Global Dust Simulations in the Multiscale Modeling Framework

Wei-Chun Hsieh, Daniele Rosa and Bill Collins

University of California, Berkeley

Earth & Planetary Science

University of California, Berkeley

Abstract

This study investigates the roles of sub-grid vertical transport in global simulations of soil-dust aerosols. In conventional global models, convective and turbulent transport are highly parameterized. This study applies the superparameterization (SP) framework in which a cloud-resolving model (CRM) is embedded in each grid cell of a global model to simulate explicit sub-grid processes. We use the SP framework in the NCAR Community Atmospheric Model (CAM). Comparison of dust profiles shows that SPCAM predicts less dust in the low to mid troposphere but relatively higher concentration in the upper troposphere. Overall, a higher mobilization flux is predicted in SPCAM than in CAM with increases of up to 10 % in some regions with high dust mobilization. Similar patterns of elevated dry deposition also produced with increases as large as 100%. For wet deposition, CAM is ~ 31 % higher than SPCAM. The differences between CAM and SPCAM demonstrate that process-oriented treatments of convection can significantly affect the distributions, sources, and sinks of global soil-dust simulations.

Coupling Between CAM and CRM for Dust

Subgrid scale processes of dust follows water vapor transport (Khairoutdinov et al., 2005)

The large scale (LS) tendency exerted in CRM

$$\left[\frac{\partial\psi}{\partial t}\right]_{LS} = \frac{\psi_{LS}-\bar{\psi}^n}{\Delta t_{LS}}$$

ψ: prognostic tracers, $\bar{\psi}^n$ is the horizontally averaged CRM variable at the step n and Δt_{LS} denotes the CAM time step

The CRM feedback to CAM

$$\left[\frac{\partial\psi}{\partial t}\right]_{CRM} = \frac{\bar{\psi}^{n+1}-\psi_{LS}}{\Delta t_{LS}}$$

$\bar{\psi}^{n+1}$ denotes horizontal mean of the CRM fields at the end of step n of the CRM integration.

The original CRM computes horizontal averaged fields including temperature, water vapor and cloud condensate. This study adds the calculations of dust, which is modeled as four particle size tracers in CAM.

Modeling Dust

- •Based on Mineral Dust Entrainment and Deposition (DEAD) model developed by Zender et al. (2003)
- •DST01 (0.1-1.0 mm), DST02 (1.0-2.5 mm) DST03 (2.5-5.0 mm), DST04 (5.0-10.0 mm)
- •Dust processes included in CRM are turbulent diffusion/ mixing and small-scale advection
- •The source and sink processes, i.e., mobilization and dry/wet deposition are calculated in the large scale model (CAM)

Model Description

Large scale model

- •Host model: CAM
- •An atmospheric component of Community Climate System Model (CCSM)
- •Developed by NCAR
- •1.9º * 2.5º horizontal resolution
- •Prognostic variables are water vapor, liquid water, ice, and aerosols
- •Time step = 900 s

Small scale model

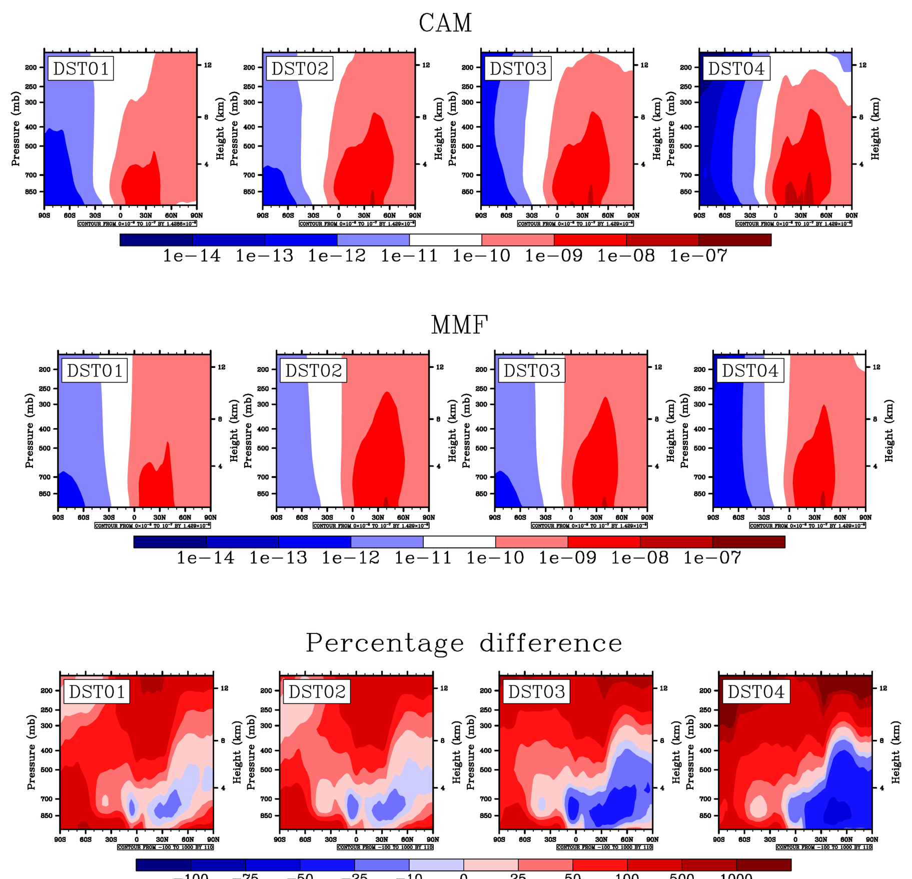
- •Cloud scale model: CRM
- •2D CRM (Khairoutdinov and Randall, 2003)
- •32 columns in each grid cell of CAM, 4 km horizontal resolution
- •CRM is arranged in east-west orientation with 26 levels collocated with the GCM vertical layers
- •CRM time step is 20 s

Model setup

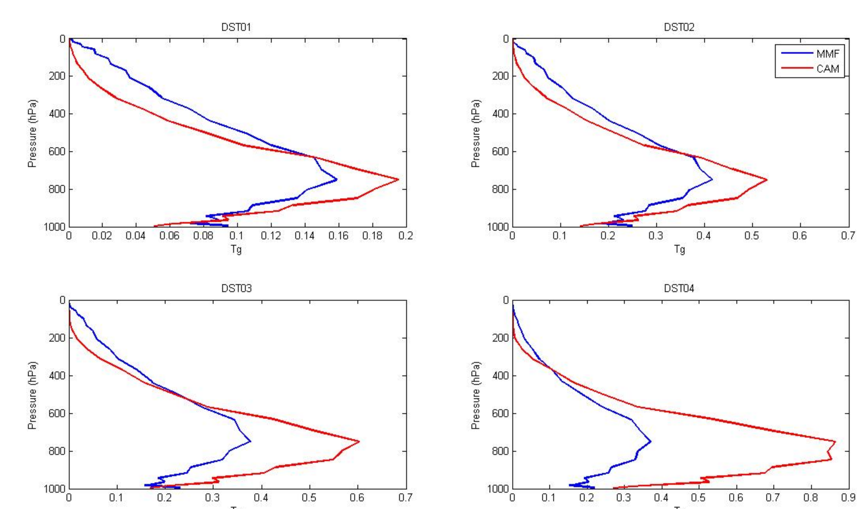
- •Finite volume dynamical core is used in all simulations
- •The model is configured in chemical transport mode
  - •NCEP reanalysis data is used for offline meteorology inputs
- •A total of 28 vertical layers in the large scale model
- •Simulations start from Dec, 1, 2000
- •Each simulation is run for 13 months, and the results are the last 1 year analysis

Dust Vertical Profiles

Vertical Profiles: Zonal Means

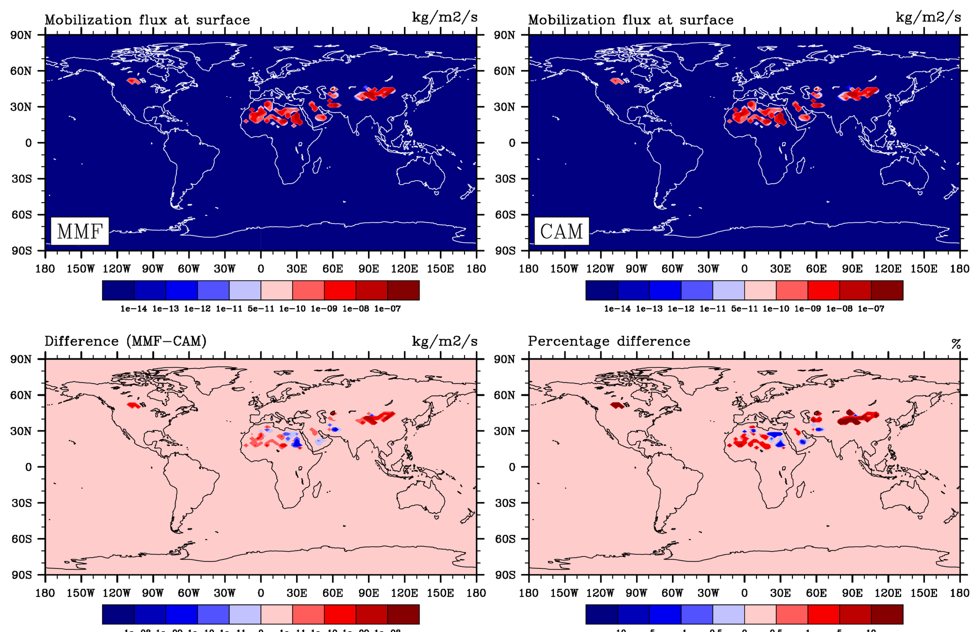


Vertical Profiles: Sum of Global Dust Mass

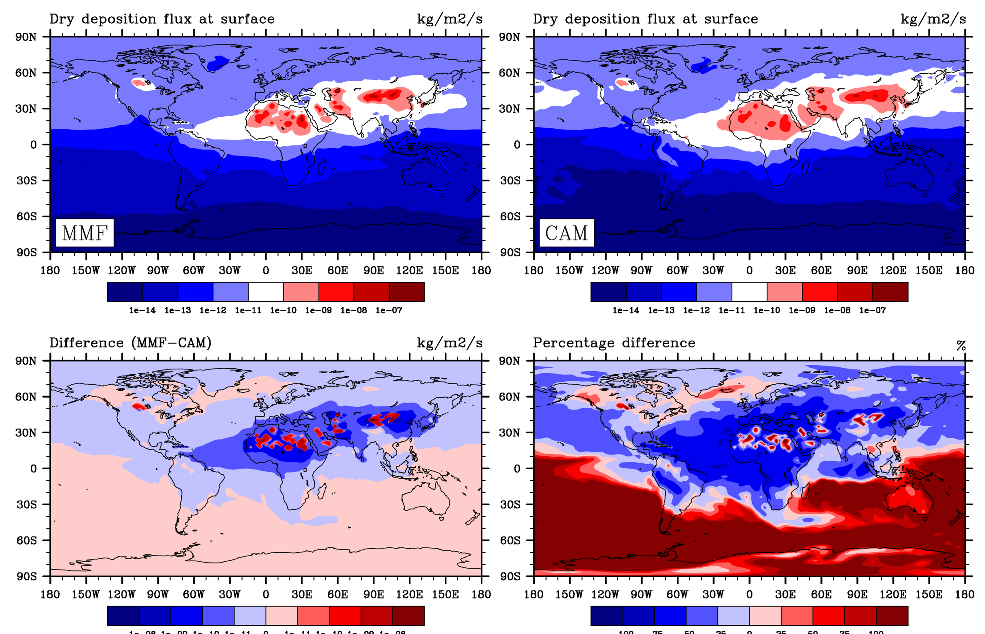


Difference Between MMF and CAM

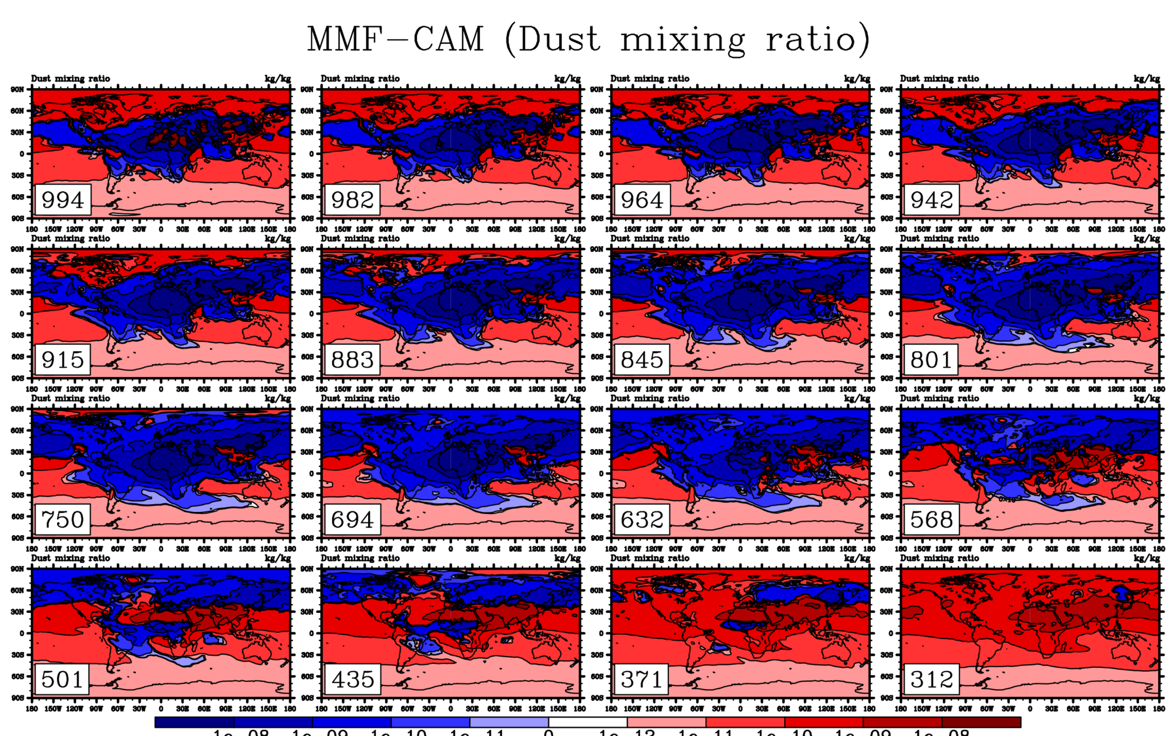
Mobilization (MMF, CAM, MMF-CAM)



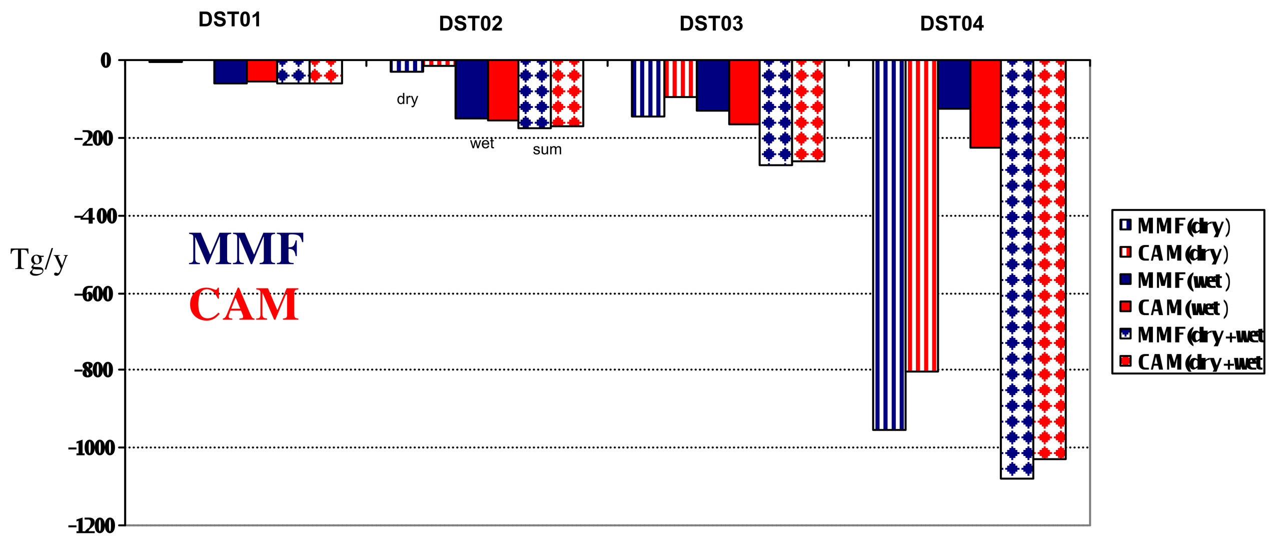
Dry Deposition (MMF, CAM, MMF-CAM)



Difference of Dust Mixing Ratio (MMF –CAM)

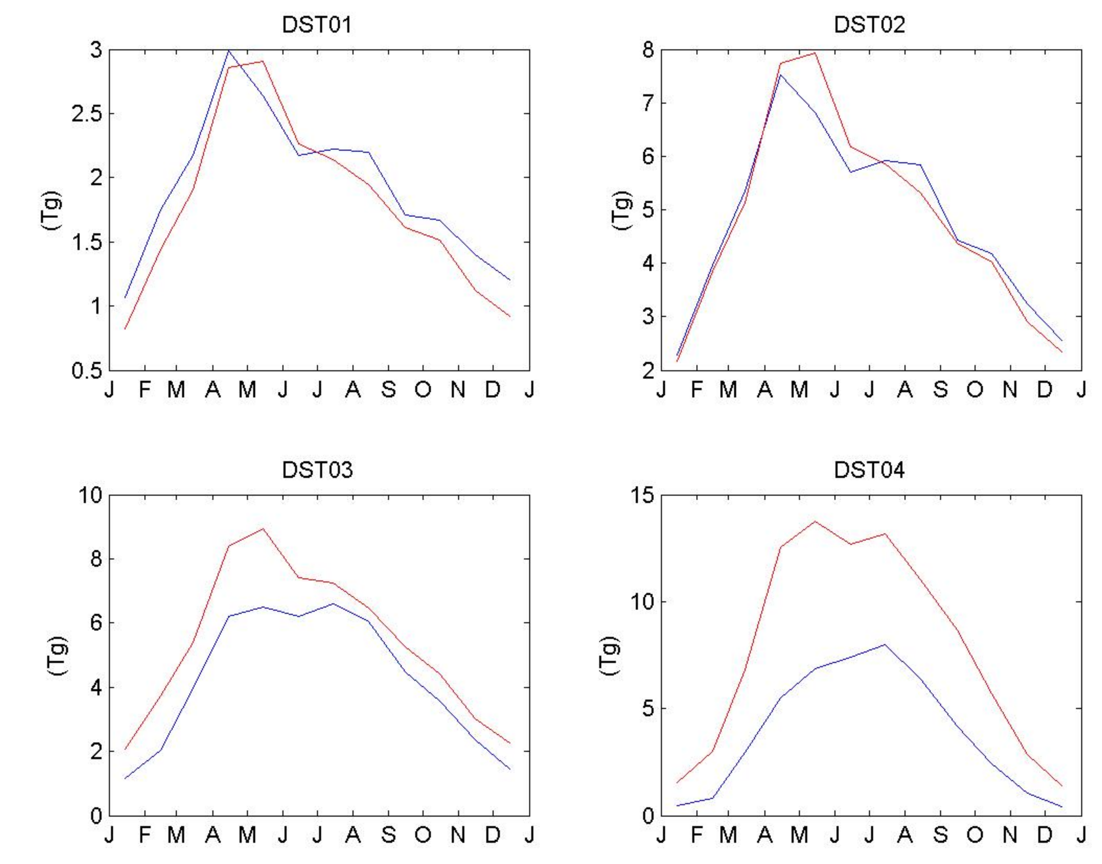


Source and sink rate (MMF and CAM)

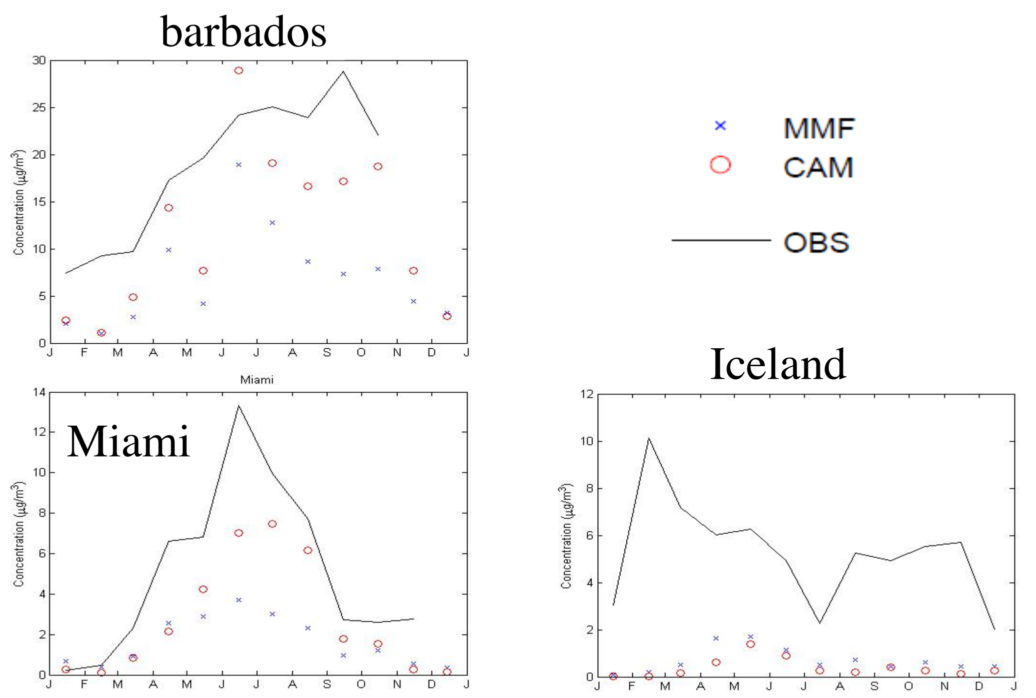


Dust Budget and Evaluation

Global Dust Burden



Concentration Comparison



Conclusion

- •Our study shows MMF changes the vertical distributions of dust. MMF shows less dust in low to mid troposphere but relatively higher concentration in upper troposphere.
- •We found CAM moves dust from the surface to low atmosphere much faster than MMF. The difference of dust amount vertically between two models causes different removal fluxes of dust deposition.
- •Overall, in our simulations, dry deposition is higher in MMF than CAM but lower in MMF than CAM for wet deposition.
- •The average burden in the simulated year for MMF and CAM is 14.8 Tg and 19.7 Tg, respectively.

Acknowledgments

This work is supported by Center for Multi-Scale Modeling of Atmospheric Processes (CMMAP). We would like to acknowledge high-performance computing support provided by NCAR's Computational and Information Systems Laboratory, sponsored by the National Science Foundation. Computing resource from TeraGrid is also acknowledged. We thank Francis Vitt, Andrew Conley, Marat Khairoudinov Charlie Zender and Joe Prospero for their help. WCH thank Jen-Ping Chen and Chung-Ling Shie for constructive discussions.