Dust transport in E3SM v1 and v0 and impacts on mixed-phase cloud properties

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How ice crystals are formed?

Multiple Ice Nucleation Mechanisms

Homogeneous

Deposition

Condensation

Freezing

Contact

Freezing

Immersion

Freezing

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Soluble/insoluble aerosol particle (substrate) (~$10^{-3} - 10^{-5}$ of aerosol population)  
Supercooled solution droplet / cloud  
Droplet  
Ice crystal

T < -37 °C

Heterogeneous (T > -37 °C)

Courtesy of G. Kulkarni
- Different Ice Nucleation schemes

**Classical nucleation theory (CNT)** (E3SM Default): immersion, contact, deposition

\[
\left. \frac{dN_i}{dt} \right|_{\text{imm}} = - \sum_x \frac{d(f_{l,x} N_{\text{aer},x})}{dt} = \sum_x J_{\text{imm},x} f_{l,x} N_{\text{aer},x}.
\]

- \( J_{\text{imm}} \): the immersion nucleation rate per aerosol particle and per time
- \( f_{l} \): the fraction of activated particles
- \( N_{\text{aer}} \): aerosol number concentration

Wang et al., ACP (2014)

**DeMott** scheme (newly implemented): immersion, deposition

\[
n_{\text{INP}}(T_k) = a (273.16 - T_k)^b (n_{a>0.5 \mu m})^{c(273.16 - T_k) + d}
\]

- \( n_{a>0.5 \mu m} \): number concentration of aerosol particles larger than 0.5 \( \mu m \)

DeMott et al., PNAS (2010)
Setup

Runtime period: 2006.10 to 2008.12, last two years for analysis
Meteorology: Wind components U and V nudged to MERRA2 data
Dynamic core: SE
E3SM version1 configuration: 72 levels, MG2, MAM4, CLUBB
E3SM version0 configuration: 30 levels, MG1, MAM3

Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>v1 CNT</td>
<td>E3SM version1, use CNT for ice nucleation parameterization</td>
</tr>
<tr>
<td>v1 DEM</td>
<td>E3SM version1, use DeMott(2010) for ice nucleation parameterization</td>
</tr>
<tr>
<td>v0 CNT</td>
<td>E3SM version0, use CNT for ice nucleation parameterization</td>
</tr>
<tr>
<td>v0 DEM</td>
<td>E3SM version0, use DeMott(2010) for ice nucleation parameterization</td>
</tr>
</tbody>
</table>
Dust simulations

<table>
<thead>
<tr>
<th></th>
<th>v1 CNT</th>
<th>v1 DEM</th>
<th>v0 CNT</th>
<th>v0 DEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust Emission [Tg/yr]</td>
<td>3693.15</td>
<td>3676.32</td>
<td>3652.57</td>
<td>3665.90</td>
</tr>
<tr>
<td>Dust AOD</td>
<td>0.0264</td>
<td>0.0262</td>
<td>0.0261</td>
<td>0.0260</td>
</tr>
<tr>
<td>Dust Burden [Tg]</td>
<td>20.27</td>
<td>20.18</td>
<td>24.27</td>
<td>24.23</td>
</tr>
</tbody>
</table>

To compare dust transport, the dust emission are tuned to the very similar value.

Since the dust transport between different ice nucleation schemes are not quite different, only v1 CNT and v0 CNT are used for dust transport analysis.
Results

$v1CNT$

$v1CNT$-$v0CNT$
Dry Deposition:

v1 CNT  2922.77 Tg/yr
v0 CNT  2280.88 Tg/yr

v1 > v0: lower dust concentration (AOD) at source regions in v1

Wet Deposition:

v1 CNT  773.83 Tg/yr
v0 CNT  1379.98 Tg/yr

v1 < v0: more dust are transported to the remote regions (the Arctic regions) in v1
Monthly dust budget in the Arctic (67°N to 90°N)
The dust concentration in E3SM v1 is nearly 10 times larger than that in E3SM v0 (CAM5 physics) and is closer to the observation at Alert, Canada.

Alert data from Song-Miao Fan, JGR (2013)
Impacts on cloud properties – Total LWP and IWP

E3SM v1

CNT

CNT-DEM

LWP

IWP

-1.629 g/m²

0.108 g/m²
Impacts on cloud properties – Total LWP and IWP

E3SM v0

CNT

CNT-DEM
### Heterogeneous nucleation modes in models

<table>
<thead>
<tr>
<th>Mixed phase</th>
<th>CNT (E3SM default)</th>
<th>DeMott</th>
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</thead>
<tbody>
<tr>
<td>immersion</td>
<td>CNT</td>
<td>ice↑: DeMott</td>
</tr>
<tr>
<td></td>
<td></td>
<td>liq↓: Bigg</td>
</tr>
<tr>
<td>deposition</td>
<td>CNT</td>
<td>DeMott</td>
</tr>
<tr>
<td>contact</td>
<td>CNT</td>
<td>Young</td>
</tr>
</tbody>
</table>
Summary

• Compared with E3SM v0, E3SM v1 shows more dust transport to the Arctic regions, which can be attributed to the smaller wet deposition rate in E3SM v1.
• More transport of dust can have implications on mixed-phase clouds
• More evaluation of dust transport, and dust indirect effects.