

Effect of Aerosols on Mesoscale Convective Systems

Xiping Zeng, Wei-Kuo Tao, Harold Pierce, and Toshihisa Matsui, Code 612, NASA GSFC; Scott W. Powell,

Robert A. Houze Jr., University of Washington; Paul Ciesielski, Nick Guy, Colorado State University

Mesoscale convective systems (MCSs) have large ($\sim 10^2$ km) cloud anvils extending laterally outward from deep convective cores. MCSs impact the climate system by contributing almost half of the total precipitation in the Tropics and by their anvils controlling both solar and terrestrial radiation fluxes. We seek observational support of the hypothesis that aerosols indirectly modulate climate by their impact on MCS anvil development.

- Two International field campaigns, AMMA (the African Monsoon Multidisciplinary Analysis) and TWP-ICE (the Tropical Warm Pool – International Cloud Experiment), took place in 2006 in West Africa and the Australia tropical coast, respectively.
- These field campaigns provided extensive observations of MCSs in both polluted and clean environments. Both the field campaign and satellite-based observations were compared to cloud-resolving model (CRM) simulations to formulate and validate concepts on aerosols and cloud anvils.
- The results demonstrate cloud anvils are sensitive to aerosol number concentration. The anvil modeled in the polluted environment has a scale of 400 km, close to that observed over AMMA (e.g., Fig. 1), in contrast to the scale of 100 km in a clean environment typically observed in TWP-ICE.

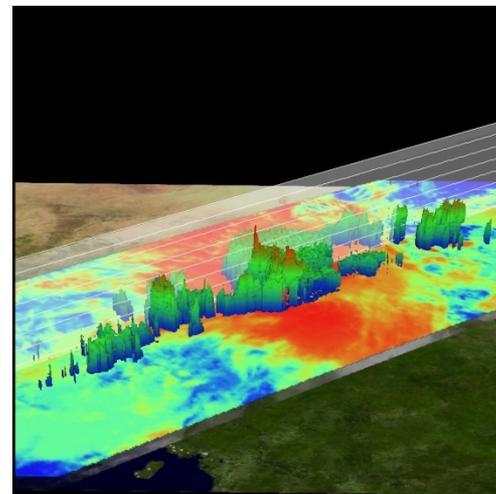


Figure 1: Three-dimensional image of AMMA MCS from TRMM satellite Precipitation Radar at ~ 0433 UTC on 11 August 2006 over west-central Africa, showing volume of convective clouds ($Z > 15$ dBZ). The image is overlaid on an infrared image from TRMM's VIRS that represents cloud anvil (red) associated with the convective clouds.

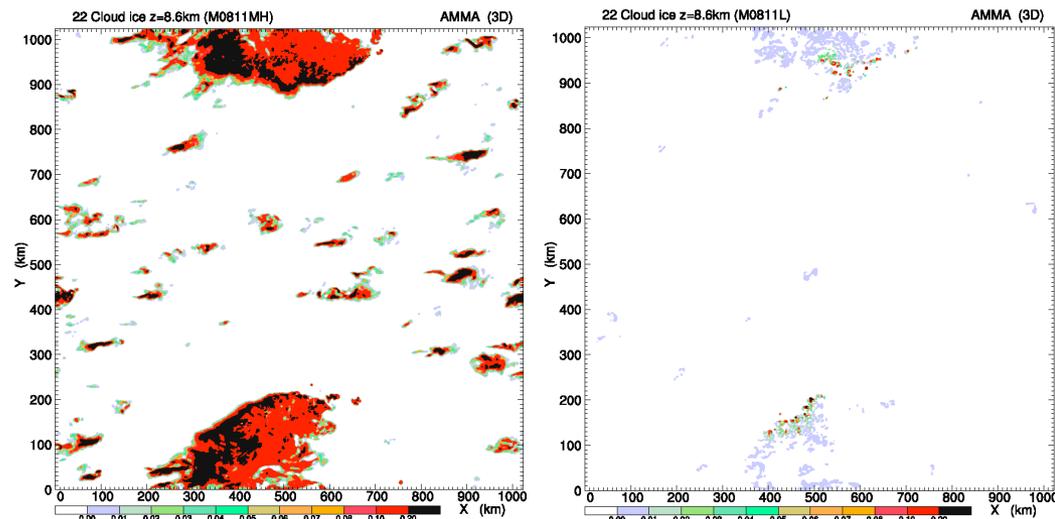


Figure 2: Horizontal distributions of the AMMA cloud anvils (or cloud ice mixing ratio at 8.6 km) modeled using high (left) and low (right) ice crystal concentrations, respectively, at 0400 UTC 11 August 2006.



Name: Xiping Zeng, Code 612 , NASA/GSFC, GESTAR/MSU
E-mail: xiping.zeng@nasa.gov
Phone: 301-614-6095



References:

Zeng, X., W.-K. Tao, S. W. Powell, R. A. Houze Jr., P. Ciesielski, N. Guy, H. Pierce and T. Matsui, A comparison of the water budgets between clouds from AMMA and TWP-ICE. *Journal of the Atmospheric Sciences*, **70**, 487-503, doi:10.1175/JAS-D-12-050.1, 2013.

Data Sources: Data used come from TRMM, CloudSat and Meteosat-8 satellites. They also come from the two international field campaigns, AMMA and TWP-ICE, that were supported by DOE/ASR, NASA and other (international) government agencies.

Technical Description of Figures:

Data used come from different observational platforms including satellites, radiosounding network, ground-based radar/lidar, and aircraft. These observations were used to constrain and evaluate cloud-resolving model (CRM) simulations, providing a physically-consistent picture on the effect of aerosols on MCSs. The CRM used in this work is the *Goddard Cumulus Ensemble* (more details at <http://cloud.gsfc.nasa.gov/index.php?section=11>).

Figure 1 displays a snapshot of a MCS over the AMMA area of observation in West Africa, as an example showing the scale of MCS (~400 km) with respect to the observation area.

Figure 2 contains the horizontal distributions of cloud ice mixing ratio at 8.6 km (or cloud anvil) from two CRM simulations: one using high ice crystal concentration (or aerosol number concentration, i.e., a polluted environment) and the other low ice crystal concentration (i.e., a clean environment). The cloud anvil modeled with high ice crystal concentration is close to observations (e.g., Fig. 1) in size. The difference in size between the two anvils contributes to our understanding of the processes that produce larger MCS anvils in AMMA (in a polluted environment) compared to those over TWP-ICE (in a clean environment).

Scientific significance: The observed increase in anthropogenic carbon dioxide cannot explain fully the observed global warming (IPCC 2007), and other candidates for the warming (e.g., aerosols) have been proposed. One of the candidates is ice nuclei (IN), a class of aerosols, which can impact cloud microphysics and subsequently radiation. Previous studies revealed that an increase in IN can bring about an increase in ice water content (IWC) in the upper troposphere and consequently a surface warming. Can this positive correlation between IN and upper-tropospheric IWC be tested with field campaign and satellite observations? In this study, two cases from dirty and clean environments (i.e., AMMA and TWP-ICE) were analyzed via CRM simulations. Results show that IN can significantly affect MCS anvil sizes, which provides strong support to hypotheses on the positive correlation between IN and upper-tropospheric IWC.

Current climate models usually overlook the indirect effect of IN (e.g., dust particles) on climate change. This case study demonstrated that IN are an important modulator of clouds and radiation and therefore of climate change. The study also provided a quantitative example to accurately represent the IN effects in climate models.

Relevance for Future Missions: Field campaign observations and cloud-resolving model simulations will be used to help the Aerosols, Clouds and Ecosystems (ACE) Decadal Survey mission to establish the global distribution of the IN effect on upper-tropospheric IWC.

Yuekui Yang¹, Stephen Palm², Alexander Marshak³, Dong Wu³, Hongbin Yu⁴, and Qiang Fu⁵

¹USRA/Code 613; ²SSAI/Code 612; ³NASA/GSFC Code 613; ⁴UMD-ESSIC/Code 613; ⁵University of Washington

Blowing snow (BLSN) is a common phenomenon over the polar regions. Over large areas of East Antarctica it occurs over 60% of the time during the winter months. Previous studies have shown that BLSN has significant impacts on the ice sheet mass balance and hydrological processes. Recently Goddard scientists found the first observational evidence that BLSN substantially affects the outgoing longwave radiation (OLR) over the Antarctic ice sheet. These results followed from the study that combined observations from three NASA sensors: CERES, which measures the Earth's radiation budget, MODIS, which observes the Earth in 36 spectral bands, and the CALIOP lidar, which provides the vertical profile needed for BLSN detection.

Under cloud free conditions, if OLR with BLSN is larger than OLR without it then the presence of BLSN leads to more radiation leaving the Earth; hence BLSN cools the surface-atmosphere system. In opposite case, BLSN warms the system.

Using observations from the NASA satellites, Goddard scientists found significant cloud-free OLR differences between the clear and BLSN conditions, with the sign and magnitude depending on season and time of the day. During nighttime, OLR with BLSN is usually larger than those without BLSN (Fig. 1b); the average difference in OLRs between these two conditions over the East Antarctica ice sheet is about -5 W/m^2 for the winter months (nighttime) of 2009 (Fig. 2). During daytime, however, OLR with BLSN is usually close to or smaller than OLR without BLSN (Fig. 1a). These results are consistent with theoretical calculations and can be explained with the existence and strength of the surface-based inversions (SBIs). For example, because of strong SBIs, during the polar night, the BLSN layer is warmer than the surface and more radiation is emitted to space compared to clear sky conditions; hence BLSN generally has a cooling effect to the surface-atmosphere system. During the polar day, however, SBIs can be destroyed and the effect of BLSN will be opposite.

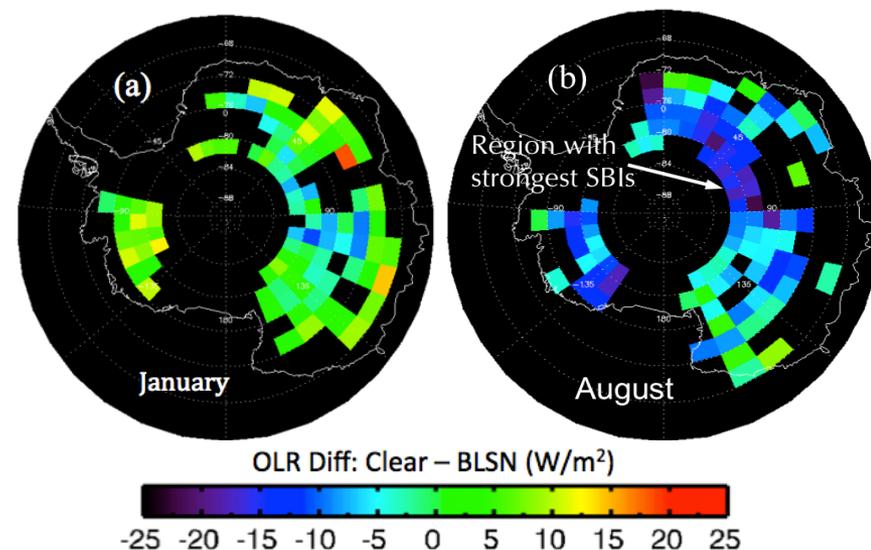


Figure 1: Monthly mean OLR flux differences between cases with and without blowing snow for (a) January (polar day) for (b) August (polar night). While about 66% of the OLR differences are positive in January, about 91% are negative in August. These results show that blowing snow generally has a cooling effect to the surface-atmosphere system during the polar night. During the polar day, however, the effect can be warming.

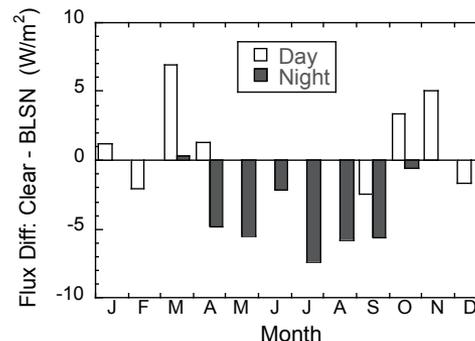


Figure 2: Monthly mean OLR differences between clear and blowing snow sky conditions averaged over the East Antarctica ice sheet for the year 2009. This figure confirms that during nighttime blowing snow generally has a cooling effect to the surface-atmosphere system.



References:

Yang, Y., S. P. Palm, A. Marshak, D. L. Wu, H. Yu, and Q. Fu (2014), First Satellite-detected Perturbations of Outgoing Longwave Radiation Associated with Blowing Snow Events over Antarctica, *Geophys. Res. Lett.* (In Press).

Palm, S. P., Y. Yang, J. D. Spinhirne, and A. Marshak (2011), Satellite remote sensing of blowing snow properties over Antarctica, *J. Geophys. Res.*, 116, D16123, doi:10.1029/2011JD015828.

Data Sources: Data used in this study are from the Level 1 and Atmosphere Archive and Distribution System (LAADS) at the NASA Goddard Space Flight Center and the Atmospheric Science Data Center (ASDC) at the NASA Langley Research Center.

Technical Description of Figures:

Figure 1: Monthly mean OLR differences between with and without blowing snow for (a) January (polar day) for (b) August (polar night). To limit the effect of environmental variability on the results, the Antarctic ice sheet is divided into grid boxes with a size of 2° latitude by 10° longitude. Then for each month, all the clear and blowing snow CERES pixels are identified and put into their corresponding grid boxes. The difference values are highly correlated with the existence and strength of the surface-based inversions (SBIs). During nighttime, when SBIs are strong, OLRs are usually larger when blowing snow is present, because the blowing snow layer is warmer than the surface; during daytime, when SBIs are destructed/weakened, OLRs associated with blowing snow pixels are usually smaller than / close to those associated with the clear pixels.

Figure 2: Differences between the monthly mean CERES OLR fluxes for clear and blowing snow sky conditions over East Antarctica for the year 2009 with day and night calculated separately.

Scientific significance: Blowing snow is a common phenomenon over the polar regions. Observations have shown that over large areas of East Antarctica it occurs over 60% of the time during the winter months. Climate in polar regions is sensitive to the radiative flux. This study shows that blowing snow events can cause significant perturbations in top of atmosphere longwave radiation. These perturbations may affect climate in the regional and even global scale, which is currently not taken into account in climate models.

Relevance for future science and NASA missions: Through innovative and synergetic use of NASA satellites data, this study demonstrate the potential impact of blowing snow on Antarctic climate. Currently, blowing snow detection is achieved through analysis of the CALIOP observations. In the future, lidar systems on board of future missions such as the Aerosol-Cloud-Ecosystems (ACE) and the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) would be helpful in extending the blowing snow record, which will enable the annual variation and long term trend studies of blowing snow radiative effects.



Volcanic and anthropogenic contributions to stratospheric aerosol trends

Mian Chin, Code 614, NASA GSFC

Volcanic emissions can be the major source of stratospheric aerosol, but there is a persistent “background” aerosol layer even without major volcanic eruptions. Recent observations seem to suggest that this “background” aerosol has been increasing in the past decade, and anthropogenic emission increase in Asia was proposed to be the cause of this increase. However, even without large volcanic eruption (i.e., at the magnitude of El Chichon or Pinatubo) in the last decade, there have been many numerous volcanic eruptions, putting SO₂ into the upper troposphere or stratosphere.

Incorporating the satellite based estimation of SO₂ from volcanic eruptions and most recent anthropogenic emission inventories, the GOCART model is used to simulate the stratospheric aerosols and to separate the sources. Figure 1 shows the volcanic SO₂ plume evolution from the Kasatochi eruption from OMI and GOCART simulation, and Figure 2 shows the time series of stratospheric aerosol extinction profile from SCIAMACHY retrieval and GOCART simulations.

Both satellite data and model have shown that even without major explosive volcanic eruptions, volcanic emissions frequently perturb the stratospheric “background” aerosols, making it difficult to define non-volcanic background aerosol values in the stratosphere. The model suggest that the increase of Asia pollution does contribute to the stratospheric aerosol, but they are mostly confined in the lower stratosphere with organized seasonal cycles and is much less than volcanic aerosols.

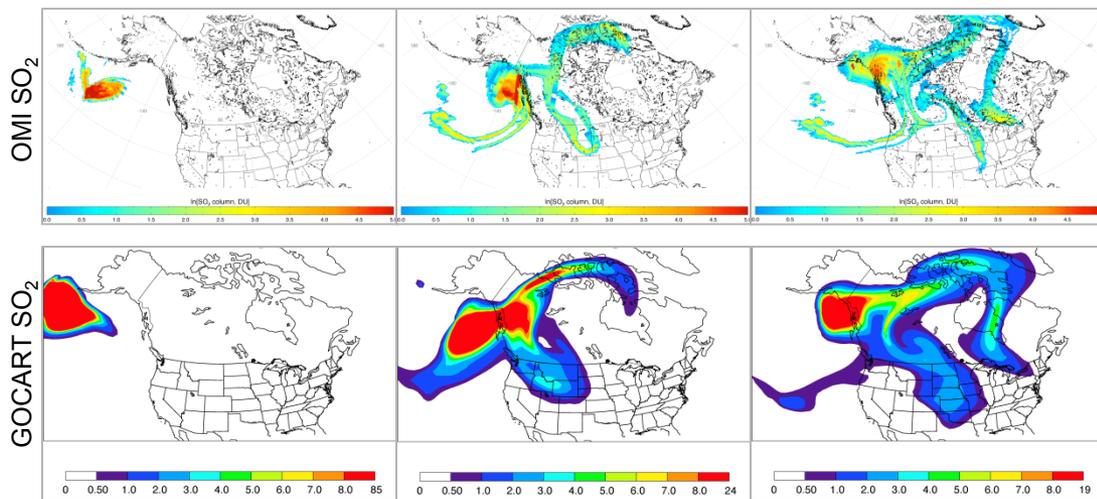


Figure 1: Column SO₂ from Kasatochi eruption, August 2008. Top row: OMI retrieval. Bottom row: GOCART simulation.

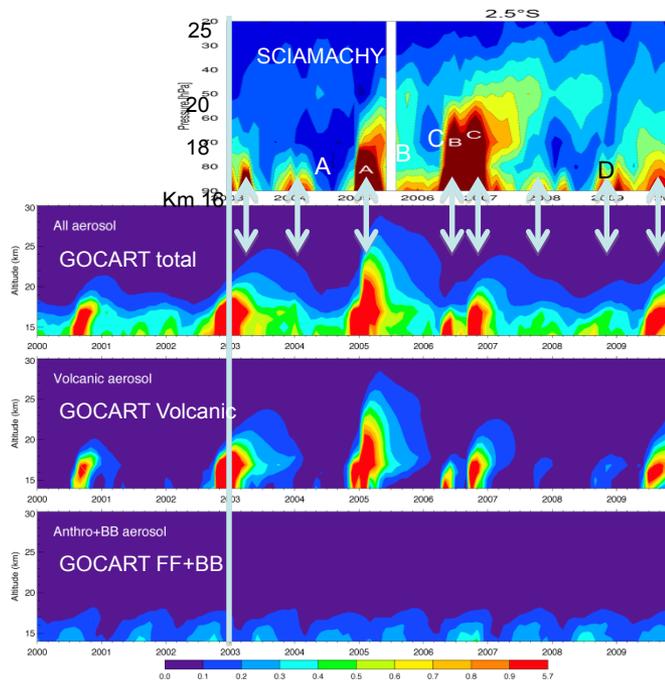


Figure 2: Time series of zonal and monthly averaged stratospheric aerosol extinction vertical profiles at 2.5°S from SCIAMACHY observations (top panel), GOCART simulation (2nd panel), GOCART volcanic aerosol only (3rd panel) and GOCART anthropogenic (fossil fuel +biomass burning) aerosol only (last panel).

- Major volcanic eruptions:
- A. Manam (Jan 2005, 4°S)
 - B. Soufriere Hills (May 2006, 16°N)
 - C. Tavurvur (Oct 2006, 4°S)
 - D. Sarychev Peak (July 2009, 48°N)



Name: Mian Chin, NASA/GSFC, Code 614

E-mail: Mian.Chin@nasa.gov

Phone: 301-614-6007

References:

Mian Chin, Thomas Diehl, Qian Tan, Huisheng Bian, John Burrows, Nickolay Krotkov, Jean-Paul Vernier, Zifeng Lu, David Streets, William Reed, 2013: Anthropogenic and volcanic aerosol contributions to the decadal stratospheric aerosol trend, paper presented at the Amer. Meteorol. Soc. Annual Meeting, Austin, TX.

Data Sources: OMI SO₂ product from GSFC; SCIAMACHY aerosol extinction profile from University of Bremen.

Technical Description of Figures:

Figure 1: Volcanic SO₂ plume transport and evolution from the Kasatochi eruption in August 2008. Top row shows three days of column SO₂ (unit in ln(Dobson Unit)) on 8/9, 8/11, and 8/12/2008 from the OMI retrievals, and the bottom row shows the corresponding SO₂ column (unit in Dobson Unit) from GOCART simulations. The OMI SO₂ is the snapshot at the OMI overpass time while the GOCART is daily average with model spatial resolution at 1 deg latitude x 1.25 deg longitude. The model in general captures the plume disperse pattern.

Figure 2: Time series of zonal and monthly averaged stratospheric aerosol extinction vertical profiles at 2.5°S from SCIAMACHY observations (top panel), GOCART simulation (2nd panel), GOCART volcanic aerosol only (3rd panel) and GOCART anthropogenic (fossil fuel+biomass burning) aerosol only (last panel). With model runs tagged with different sources, the model is able to separate the contribution of anthropogenic and volcanic sources to stratospheric aerosols in the past decade, suggesting that the volcanic contribution is much larger than anthropogenic source to stratospheric aerosols, although anthropogenic sources seem to have steady increase in the lower stratosphere with organized seasonal cycles.

Scientific significance: These results provides an assessment of anthropogenic and volcanic contributions to the stratospheric aerosols in the period without large volcanic eruptions.

Relevance for future science and relationship to Decadal Survey: The study will help understand the impact of stratospheric aerosol on radiative forcing, and is relevant to the future NASA missions, such as ACE and CATS.