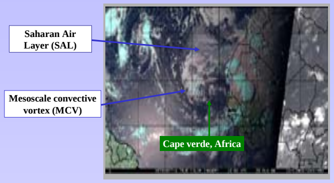
Impacts of Dust in the SAL as CCN on the Evolution of an Idealized Tropical Cyclone

Henian Zhang[1], Greg M. McFarquhar[1], Stephen M. Saleeby[2], and William Cotton[2]

[1]University of Illinois, Urbana, Illinois [2]Colorado State University, Fort Collins, Colorado

Motivation

What is the impact of desert dust particles in the SAL acting as CCN on the development of TCs?



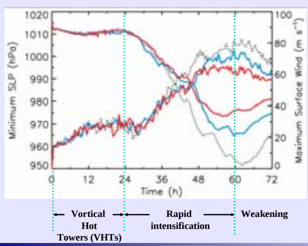
A vortex associated with the African Easterly Wave (AEW) can be seen from the Meteosat-8 visible imagery on August 26th, 2006. The SAL consisting of hot, dry and dusty air is drawn into the vortex center from north and northeast.

Below are three photos taken from the DC-8 on 5 September 2006 during the **NAMMA** (NASA African Monsoon Multidisciplinary Analyses) field campaign based at Cape Verde, Africa. As the DC-8 flew inland toward the dust source, a significant increase in dust loading was observed.

Model setup

- Regional Atmospheric Modeling System (RAMS) version 4.3 developed at CSU used.
- Model initialized with an axisymmetric MCV (Montgomery et al., 2006).
- Two-moment microphysics scheme (Saleeby and Cotton, 2004) implemented
- 3 domains with the finest horizontal resolution 2 km used
- SST = 29ºC *Simulation time = 72 hours *No environmental winds included
- Mean Atlantic hurricane season sounding (Jordan sounding) initialized the model.
- CCN concentration was varied from 100, to 1000 and 2000 cm^{-3} between 1 and 5 km, where dust is typically found.

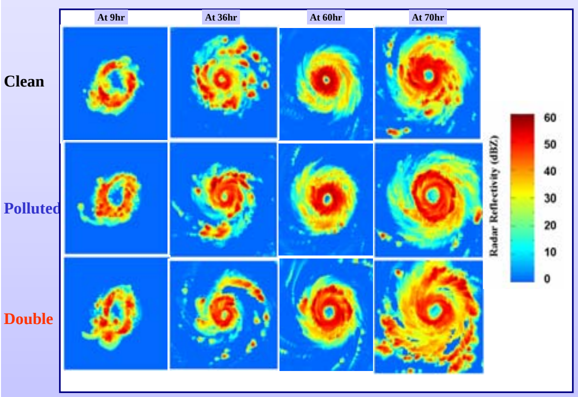
Impacts on storm intensity



Clean – 100 cm^{-3}
Polluted – 1000 cm^{-3}
Double – 2000 cm^{-3}

- Storm intensity decreases with increasing CCN concentration.

Evolution of surface radar reflectivity



- Small-scale cumulonimbus towers, termed vortical hot towers (VHTs, Montgomery et al. 2006), formed in regions with high absolute cyclonic vorticity (9 hr).
- Eye and eyewall can be clearly identified for all three simulations.
- "Clean" became the strongest storm with the smallest eye and most intense eyewall.
- Storms started to weaken around 60 hr. Prominent rain bands propagating outwards can be seen in "Double".

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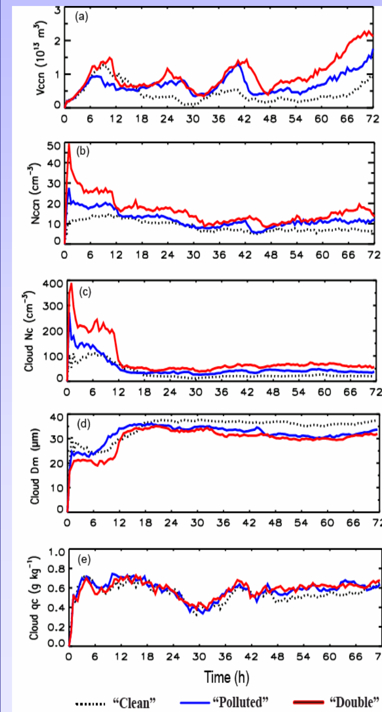
Impacts on cloud properties



With increasing ambient CCN concentration

- Total air volume with CCN activation ↑
- Activated CCN number concentration ↑
- Cloud droplet number concentration ↑
- Mean cloud droplet diameter ↓
- Cloud mixing ratio

Impacts on other hydrometeor categories

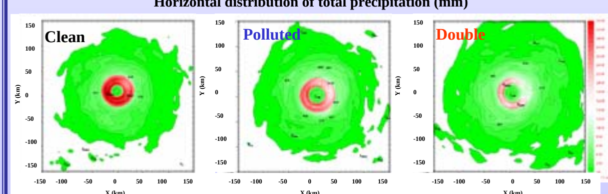
Varying CCN affected not only the cloud droplets but also other hydrometeor categories.

Mann-Whitney U tests determined whether number concentration, mean diameter & total mass determined had statistically similar mean values for the 3 simulations (x indicates mean values were statistically different).

	cloud	rain	ice	snow	aggregate	graupel	hail
Number	x	x	x	x	x	x	x
Diameter	x			x	x	x	x
Total Mass	x		x	x			

Impacts on total precipitation distribution

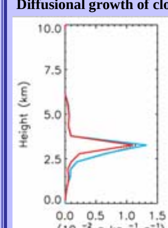
Horizontal distribution of total precipitation (mm)



The total precipitation reaching ground integrated over 72 hours for "Clean", "Polluted" and "Double" differed by less than 5%, but differences in precipitation distributions were noted.

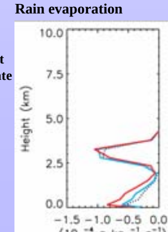
Impacts on microphysical processes

Diffusional growth of cloud droplet



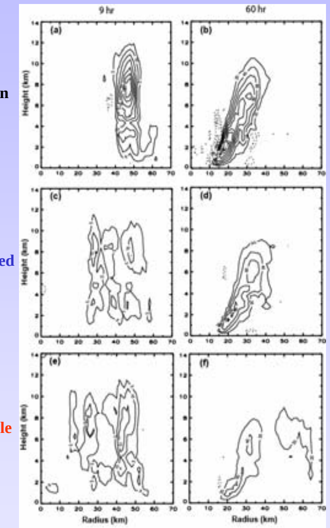
Double has the lowest diffusional growth rate of cloud droplet.

Rain evaporation



Double has the highest rain evaporation rate near surface.

Impacts on diabatic heating/cooling rate (k/hr)

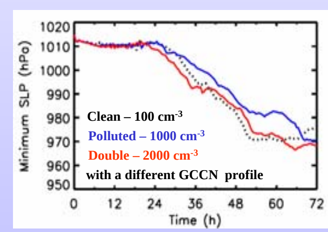


Differences in azimuthally averaged diabatic heating rates seen as early as the initial VHTs forming stage.

A tilted eyewall can be seen from the slopes in diabatic heating distributions. As the strongest storm "Clean" had the highest diabatic heating rates.

Discussion

- Dust in the SAL acting as CCN induced changes in hydrometeor properties → modified diabatic heating distribution and thermodynamic structure → influenced TC intensity through complex dynamical responses.
- Storm intensity decreased with increasing CCN for the above three simulations. To examine if this trend is true in general, an additional set of three simulations was performed using CCN concentrations that were identical to those described in "Clean", "Polluted" and "Double", but initialized with a different background GCCN profile.



- Although increasing CCN still led to increases in cloud number concentration and decreases in cloud mean diameter (figures not shown), there was no longer a monotonic decrease of MSLP with increasing CCN for simulations with the alternate GCCN profile. The impact of CCN on storm intensity is presumably also sensitive to other environmental factors.
- The physical processes responsible for the impact of dust as nucleating aerosols on TC development need to be examined in the future under a wide range of environmental conditions.