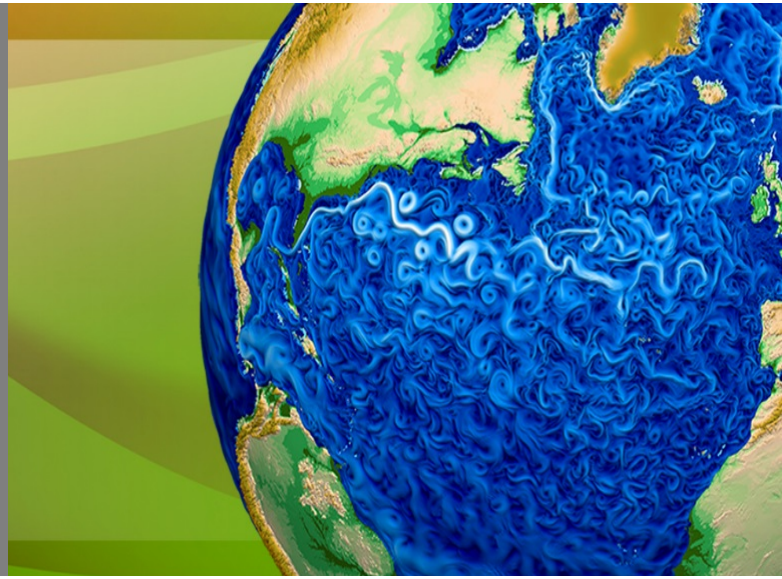
E3SM Energy Exascale Earth System Model

Argonne NATIONAL LABORATORY

Quantifying the Impact of Increasing Model Resolution on Aerosol Simulations



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U.S. DEPARTMENT OF ENERGY

Motivation

- Development of high-resolution Earth System Models requires re-calibration of "resolution-dependent" aerosols, because of their dependency on sub-grid parameters and processes

  - Topography
  - Wind speed
  - Soil moisture

  } *Source: dust/sea salt*

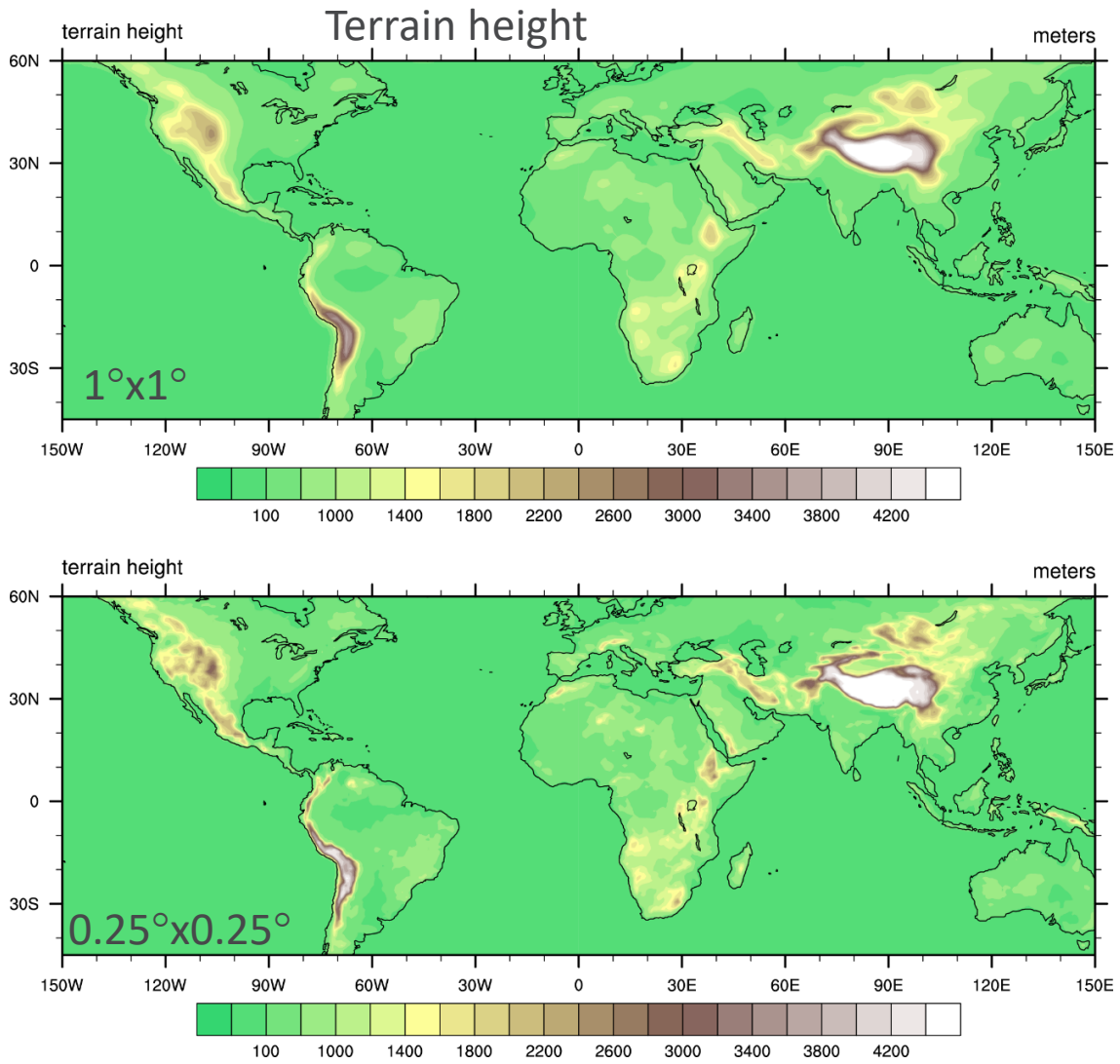
  - Advection/diffusion

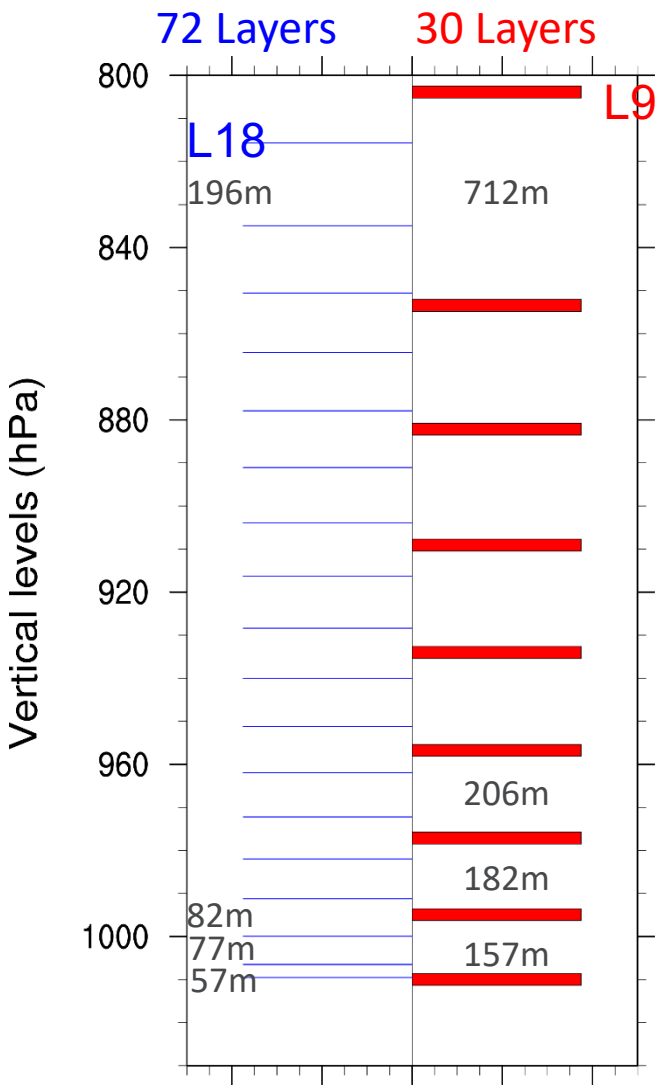
  Transport: all aerosols

  - Cloud
  - Precipitation

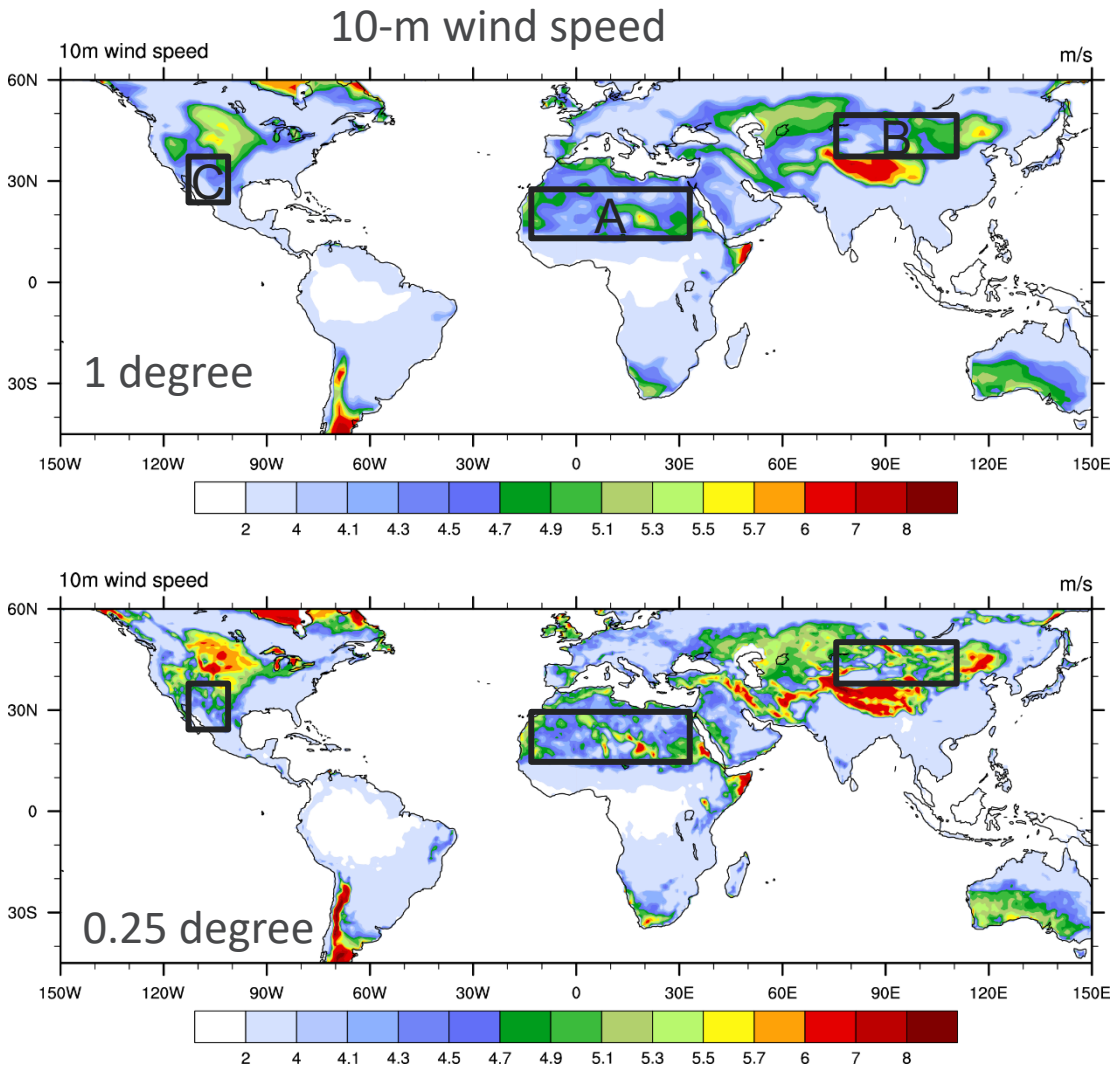
  } *Sink: all aerosols*

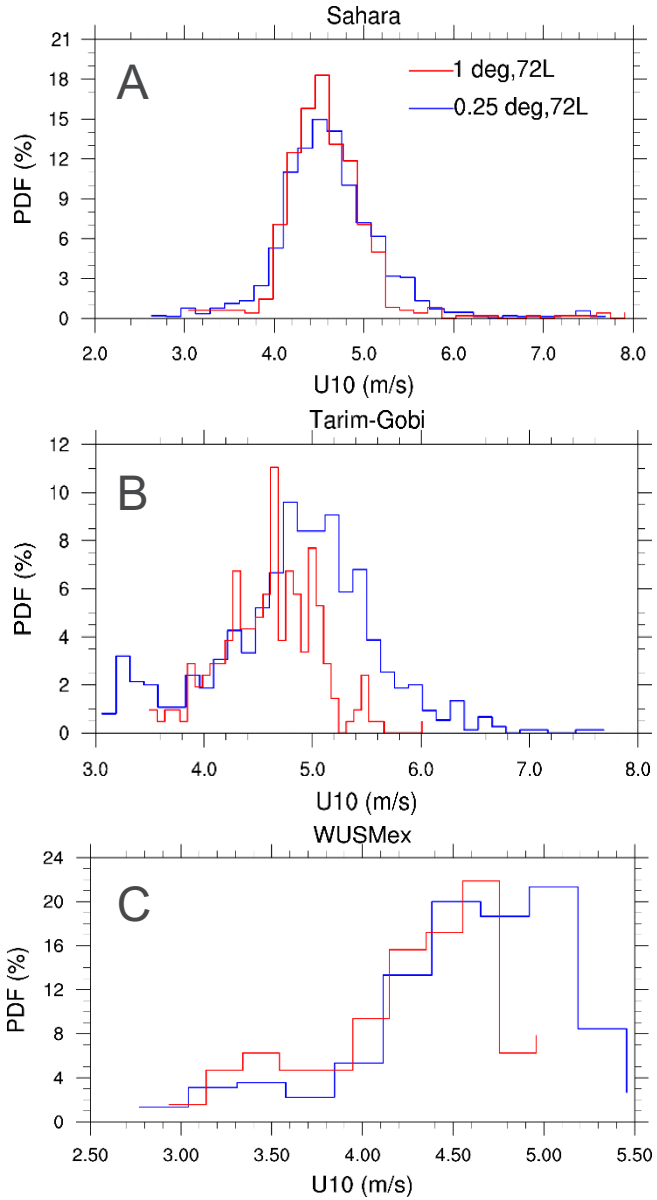
EAM model resolution (1° or 0.25°, 72 layers)





Increasing horizontal resolution: effect on surface wind speed





E3SM Energy Exascale Earth System Model

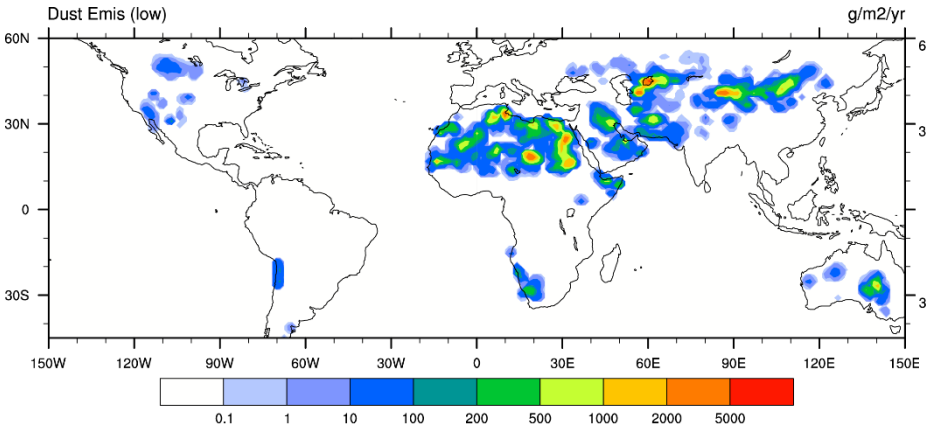
Consistent with Ridley et al. (2013); Zhang et al. (2016)

Effects on dust emission, burden and deposition

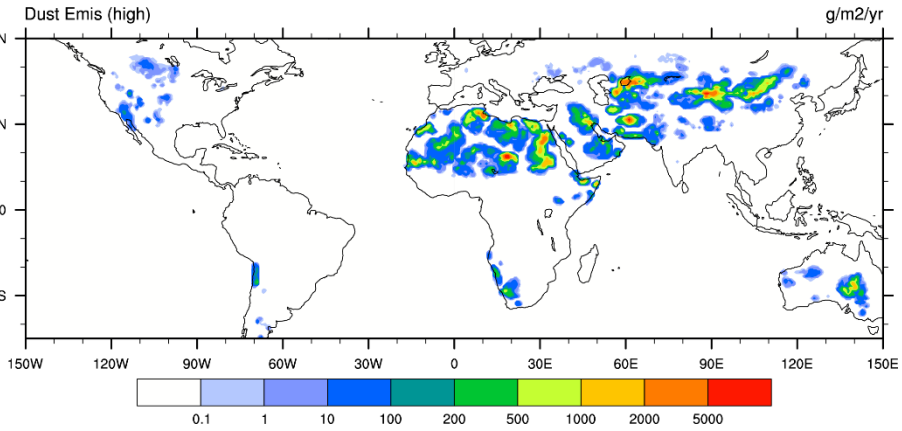
Horizontal resolution	1°	0.25° (same emis. factor)	0.25°(emis. scaled)
Global emission $\sim U_{10}^3$ (Tg/yr)	4702	6044	4950
Burden (Tg)	22.9	34.3	28.5
Dry deposition rate (1/day)	0.43	0.35	0.34
Wet deposition rate (1/day)	0.12	0.13	0.13

Emissions (g/m^2/yr)

1°x1°



0.25°x0.25° (global emis. scaled)



After scaling, same on the global emissions and different on the regional scale

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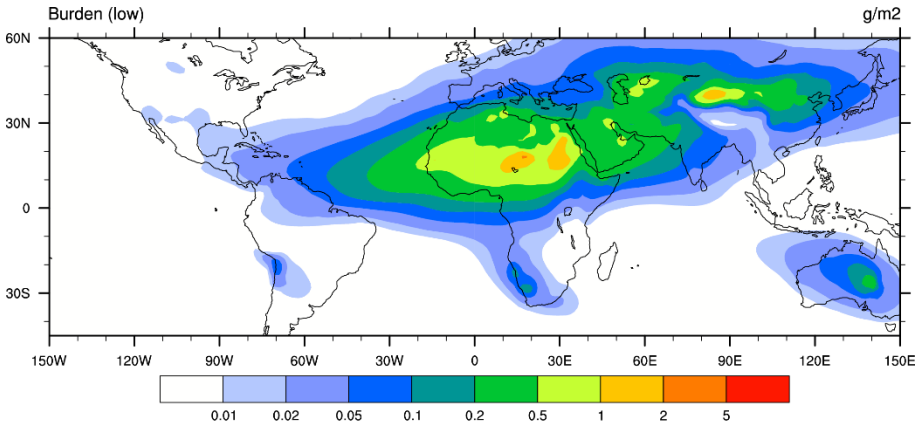
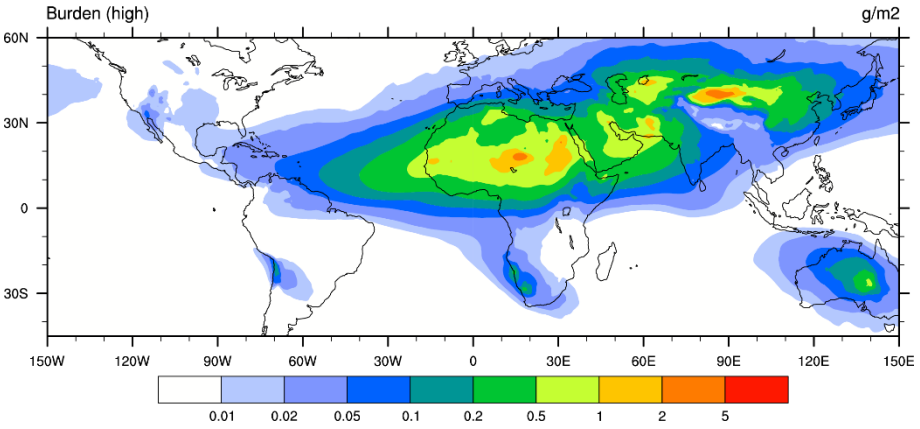
Burden (g/m^2)

1°x1°



0.25°x0.25° (emis. scaled)



With the same global emissions, burden is higher with increase of model resolution

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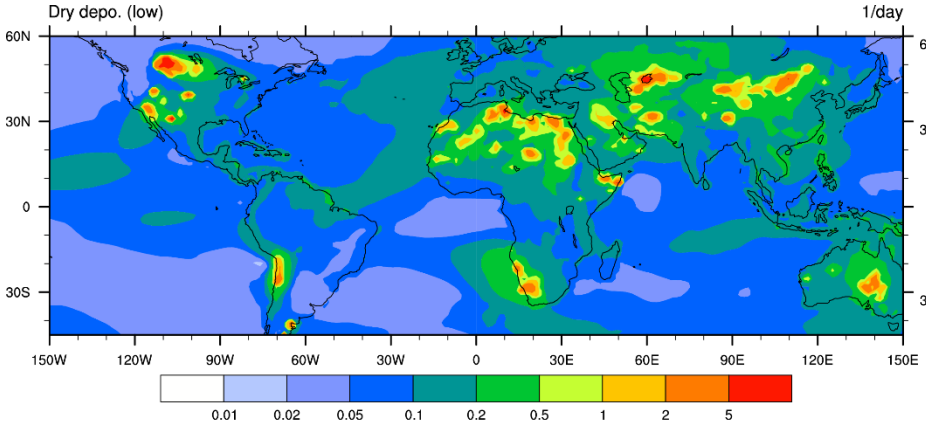
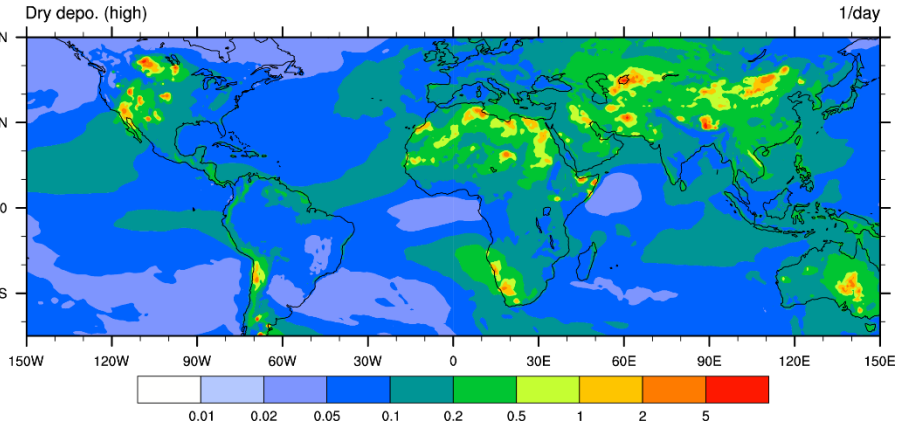
Dry deposition rate (1/day) $= \frac{dry\ deposition\ flux\ (TgYr^{-1})}{burden\ (Tg) \times 365.}$

1°x1°



0.25°x0.25° (emis. scaled)



Gravitational settling: 75% → 78% ← stronger turbulence mixing

Effects on dust emission, burden and deposition

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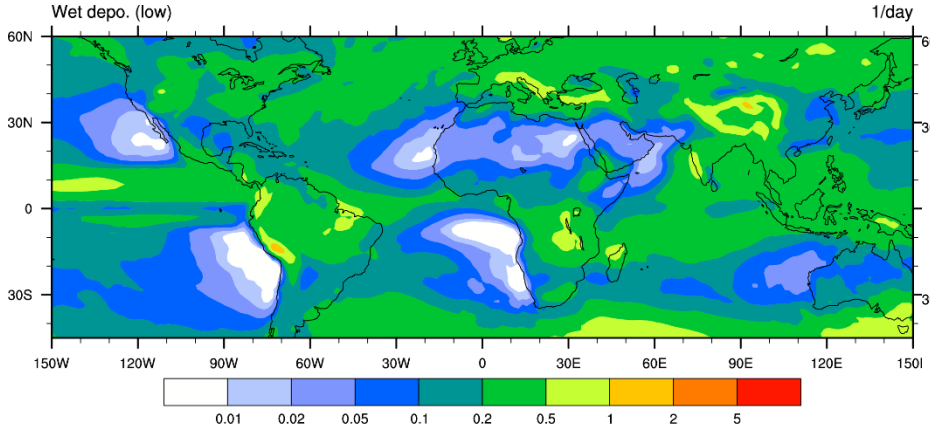
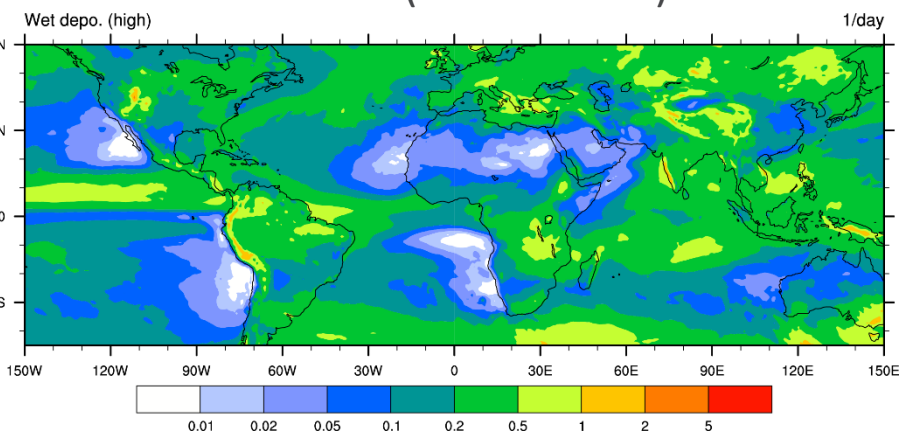
1°x1°



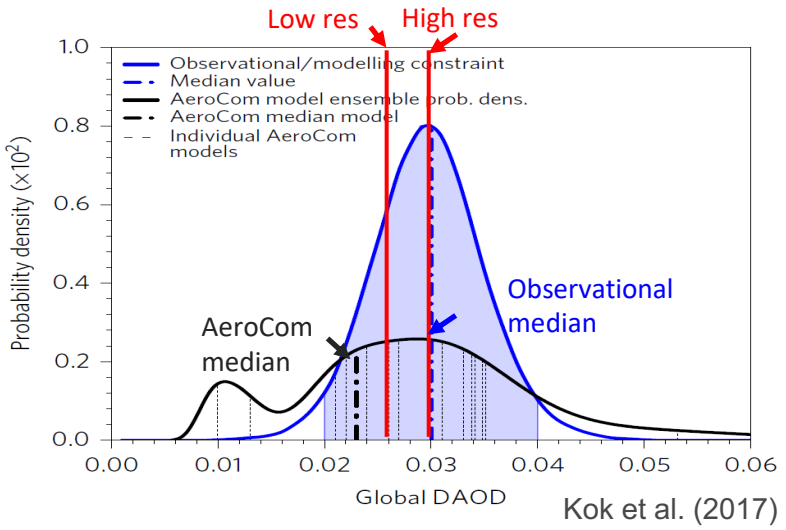
0.25°x0.25° (emis. scaled)



Contribution to total deposition: 22% → 28% → Increased wet removal fraction

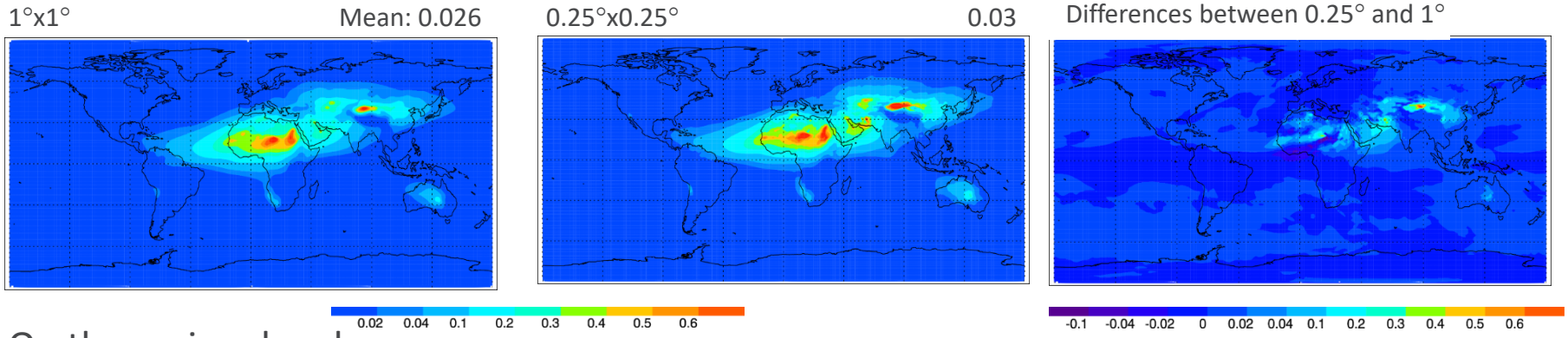
Impact on dust aerosol optical depth

- With about the same global emissions, increase of horizontal resolution (by 4x) leads to higher dust burden (+25%) and AOD (+15%), due to a weaker dry deposition (-21%) and slightly enhanced wet deposition efficiencies



Kok et al. (2017)

Dust Aerosol Optical Depth (AOD)

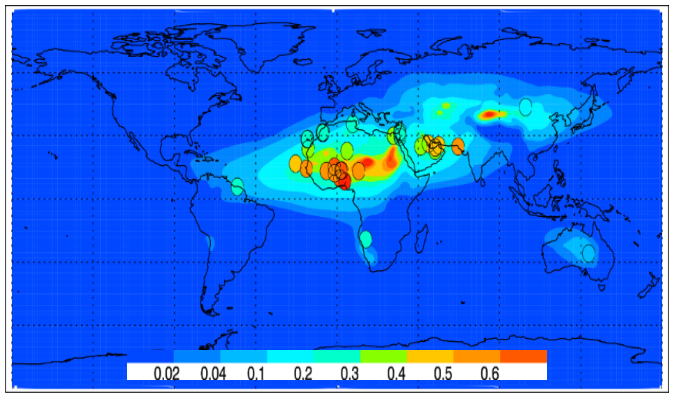


On the regional scale:

- higher dust AODs predicted over source regions, and lower AODs predicted associated with tropical deep convection and in mid- and high- latitudes;
- Larger contribution to total AOD from coarse-mode dust (0.017 to 0.02)

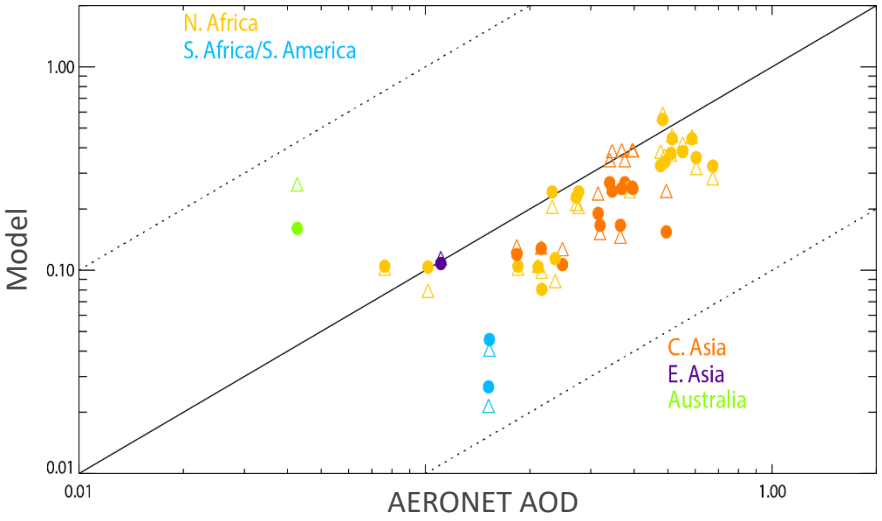
Comparison of dust AOD with AERONET

Dust AOD (1°x1°)



AERONET data are inserted on top by filled circles

- Both resolutions (0.25° vs 1°) **underestimate dust AOD compared with the AERONET data**;
- The high res (0.25°) model improves the mean dust AOD averaged over all the sites and in the C. Asia

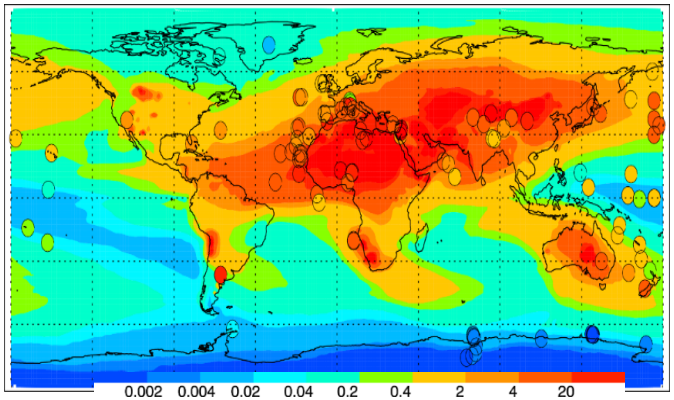


Low res (filled circle) and high res (triangle)

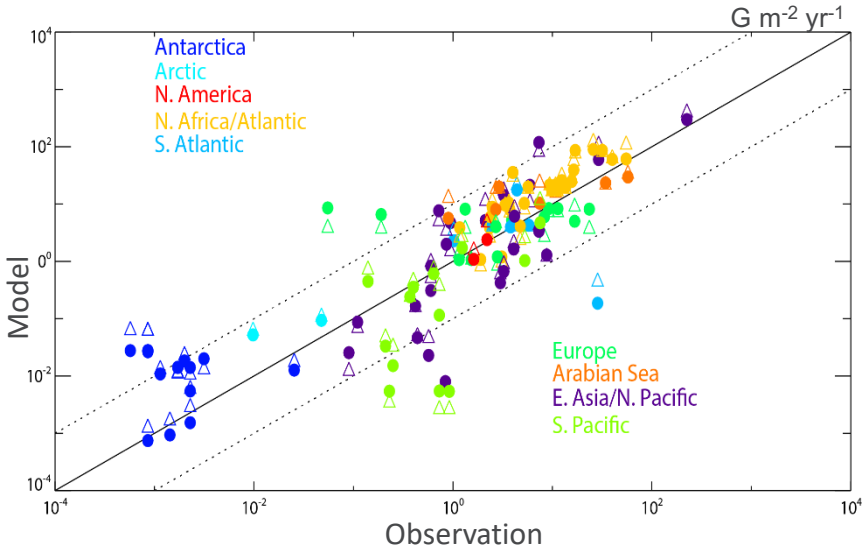
Region (n)	Dust AOD at AERONET sites		
	AERONET	Low (1°)	High (0.25°)
N Africa (19)	0.37	0.27	0.27
C Asia (13)	0.34	0.20	0.26
E Asia (1)	0.11	0.11	0.12
S Africa/S America (2)	0.15	0.04	0.03
Australia (1)	0.04	0.16	0.27
All sites (36)	0.33 (0.34±0.16)	0.22 (0.24±0.12)	0.25 (0.24±0.14)

Comparison of dust deposition with observations

Dust deposition (1°x1°)



Observations (**Albani et al., 2014**) are inserted on top by filled circles



Low res (filled circle) and high res (triangle)

- Both resolutions **overestimate compared with the observations**
- **The high res is better over the remote oceans** ;
- These overestimations suggest that the model emissions are 'tuned' up too high to match AOD - what causes the AOD low bias?

Region (n)	Dust deposition		
	AERONET	Low (1°)	High (0.25°)
N Africa/Atlantic (27)	12	26	32
Europe (13)	6.4	5.5	4.5
Arabian Sea (7)	17	17	23
E. Asia/N Pacific (23)	14	24	31
S Atlantic (6)	7.7	5.4	6.8
S Pacific (13)	1.5	0.7	1.6
Antarctica (15)	0.003	0.015	0.026
All sites (108)	8.3 (2.5±24)	14 (4±35)	17 (3.8±48)

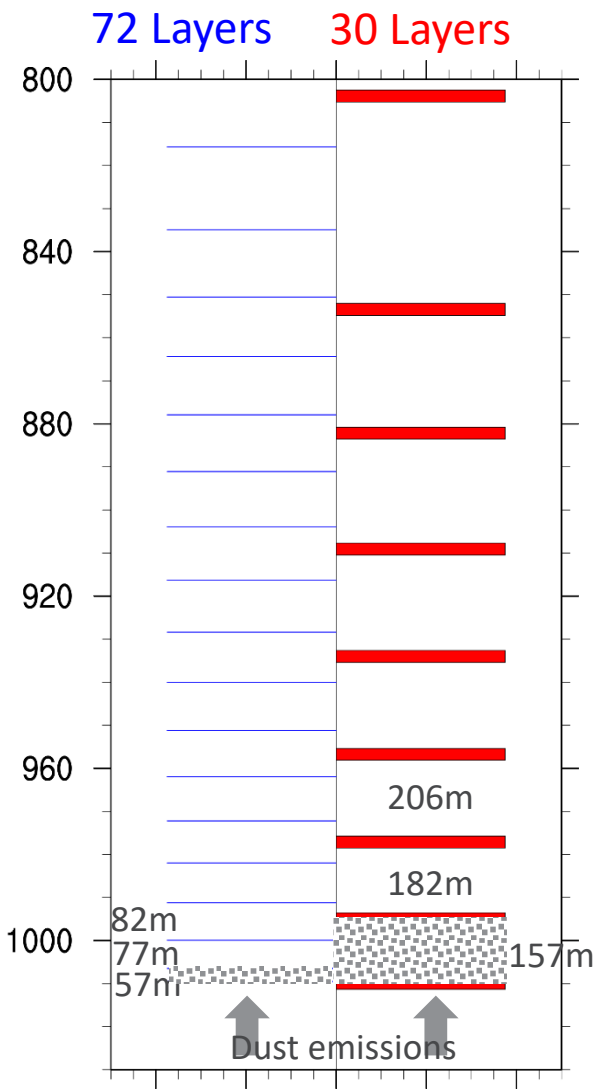
Increasing vertical resolution: enhances dust dry deposition and reduces life time

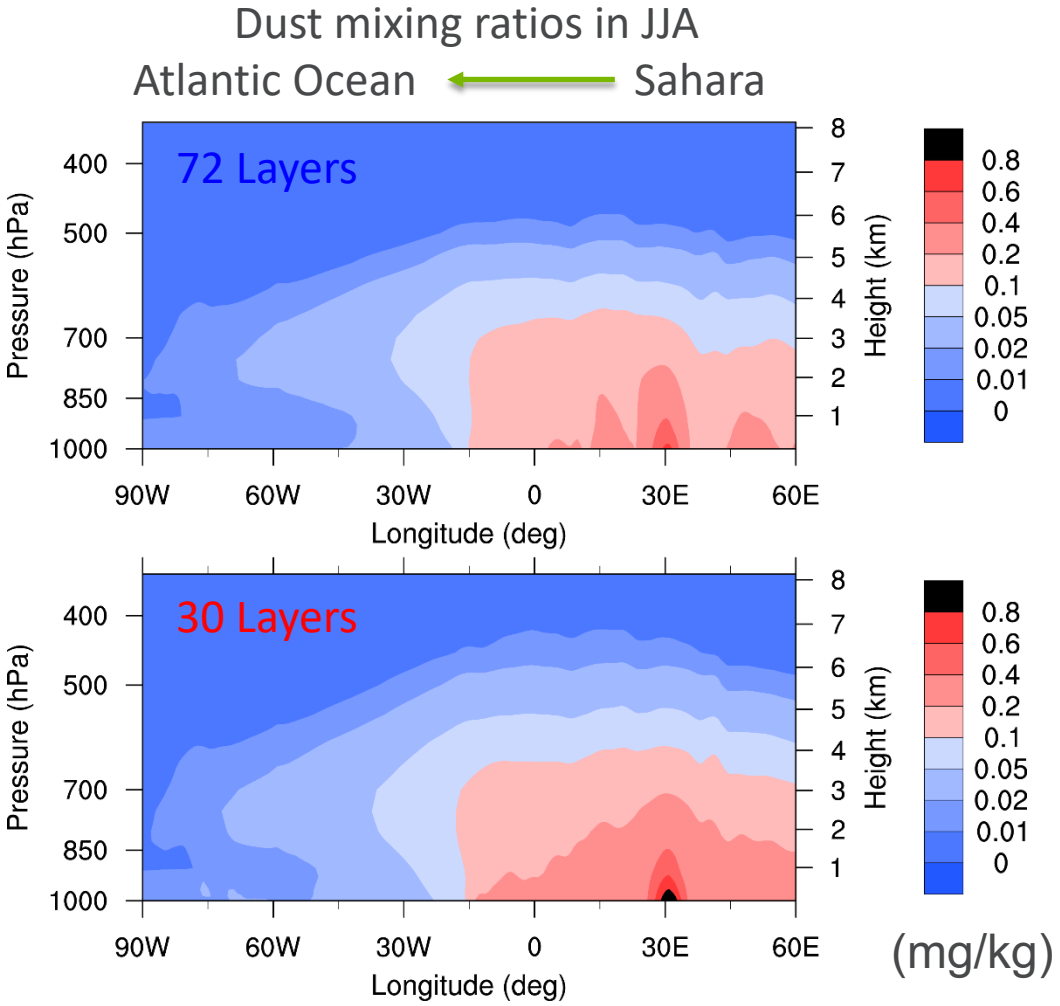
Vertical	EAM (1°) 72 layers	EAM (1°) 30 layers	CAM5* (1.9°) 30 layers	AeroCom* Variable
Global emission (Tg/yr)	4271	4173	3122	1840
Dry deposition rate (1/day)	0.42	0.29	0.24	0.23
Wet deposition rate (1/day)	0.13	0.13	0.14	0.08
Burden (Tg)	21.6	28.3	22.4	-
Lifetime (day)	1.8	2.4	2.6	4.14

*CAM5 (Liu et al., 2012); AeroCom II (Huneeus et al., 2011)

- Dry deposition efficiency in EAM is enhanced (+45%) with the number of vertical layers increased from 30 to 72, while wet deposition is about the same;
- EAM inherits the strong wet deposition from CAM5, which results in a much shorter life time of dust than the AeroCom model median;
- With the same vertical grid spacing, dry deposition in EAM is stronger than CAM5, due to the aerosol re-suspension effect implemented

Vertical distribution of dust aerosols



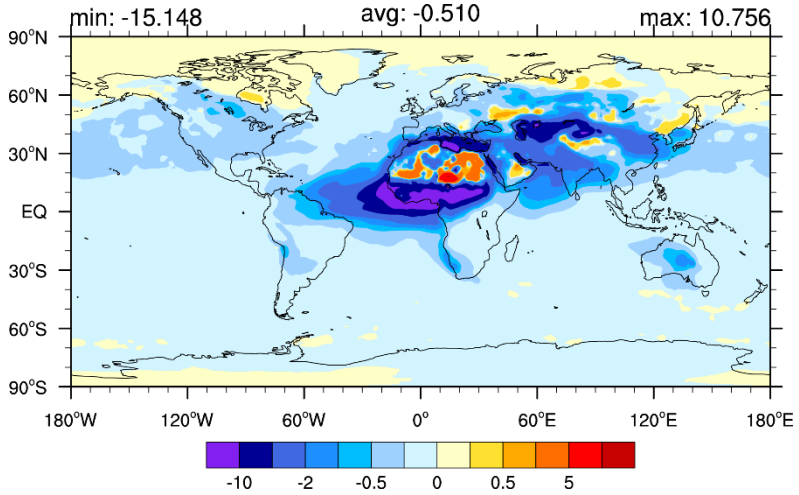


- Adding more model layers near the surface results in less vertical transport of dust

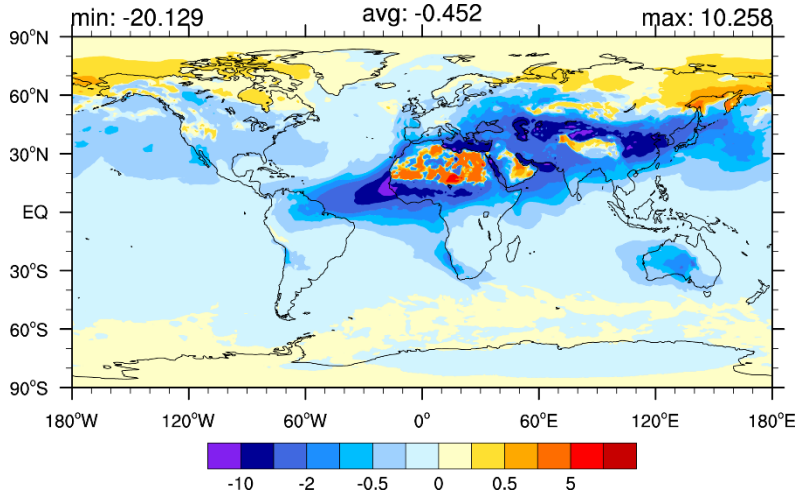
Direct radiative effect of dust

April

Low res (1°, 72 layers)



High res (0.25°, 72 layers)



	Size distr. at emiss.	Optics	AOD	TOA (W/m2)			ATM (W/m2)			Surface (W/m2)		
				SW	LW	NET	SW	LW	NET	SW	LW	NET
Low res (April)	Kok (2011)	AERONET	0.035	-0.65	0.14	-0.51	0.95	-0.6	0.35	-1.6	0.74	-0.86
High res(April)	Kok (2011)	AERONET	0.031	-0.60	0.14	-0.45	0.87	-0.59	0.29	-1.47	0.73	-0.74

Conclusions

- Global AODs in both low and high res models are consistent with other model estimates and AERONET data, constraining the global mean energy balance.

- Increase of 30 vertical layers to 72 layers leads to over-deposition and weaker vertical transport. For dust, dry deposition efficiency increases by 45%. Impact on wet deposition is negligible for dust

- For resolution-dependent aerosol sources, increase of horizontal resolution improves dust AOD comparison near source regions especially in C. Asia by better resolving the topography.

- Increase of model horizontal resolution (4x) reduces dry deposition efficiency (-21%) by increasing turbulence mixing. Wet deposition is enhanced but the effect is relatively small for dust.

- Impact of increasing model horizontal resolution (4x) on dust direct radiative effect is about +11% (April) mainly through SW. This is comparable to other uncertainties such as aerosol optics, and with larger regional differences.