Aerosol effects on liquid water path of stratiform clouds under contrasting humidity

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Introduction: Ackerman et al. (2004) indicates that responses of liquid water path (LWP) to increasing aerosols in stratiform clouds depend on the humidity of the free atmosphere overlying the PBL. To better understand the dependence of the LWP responses on humidity, this study investigates different aerosol effects on the microphysics and dynamics of the two cases of stratocumulus over the North Atlantic developing under wet and dry environmental conditions.

1. Simulations

To examine the sensitivity of aerosol effects on the LWP to environmental humidity, two sets of simulations are performed. The first set of simulations with high humidity (~ 80 %) around the top of the PBL is referred to as WET and the second set with low humidity (~40%) as DRY. Each set of simulations is composed of high- and low-aerosol runs. A detailed description of simulations can be found in Table 1.

	WET (RH=80%)	DRY (RH=40%)
Location	42˚ N 63˚ W	42˚ N 53˚ W
Period	02 – 14 LST July 1st 2002	02 – 14 LST July 1st 2002
Average aerosol number in the PBL (cm^{-3})	◦High (present-day) aerosol : ~ 3100 ◦Low (preindustrial) aerosol: ~ 1200	◦ High (present-day) aerosol : ~ 2200 ◦ Low (preindustrial) aerosol: ~ 1100

Table 1. Description of simulations

		WET	DRY
Domain-averaged LWP ($g\ m^{-2}$)	High aerosol	46.16	29.70
	Low aerosol	35.43	30.21
	MODIS	48.10	31.20
Domain-averaged cumulative condensation at the last time step (mm)	High aerosol	0.89	1.39
	Low aerosol	0.69	1.41
Domain-averaged cumulative conversion of Small droplet to large droplet and rain (autoconversion +accretion) at the last time step (mm)	High aerosol	6.35×10^{-3}	7.62×10^{-3}
	Low aerosol	3.00×10^{-2}	1.57×10^{-2}
Average cloud-top growth rate ($cm\ s^{-1}$)	High aerosol	1.39	2.16
	Low aerosol	0.97	2.06

Table 2. LWP, condensation, conversion of cloud liquid to rain, and cloud-top growth rate

2. Results

Table 2 shows comparisons of the simulated LWP to the MODIS-observed LWP. The difference is within ~ 5 % relative to the MODIS LWP, demonstrating that the simulations are reasonably good. The LWP at high aerosol in WET (DRY) is higher (lower) than at low aerosol. The difference (high-low) in domain-averaged cumulative condensation at the last time step in WET is large enough to explain the higher LWP. It compensates for the increased entrainment at high aerosol, indicated by the higher cloud-top growth rate (Table 2). The difference in the cumulative conversion of small droplet to large droplet and rain is ~ one order of magnitude smaller than that in condensation, leading to negligible differences in the sedimentation of cloud droplets and rain as compared to those in condensation. This indicates that the enhanced LWP and entrainment is mainly controlled by increased condensation at high aerosol; increased condensation provides a source of liquid water, evaporative cooling and condensational heating increasing the LWP and intensity of downdrafts as well as updrafts, leading to larger TKE and thereby entrainment. This is at odds with Ackerman et al. (2004) which ascribed different LWP and entrainment rates to differences in the sedimentation of droplets and rain.

In the DRY simulations, increased entrainment of drier air at high aerosol contributes to reduced differences in condensation and the LWP, in contrast to the situation in WET. Also, it is found that a larger variance of the upward velocity (w'w') occurs at low aerosol between 07 LST and 08 LST in the cloud layer (Figure 1), leading to larger condensation around 08 LST (Figure 2) and, thereby, contributing to the larger LWP at low aerosol. This larger w'w' is led by greater instability around cloud base (Figure 3). More cooling from the evaporation of rain and large droplets at low aerosol induces the greater instability.

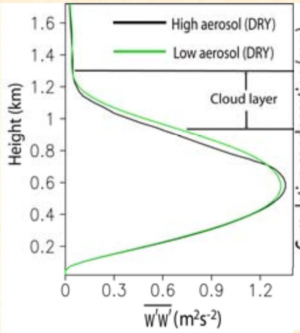

Figure 1. w'w' averaged between 07 and 08 LST

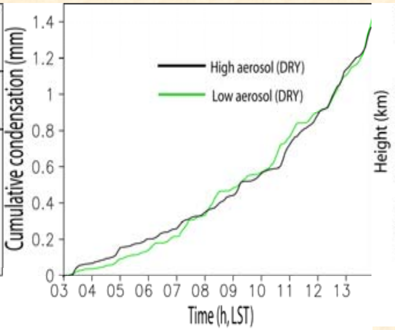

Figure 2. Cumulative condensation

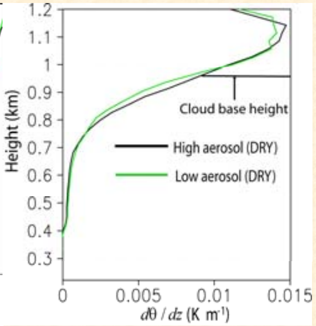

Figure 3. $d\theta / dz$ averaged between 03 and 07 LST

3. Summary and Discussion

Simulations in WET show that condensation plays a critical role in the LWP and entrainment. Aerosol-induced differences in condensation lead to differences in the LWP and evaporation (thereby dynamics and entrainment). However, the role that the sedimentation of droplets and rain plays in the development of the different LWP and entrainment rates is negligible. This indicates that the sedimentation is not always a major contributor to the different responses of the LWP and entrainment to aerosols; interactions among aerosols, condensation and dynamics can determine the responses primarily.

Simulations in DRY showed that the LWP decreases at high aerosol under a dry environment as reported by Ackerman et al.(2004). In addition to the role that increased entrainment of drier air in DRY plays in the reduction of LWP at high aerosol, larger instability contributes to the larger LWP at low aerosol in DRY.

4. Acknowledgments

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5. Reference

Ackerman, A. S., Kirkpatrick, M. P., Stevens, D. E., and Toon, O. B.: The impact of humidity above stratiform clouds on indirect aerosol climate forcing, *Nature,* 432, 1014-1017, 2004.