Radiative forcings due to aerosol-radiation and aerosol-cloud interactions using an online aerosol model in NICAM with a global 14 km grid resolution

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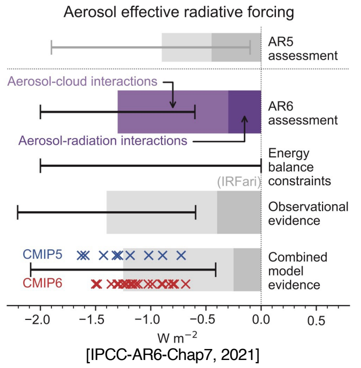
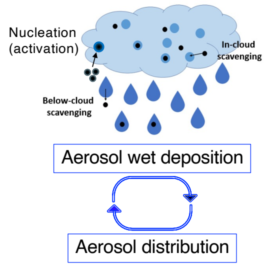
1. Introduction

Large uncertainty of aerosol-cloud interaction among aerosol models

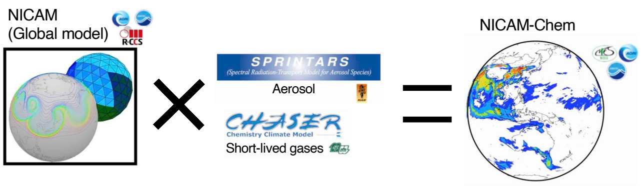


[IPCC-AR6-Chap7, 2021]



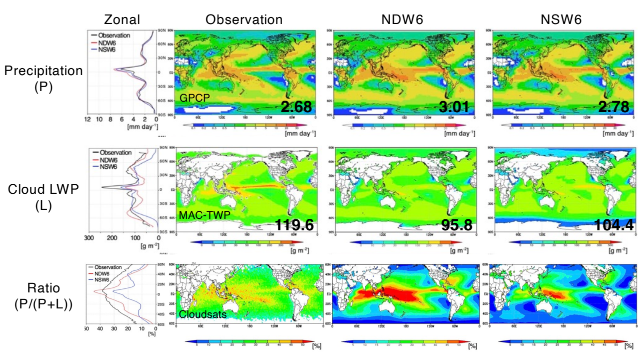
To reduce this uncertainty, we use the following methods:
1. higher-resolution model
2. better cloud module

2. Model description: NICAM-Chem



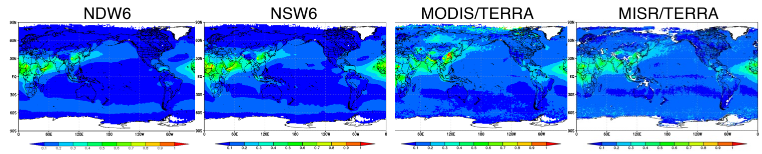
Process	Advanced	Standard
Transport	Improved van Leer (1977) (Miura, 2007; Niwa et al., 2011)	
Cloud microphysics	NDW6 (Seiki and Nakajima, 2014)	NSW6 (Tomita, 2008)
Cumulus	No parameterization	
Auto-conversion	Seifert and Beheng (2006)	Khairoutdinov and Kogan (2000)
Turbulence	Meller & Yamada (1974), Nakanishi & Niino (2004, 2006)	
Radiation	MSTRN-X (Sekiguchi and Nakajima, 2008)	
Horizontal grid	14 km	
Vertical grid	78 layers (15 layers below 2-km height)	
Timestep	30 seconds	
Period	6-year integration (after +1 year spinup), but now 10 years	
Aerosol	SPRINTARS (Takemura et al., 2005) --- 1 moment bulk	
Aerosol tracer	Dust (6-bins), Seasalt (4-bins), Pure organic carbon (OC), Pure black carbon (BC), OC-BC internal mixture, sulfate, SO_2, and DMS	
Emission & Boundary	HTAP-v2.2, GFED v4, GEIA (terpenes), Online (dust in Takemura et al., 2000, seasalt in Monahan et al., 1986, and DMS in Bates et al., 1987), Offline Oxidants (Sudo et al., 2002)	
PI conditions	No anthropogenic SO_2, OC, and BC	
Calculation	1 year integration requires approximately 7-10 days with 2560 processors (640 nodes) in Fugaku	

3. Evaluation of Cloud and precipitation



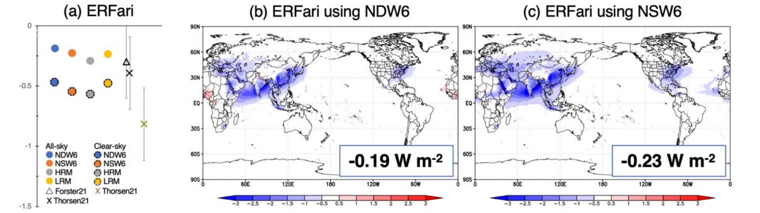
The zonal and annual distributions of the NDW6-simulated LWP near the polar regions (> 45°S and > 45°N) are more comparable to the MAC results than to the NSW6 results. This feature is explained by the better reproducibility of supercooled liquid water in low-level mixed-phase clouds (Roh et al., 2020; Seiki and Roh, 2020; Noda et al., 2021).
Regarding the wet deposition of aerosols, the precipitation-to-cloud ratio is important and there are differences between NDW6 and NSW6. That is, the NDW6-simulated wet deposition is greater than the NSW6-simulated result.

4. Evaluation of aerosol optical thickness



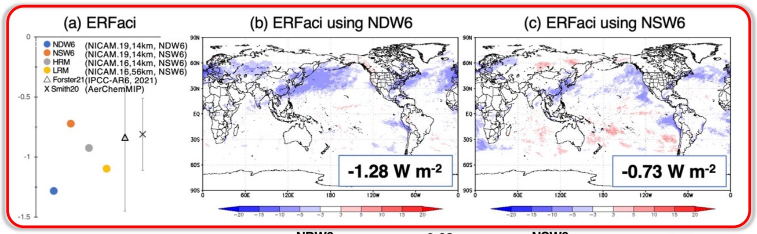
Since the precipitation-to-cloud ratio in NDW6 is larger than that of NSW6, the NDW6-simulated aerosol concentrations tend to be lower than the NSW6-simulated results (but the differences in AOD are within the uncertainty of satellite estimations).

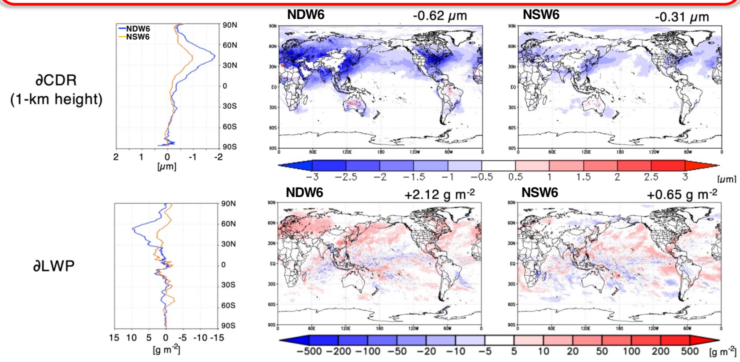
5. Effective Radiative Forcing due to aerosol-radiation interaction (ERFari)



The ERFari calculated using NDW6 and NSW6 was found to differ by approximately 20% (0.04 Wm⁻²). The difference in ERFari between NDW6 and NSW6 strongly reflects differences in the spatiotemporal distribution of aerosols themselves. This difference can be interpreted as arising from variations in the cloud-precipitation conversion ratio, which in turn leads to differences in aerosol abundance. However, the aerosol fields calculated using both NDW6 and NSW6 fall within the observed range, and the ERFs of both NDW6 and NSW6 fall within the uncertainty range of the reference studies. The difference in ERFari calculated using NDW6 and NSW6 was smaller than the difference with HRM using a different model version (0.07 Wm⁻²), and smaller than the difference in ERFari caused by the difference in model resolution between 14 km and 56 km grids (0.06 Wm⁻²). In other words, the difference in ERFari due to differences in the cloud microphysics model was smaller than the differences due to horizontal resolution or model version.

6. Effective Radiative Forcing due to aerosol-cloud interaction (ERFaci)





This result differs from the ERFari, as the difference in ERFaci calculated using NDW6 and NSW6 was large (0.55 Wm⁻²). This difference was larger than the difference between different HRM versions of the model (0.20 Wm⁻²) and larger than the difference in ERFari arising from differences in model resolution (0.17 Wm⁻²). All results fall within the uncertainty range observed in IPCC-AR6, but the difference between the results calculated using NDW6 and NSW6 is notable. When comparing the changes in effective cloud droplet radius (CDR) and cloud liquid water path (LWP)—physical quantities related to ERFaci—it was found that both quantities showed larger values in results using NDW6 than in those using NSW6. One reason for this is that NDW6 enables positive calculation of the number concentration of water droplets and ice particles in precipitation, thereby improving the reproducibility of supercooled water droplets. This led to better reproduction of cloud microphysical changes in response to aerosol variations. Another major factor is that NSW6 assumes cloud particle number concentration to be equal to cloud condensation nuclei (CCN), which differs significantly from NDW6, which explicitly calculates cloud particle number concentration.

This study was based on Goto D., Seiki T., Suzuki K., Yashiro H, Takemura T. (2024) Impacts of a double-moment bulk cloud microphysics scheme (NDW6-G23) on aerosol fields in NICAM.19 with a global 14-km grid resolution. Geoscientific Model Development, 17(2), 651-684, doi:10.5194/gmd-17-651-2024.

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