climatology for aerosol total optical depth (ATOD) is based on the total-column value from Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging Spectroradiometer (MISR) and Ozone Monitoring Instrument (OMI) observation data with seasonal variations. In the previous scheme, other optical properties of aerosols (such as the single scattering albedo (SSA) and asymmetry factor (ASF)) were specified as identical background values of continental and maritime types with no seasonal variation in line with WMO (1986), and it was insufficient to represent a radiative effect on aerosols consisting of different chemical species depending on locations. To address this problem, JMA developed a new aerosol radiation scheme allowing consideration of five aerosol types (sulfate, black carbon, organic carbon, sea salt and mineral dust) and their radiative properties.

2. Outline of the new scheme

The five aerosol types specified above are considered in the new aerosol radiation scheme, with mineral dust and sea salt having 6- and 2-size bins, respectively. The three-dimensional monthly climatological distributions of aerosol mass concentrations were derived from a climatological run of the Meteorological Research Institute aerosol transport model (MASINGAR mk-2, Yukimoto et al. 2011), and ATOD distribution is adjusted to the above satellite-based climatology because no aerosol data assimilation was conducted in this derivation.

Radiative parameters corresponding to the new aerosol types (e.g., extinction coefficient, SSA and ASF) were derived via Mie scattering calculation, in which size distribution parameters and the complex refractive indices of each type are generally obtained from the Optical Properties of Aerosols and Clouds (OPAC) database (Hess et al. 1998) and partly taken from recent aerosol observation data. Hygroscopic growth factors of aerosol due to water uptake depend on relative humidity, and are derived from the κ-Köhler theory (Petters and Kreidenweis 2007). All aerosol types are assumed to be externally mixed, and SSA and ASF parameters for all types are averaged and utilized in model radiative computation.

3. Impact of the new scheme on the global atmospheric model climate

To evaluate impact of the new scheme on GSM climatology, 10-year cases of one-month prediction experiments were conducted with a low-resolution (TL479) version of the model and analytically prescribed land/sea surface conditions. The 10 cases of monthly mean prediction data were averaged to give a rough estimate of the model's monthly climatology. Below, NEW (OLD) represents the experiment using the GSM with the new (previous) aerosol radiation scheme.

Figure 1 shows clear-sky downward longwave (LW) radiation flux at the surface compared to the Clouds and the Earth's Radiant Energy System (CERES) observation-based climatology. Around the Sahara Desert and the Arabian Peninsula, values increase by about 10 W/m^2 in the new scheme due to a warmer tropospheric atmosphere caused by enhanced absorption of shortwave (SW) radiation flux by mineral dust aerosols. More realistic representation of SW absorption by mineral dust in NEW is considered to improve downward LW radiation flux shortages of the model in clear-sky conditions.

Figure 2 shows differences in 850 hPa temperature (T850), sea level pressure (Psea) and precipitation amount (Rain) between OLD and NEW (first week mean). It can be seen that T850 is raised in some locations from North Africa to the Middle East due to enhanced SW absorption of mineral dust. A raised T850 area is also seen in the southeast Atlantic, where light-absorbing carbonaceous aerosols originating from biomass burning in Central Africa are distributed in NEW. The impact of aerosol light-absorption on temperature is higher in the downward direction in the troposphere, inducing more unstable atmospheric conditions. This causes cyclonic circulation anomalies over the desert area and the eastern part of the Central Atlantic Ocean (areas with negative Psea difference as shown in Fig. 2 b). These changes also affect wider atmospheric circulation conditions in the model, inducing the modification of precipitation climatology in some tropical areas. In the tropical Atlantic Ocean, a contrast in increased precipitation near the African Continent and decreased precipitation near the Southern American Continent is shown, representing weaker Walker circulation in the Atlantic caused by enhanced light absorption due to mineral dust aerosol (as noted by Lau et al. (2009)).

4. Impact of the new scheme on GSM forecast performance

Short-range forecast experiments were also conducted with atmospheric data assimilation using a subset of the operational analysis and prediction system and a high-resolution (TL959) version of the GSM. Here, TEST (CNTL) refers to the GSM experiment with the new (previous) aerosol-radiation scheme. Figure 3 shows relative improvement in various forecast skill scores of TEST against CNTL for August and January 2015. Numerous scores for the tropics and the summer hemisphere are significantly improved, suggesting that enhanced light absorption by aerosols has a positive influence on model performance both in the tropical region and in the middle latitudes via the modulation of global atmospheric circulation.

In May 2017, the new aerosol-radiation scheme was introduced into the new operational GSM.

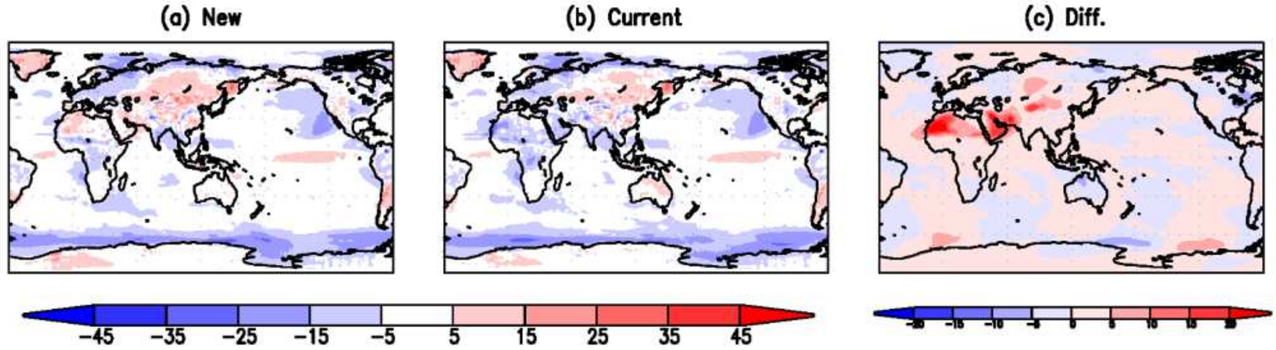

Fig. 1 Climatological difference of clear-sky downward longwave radiation flux at the surface in July: (a) Experiment using the GSM with the new aerosol-radiation scheme (NEW) minus CERES observational climatology; (b) experiment using the GSM with the previous scheme (OLD) minus CERES; and (c) NEW − OLD. Units are W/m^2.

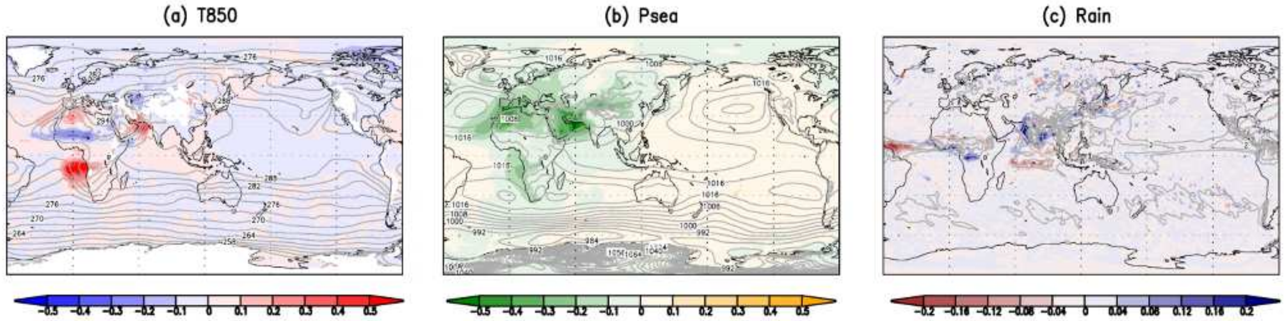

Fig. 2 Climatological difference of (a) 850 hPa temperature [K], (b) sea level pressure [hPa] and (c) precipitation [mm/day] for July. Shading indicates NEW − OLD, and contours show climatological distributions of OLD.

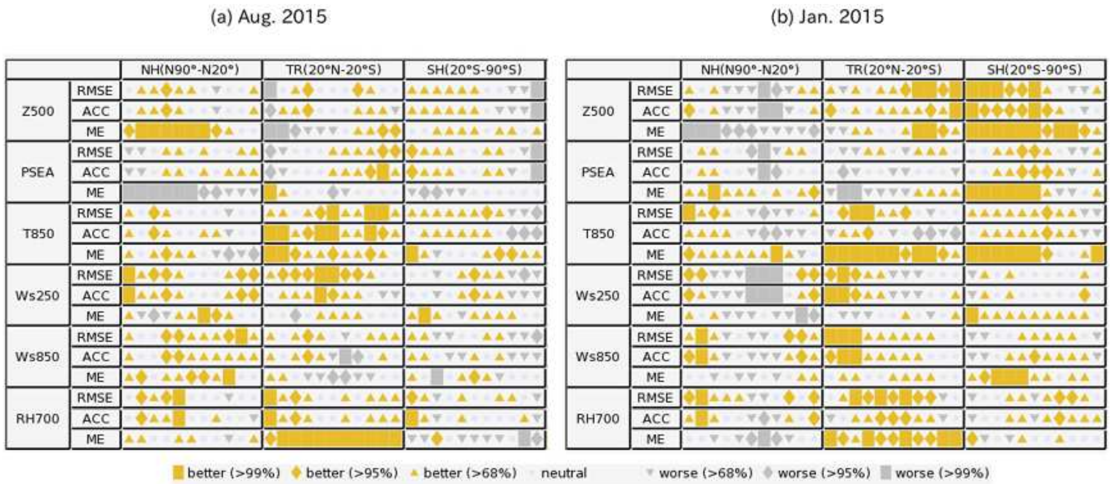

Fig. 3 Significance of improved forecast skill scores in the experiment using the GSM with the new scheme (TEST) against that with the previous scheme (CNTL). Scores represent root mean square errors (RMSEs), anomaly correlation coefficients (ACCs) and mean errors (MEs). Verification is performed for 500 hPa height (Z500), sea level pressure (PSEA), 850 hPa temperature (T850), 250 and 850 hPa wind speed (Ws250 and Ws850) and 700 hPa relative humidity (RH700), averaged over the Northern Hemisphere (NH), the tropic region (TR) and the Southern Hemisphere (SH). Yellow (gray) marks indicate better (worse) scores with statistical significance levels of 68, 95 and 99%. The 11 marks in each cell correspond to forecast days (from left (day 1) to right (day 11)). Evaluation terms are (a) August 2015 and (b) January 2015.

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