The Comparison of Dust-Radiation versus Dust-Cloud Interactions on the Development of a Simulated Mesoscale Convective System over North Africa

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Supported by NASA CloudSat and CALIPSO Science Team Program (NNX16AP17G)
Cold air generated by westward-propagating MCSs reaches the arid desert and produces haboob.
**Introduction**

What is the relative importance and impacts of dust-radiation and dust-cloud effects on MCS development over North Africa?

**Dust-Radiation Interaction**

- **SW Absorption Scattering**
- **LW Absorption Scattering**
- **Emission**

**Dust-Cloud Interaction**

- Increase IN/CCN cloud micro- and macro- structure lifetime and precipitation
- Convective invigoration
- Cloud-radiation interaction

**Instability**

$$\sigma = \frac{g}{\theta} \frac{d\theta}{dz}$$

**Thermal wind relation**

$$\vec{V}_T = \frac{R}{f} \hat{k} \times \nabla T \ln \frac{p_L}{p_U}$$
A MCS case

- An MCS over North Africa: 04-07 July 2010
- Two convective cycles
A MCS case

- An MCS over North Africa: 04-07 July 2010
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- Developed near a moderate dust plume
- CloudSat and CALIPSO satellites passed over the MCS
Model & Experiments

- **WRF-dust model** \((Chen et al. 2010, 2015)\)
- Three domains – 27, 9 and 3 km
- **Dust-Radiation**: GSFC SW/LW scheme \((Chou et al. 2001)\)
- **Dust-Microphysics**: 2-moment scheme \((Cheng et al. 2010)\)
- Other physics schemes: MRF PBL, Kain-Fritsch cumulus

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Dust-Cloud Interaction (Dust-MP)</th>
</tr>
</thead>
</table>
| Dust-Radiation Interaction (Dust-RA) | \begin{tabular}{c|c|c}
  ON & \text{YRYM} & \text{YRNM} \\
  OFF & \text{NRYM} & \text{NRNM} \\
\end{tabular} |

AOD data assimilation | 4 sensitivity experiments
Verification – Aerosol Optical Depth (AOD) & Cloud Top Temperature (CTT)

**AOD**

12Z July 5

**CTT**

02Z July 6
Verification – MCS Structure

2010-07-06 02Z (2nd cycle)

Radar reflectivity

Asymmetric anvil clouds
Weak echo
Convective overshoot

Bright band
Convective cores

Goddard Satellite Data Simulator Unit
(Matsui et al 2013, 2014)
MCS Comparison
Radar reflectivity

CloudSat

OBS

Model results

YRYM

YRNM

NRYM

NRNM

(dBZ)
Vertical wind shear

Thermal wind relation

\[ \vec{V}_T = \frac{R}{f} \hat{k} \times \nabla \ln \frac{p_L}{p_U} \]

Color shading & arrow: **600-900 mb Vertical wind shear (m s\(^{-1}\))**

Grey shading: **model cloud**

Blue contours: **600-900 mb thickness (m)**

Red contours: **AOD**

2010-07-05 18Z (2\(^{nd}\) cycle)
Convective energy & Surface Radiation Fluxes

[Day]
- Stabilization
- Larger CIN and CAPE

[Night]
- Reduce stability
- Promote storm intensification

Dust-Radiation Interaction

Net surface downward SW flux

Surface downward LW flux

Max CAPE (J/kg)

Max CIN (J/kg)
MCS Strength & Cloud Properties

[Area-Summed over MCS]
Color shading:
Total hydrometeors (kg m\(^{-3}\))

[Area-Averaged over MCS]
Black contours:
Convective updraft mass flux
\[ = (\rho w) \quad (kg \ m^{-2} \ s^{-1}) \]
[Only for grids with \( w > 1 \text{ ms}^{-1} \)]

Red dotted lines:
0 & -40 °C isotherms
Differences:
MCS Strength & Cloud Properties

Percentage increase of accumulated rainfall (ref: NRNM)
7/4 12Z – 7/5 12Z

<table>
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<tr>
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<th>Dust-RA effect (w/ MP)</th>
<th>Dust-MP effect (w/ RA)</th>
<th>Both effect</th>
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<tbody>
<tr>
<td>Dust-RA</td>
<td>14%</td>
<td>18%</td>
<td>39%</td>
</tr>
<tr>
<td>Dust-MP</td>
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Dust-RA effect (w/ MP)

Dust-MP effect (w/ RA)

Both effect

Differences:
YRYM-NRYM

YRNM-NRNM

YRYM-YRNM

NRYM-NRNM

Dust-RA effect (w/ MP)

Dust-MP effect (w/ RA)

Both effect
Ice Particle Freezing Rate

[Averaged over MCS & 7/4 12Z - 7/6 02Z]

Solid lines:  
Homogeneous nucleation  
+ deposition nucleation on dust particles  
+ heterogeneous freezing on bk aerosols

dotted lines:  
Immersion freezing on dust particles

The dust-MP effect enhances the dust-RA effect on MCS development by enhancing immersion freezing
• HIGH dust concentration: dust direct effect > dust indirect effect.

• The dust-radiation interaction: stronger storms with more extensive anvil/stratiform cloud.

• The dust-cloud interaction: - slows initial storm development - enhances immersion freezing - extends cloud lifetime.

• The impacts of the dust indirect effect on the MCS’s development are strongly modulated by the simulation of dust-radiation interactions.
Thank you

Dust-Radiation: Goddard Space Flight Center
SW/LW radiation scheme (Chou and Suarez, 1999; Chou et al. 2001)

Microphysics: 2-moment microphysics scheme (Cheng et al. 2010)

\[
\frac{\partial \mu\gamma}{\partial t} = \nabla \cdot \vec{V} \mu\gamma + C_{pbl} + C_{con} + C_{mic} + S_\gamma + E_\gamma
\]

\( \gamma \) : Dust mixing ratio; \( \mu = p_{hs} - p_{ht} \) (mass)
\( C = \mu\gamma \) (Coupled dust mixing ratio)
\( S_\gamma \) : Sedimentation (time splitting)
\( E_\gamma \) : Source / Sink (emission, wet scavenging, dry deposition)

Dust-cloud-radiation Interaction
- Dust-Radiation: Goddard Space Flight Center
  SW/LW radiation scheme (Chou and Suarez, 1999; Chou et al. 2001)
- Microphysics: 2-moment microphysics scheme (Cheng et al. 2010)

Dust emission:
- Barren type vegetation
- Soil moist volumetric fraction < 0.2
- 10-m wind > 6.0 ms\(^{-1}\)

Tegen and Fung (1994); Kok et al. 2011

Hygroscopicity parameter
\( \kappa = 0.05 \) (Koehler et al. 2009)
A MCS case

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AOD verification