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

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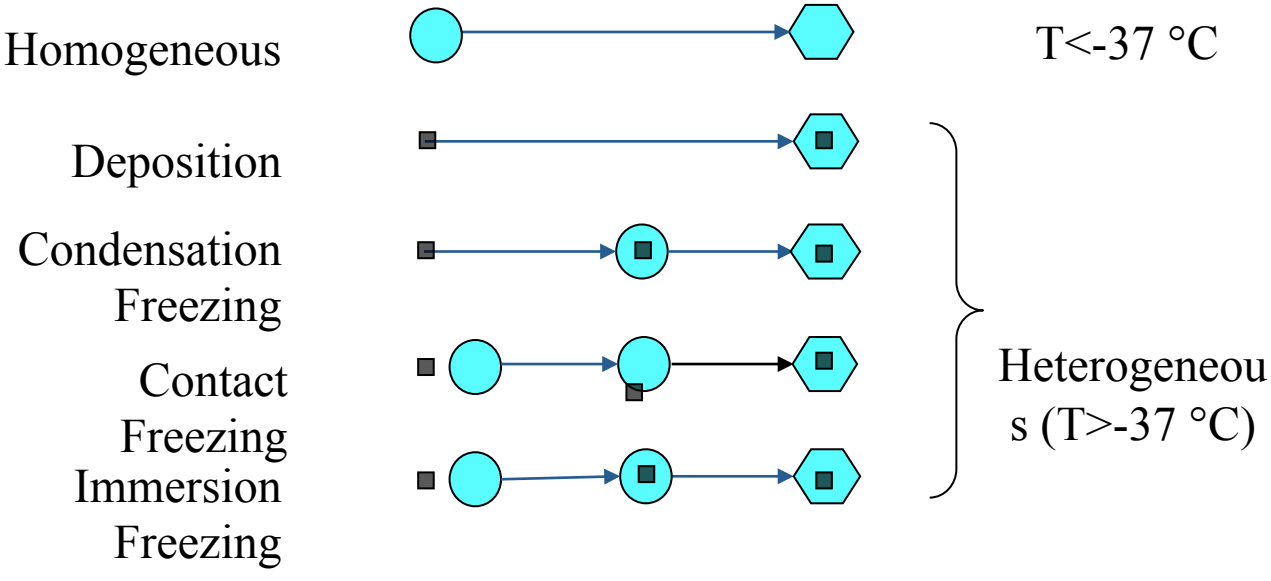
CMDV

Mesoscale Convective Systems

How ice crystals are formed?

Multiple Ice Nucleation Mechanisms



Soluble/insoluble aerosol particle (substrate) (~10^{-3} – 10^{-5} of aerosol population)

Supercooled solution droplet / cloud droplet

Ice crystal

Courtesy of G. Kulkarni

Introduction - 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_{imm} *the immersion nucleation rate per aerosol particle and per time*
f_l *the fraction of activated particles*
N_{aer} *aerosol number concentration*

Wang et al., ACP (2014)

DeMott scheme (newly implemented): immersion, deposition

$$n_{\text{INP}}(T_{\text{k}}) = a(273.16 - T_{\text{k}})^b (n_{\text{a}>0.5\,\mu\text{m}})^{(c(273.16-T_{\text{k}})+d)}$$

$n_{a>0.5\mu m}$ *number concentration of aerosol particles larger than 0.5 μm*

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

v1 CNT	E3SM version1, use CNT for ice nucleation parameterization
v1 DEM	E3SM version1, use DeMott(2010) for ice nucleation parameterization
v0 CNT	E3SM version0, use CNT for ice nucleation parameterization
v0 DEM	E3SM version0, use DeMott(2010) for ice nucleation parameterization

Dust simulations

	v1 CNT	v1 DEM	v0 CNT	v0 DEM
Dust Emission [Tg/yr]	3693.15	3676.32	3652.57	3665.90
Dust AOD	0.0264	0.0262	0.0261	0.0260
Dust Burden [Tg]	20.27	20.18	24.27	24.23

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

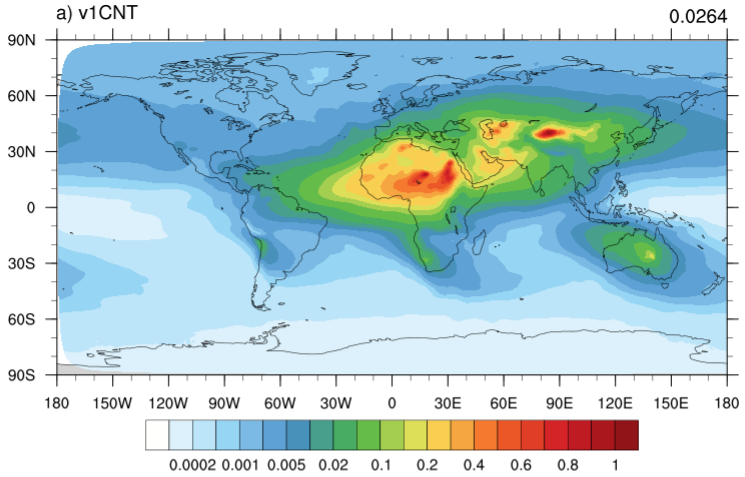
Since the dust transport between different ice nucleation schemes are not quite different, only v1 CNT and v0 CNT are used for dust transport analysis.

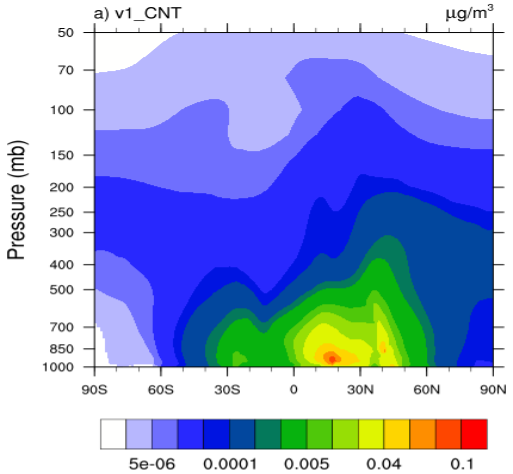
Results

AODDUST

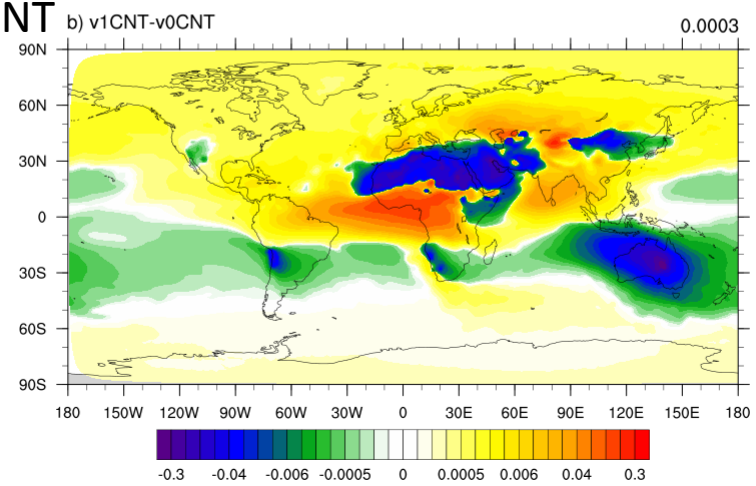
Dust Concentration

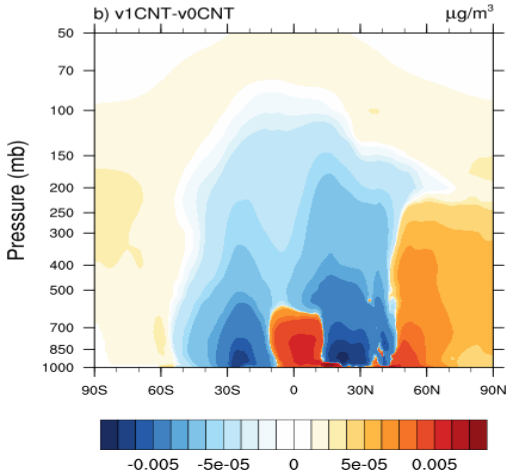
v1CNT

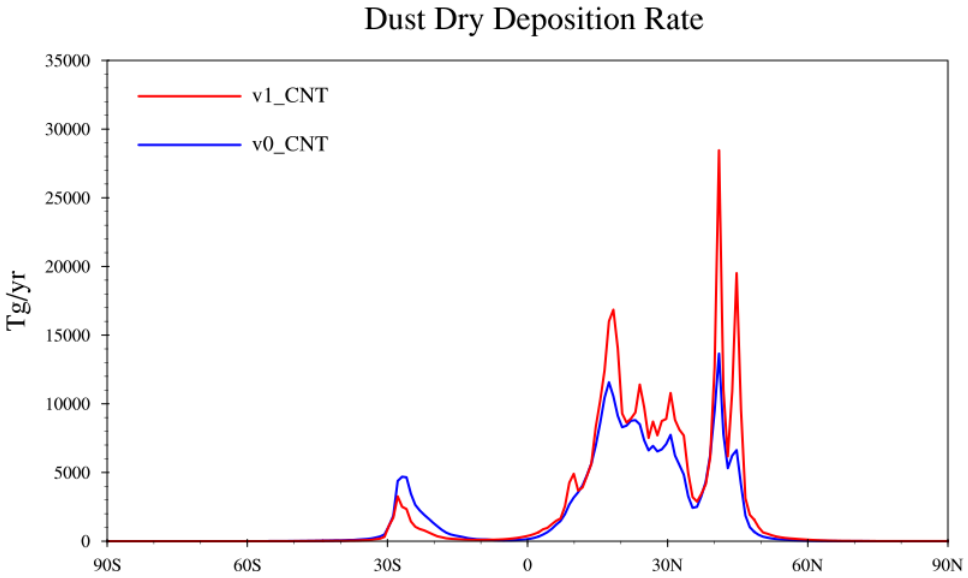




v1CNT-v0CNT





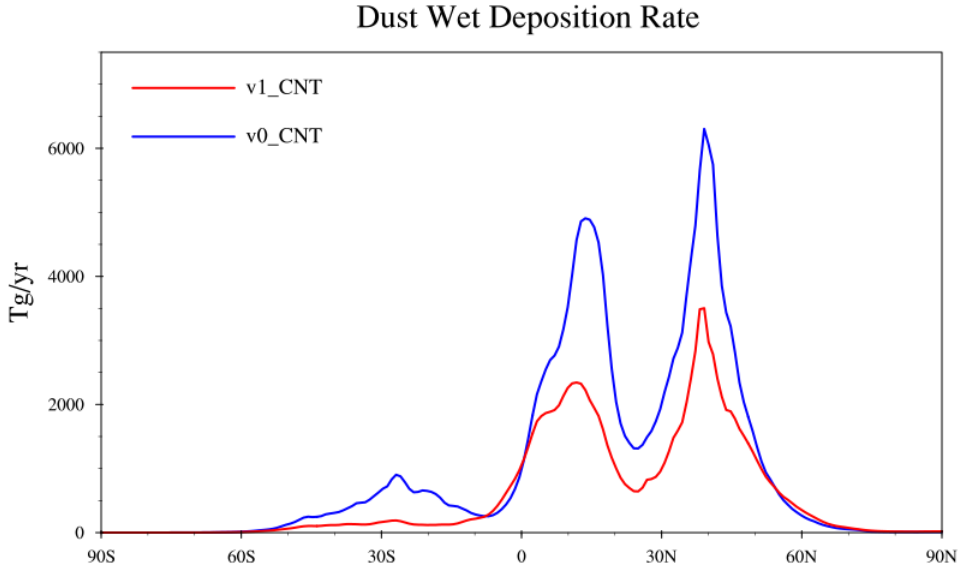


Dry Deposition:

v1 CNT 2922.77 Tg/yr

v0 CNT 2280.88 Tg/yr

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



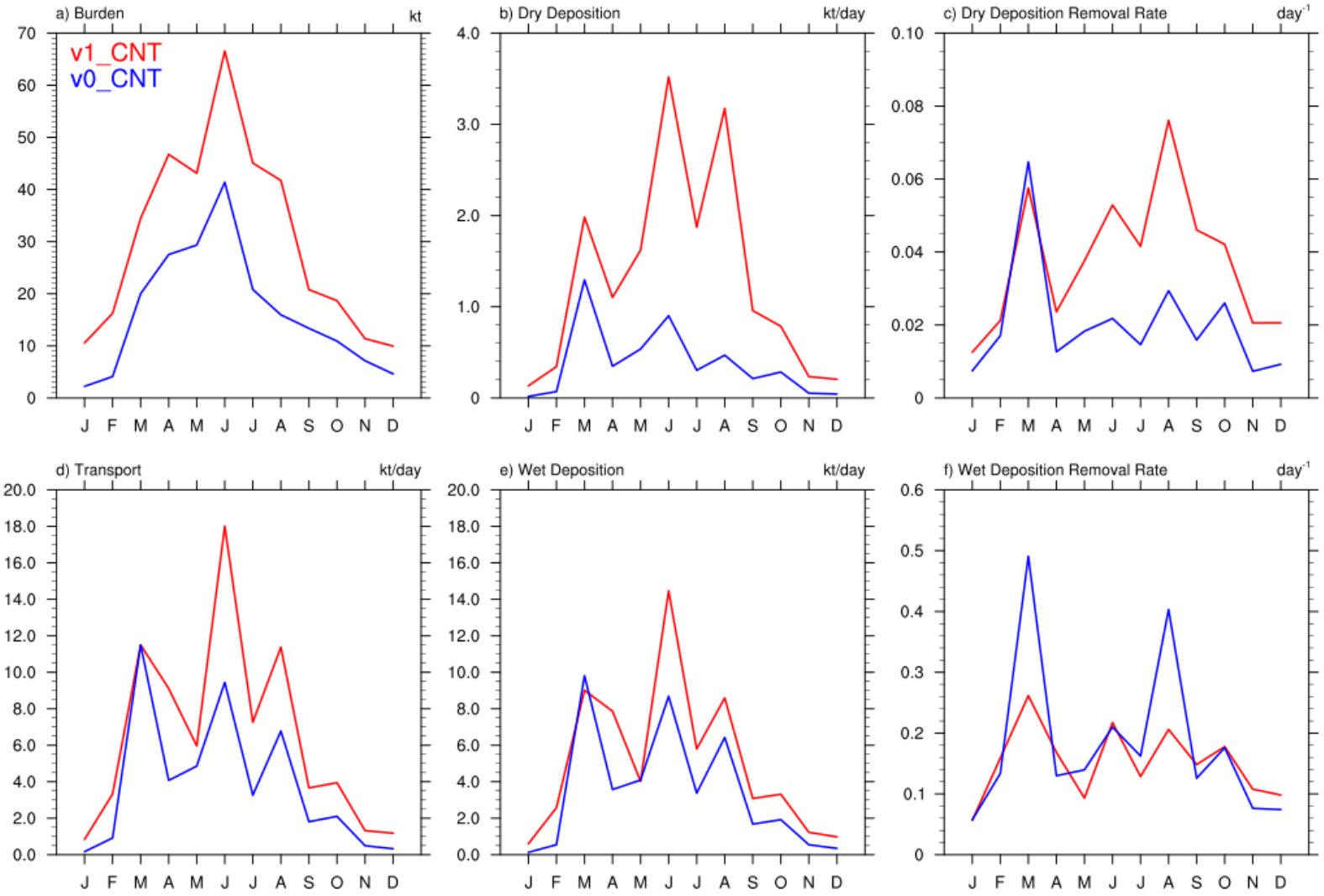
Wet Deposition:

v1 CNT 773.83 Tg/yr

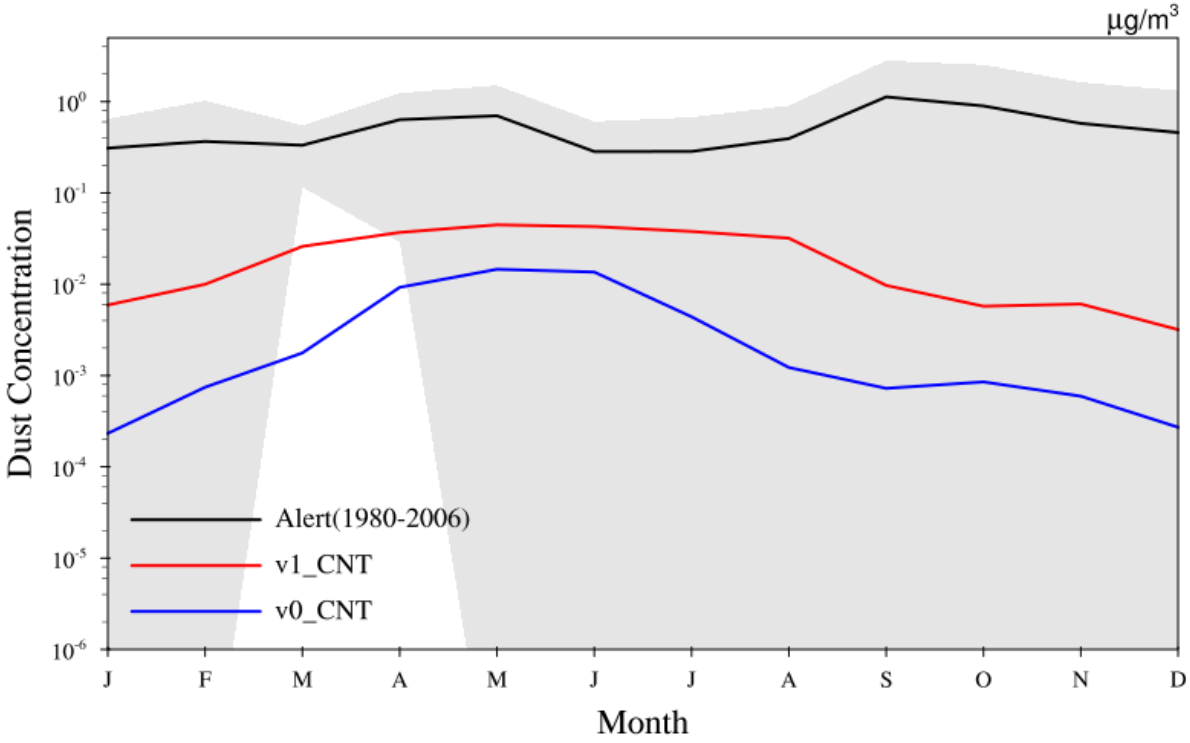
v0 CNT 1379.98 Tg/yr

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)



Dust concentration at Alert (82.39°N,62.3°W)



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)

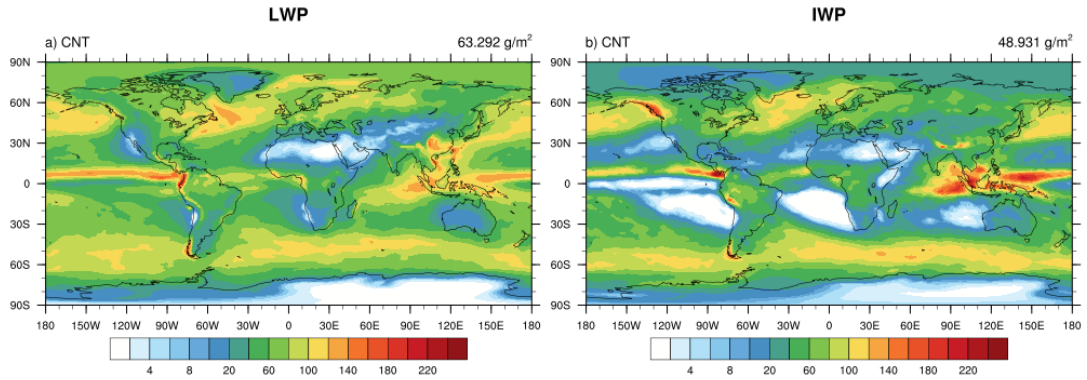
Impacts on cloud properties – Total LWP and IWP

E3SM v1

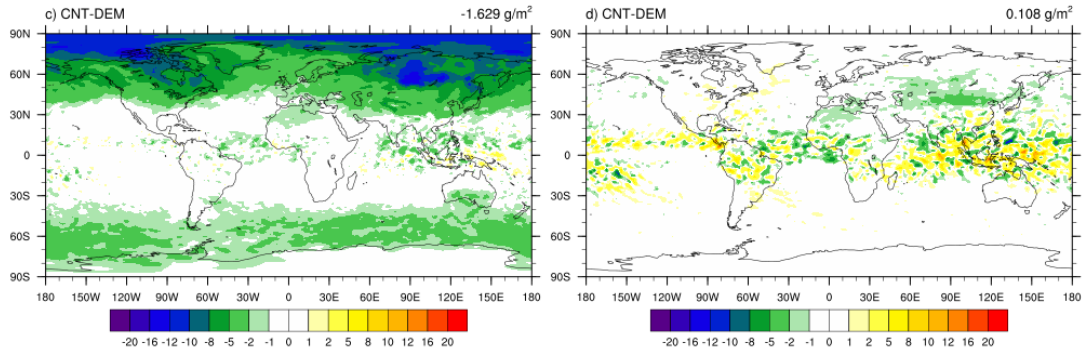
LWP

IWP

CNT



CNT-DEM



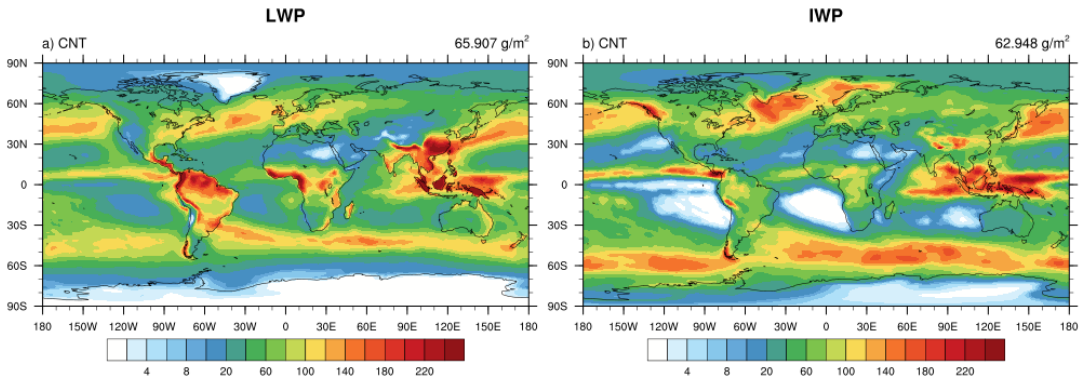
Impacts on cloud properties – Total LWP and IWP

E3SM v0

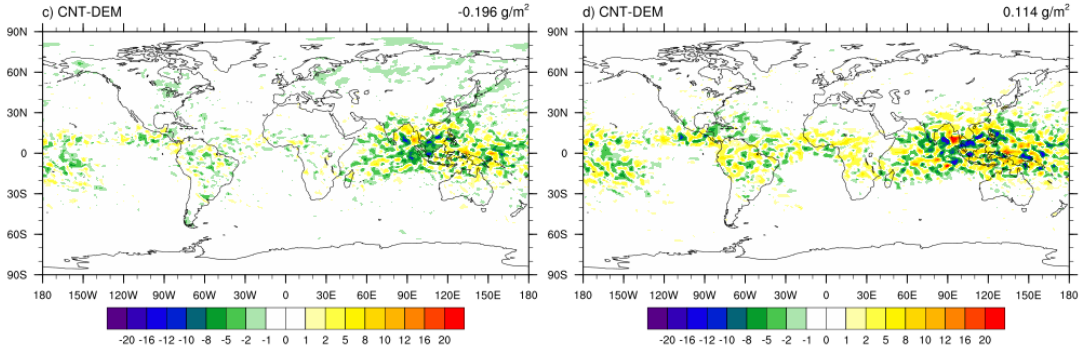
LWP

IWP

CNT



CNT-DEM



Heterogeneous nucleation modes in models

Mixed phase	CNT (E3SM default)	DeMott
immersion	CNT	ice↑: DeMott liq↓: Bigg
deposition	CNT	DeMott
contact	CNT	Young

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.