Testing MOSAIC aerosol scheme implemented in CESM and evaluation with observations

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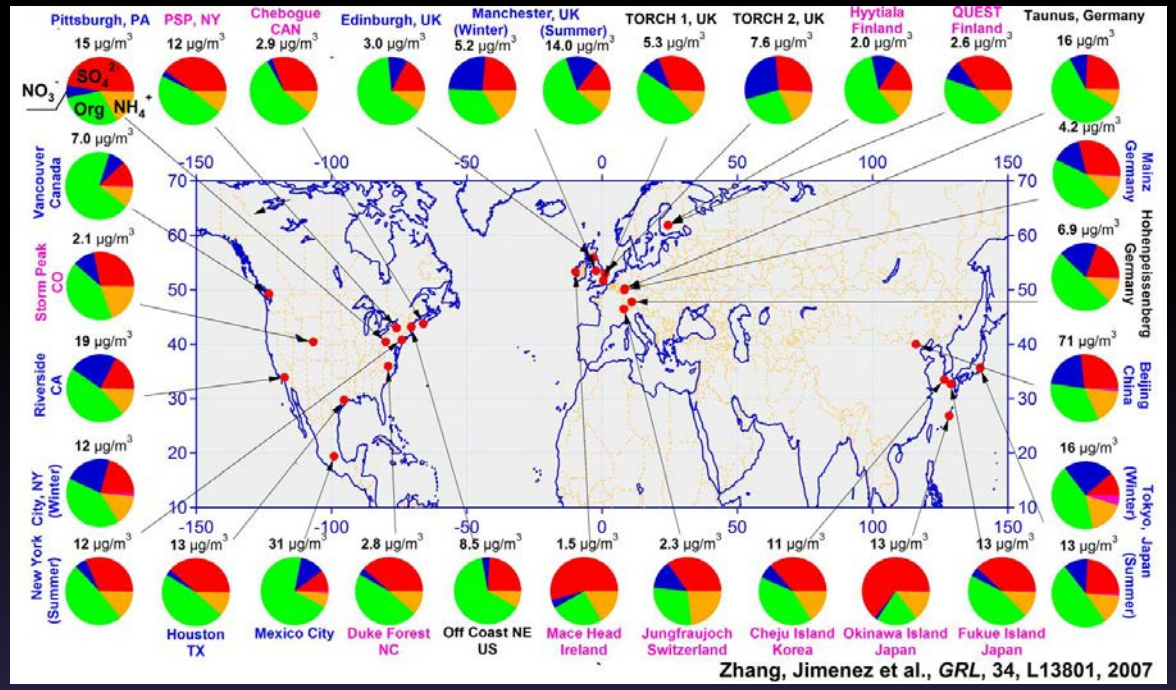
Motivation

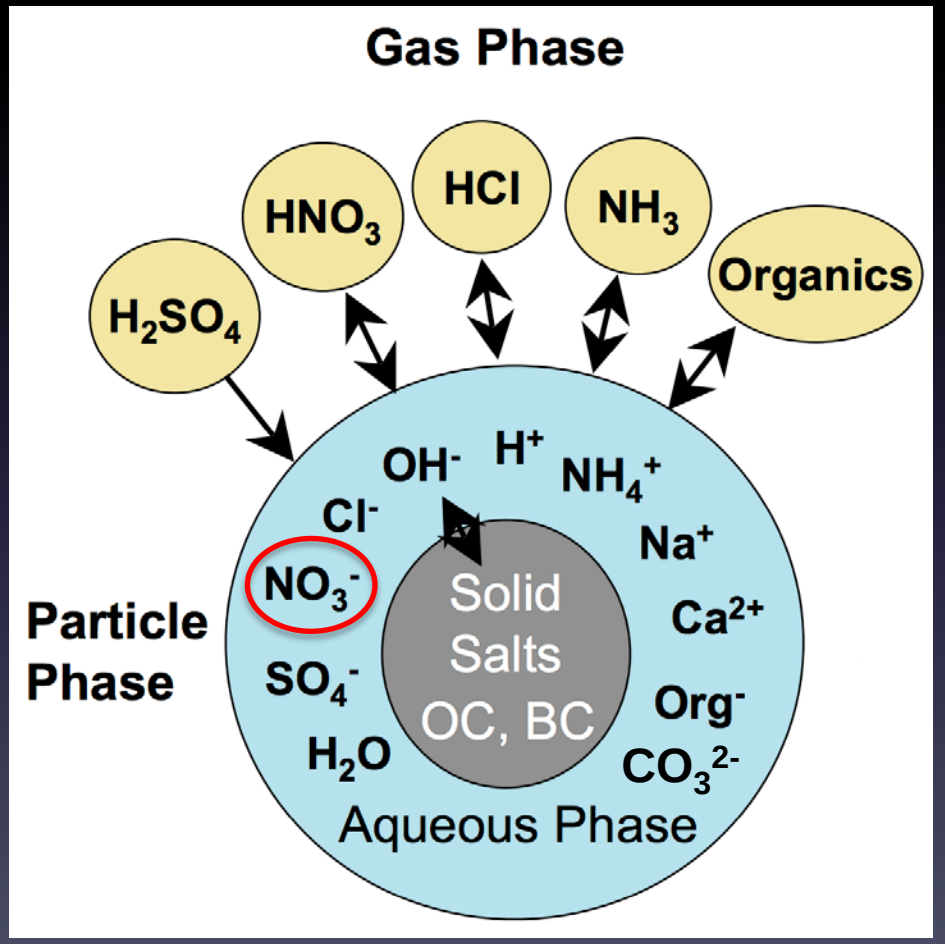


- Nitrate aerosol (NO3): a significant source of anthropogenic aerosols [IPCC, 2013]
- Nitrate aerosol (NO3):
  - Similar radiative forcing compared to SO4 [Adams et al., 2001]
  - Important for tropospheric chemistry [Liao et al., 2003]
  - An important component of global nitrogen cycle [Söderlund and Svensson, 1976]

Introduction

- In order to better treat NO3 aerosols, Model for Simulating Aerosol Interactions and Chemistry (MOSAIC) module [Zaveri et al., 2008] is coupled with MAM4 and MAM7 (MOSAIC-MAM4/7)

- In the version of MAM coupled with MOSAIC, gas-aerosol exchange is treated by MOSAIC. The remaining processes are handled by MAM



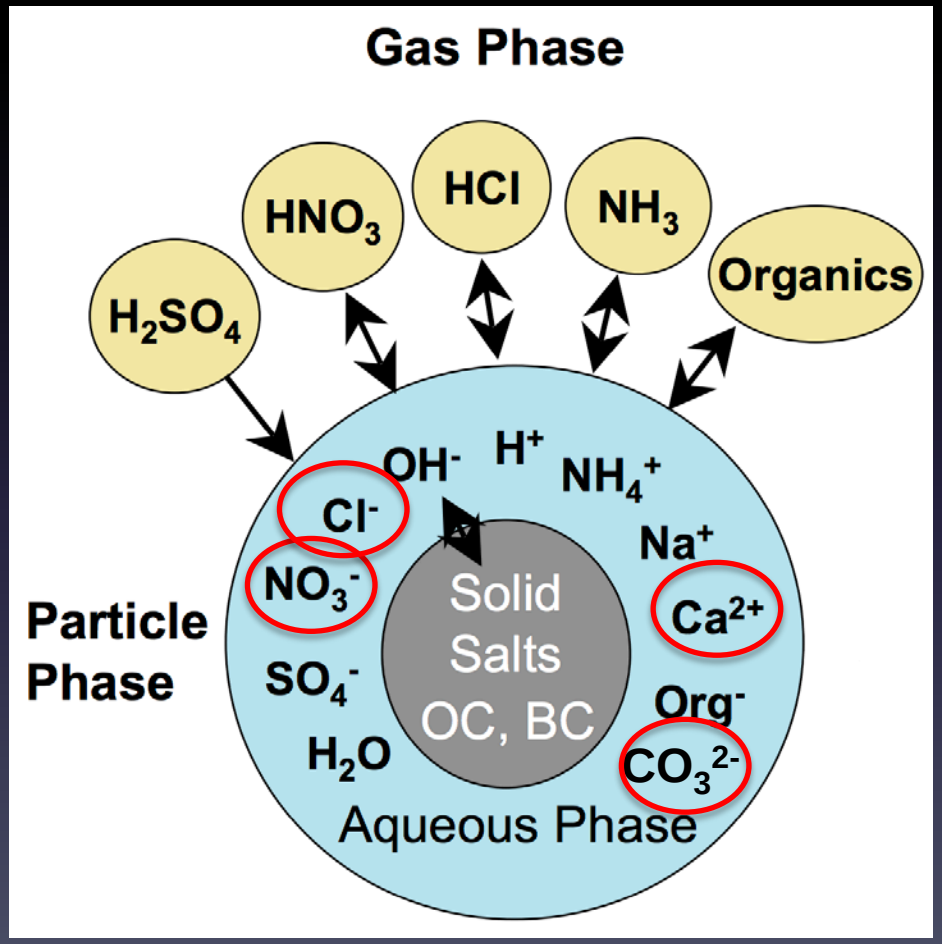
Red circles: new aerosol species

Modified based on the presentation by Zaveri, WRF tutorial, 2008

Introduction – new species in MOSAIC-MAM7

No.	Species	Accum.	Aitken	Primary Carbon	Fine Sea salt	Coarse Sea salt	Fine Dust	Coarse Dust
1.	BC	X		X				
2.	POM	X		X				
3.	SOA	X	X					
4.	SO4	X	X		X	X	X	X
5.	NH4	X	X		X	X	X	X
6.	NO3	X	X		X	X	X	X
7.	Cl	X	X		X	X	X	X
8.	Na	X	X		X	X		
9.	Dust						X	X
10.	Ca						X	X
11.	CO3						X	X
Total		8	6	2	5	5	7	7

Total aerosol tracers = 42



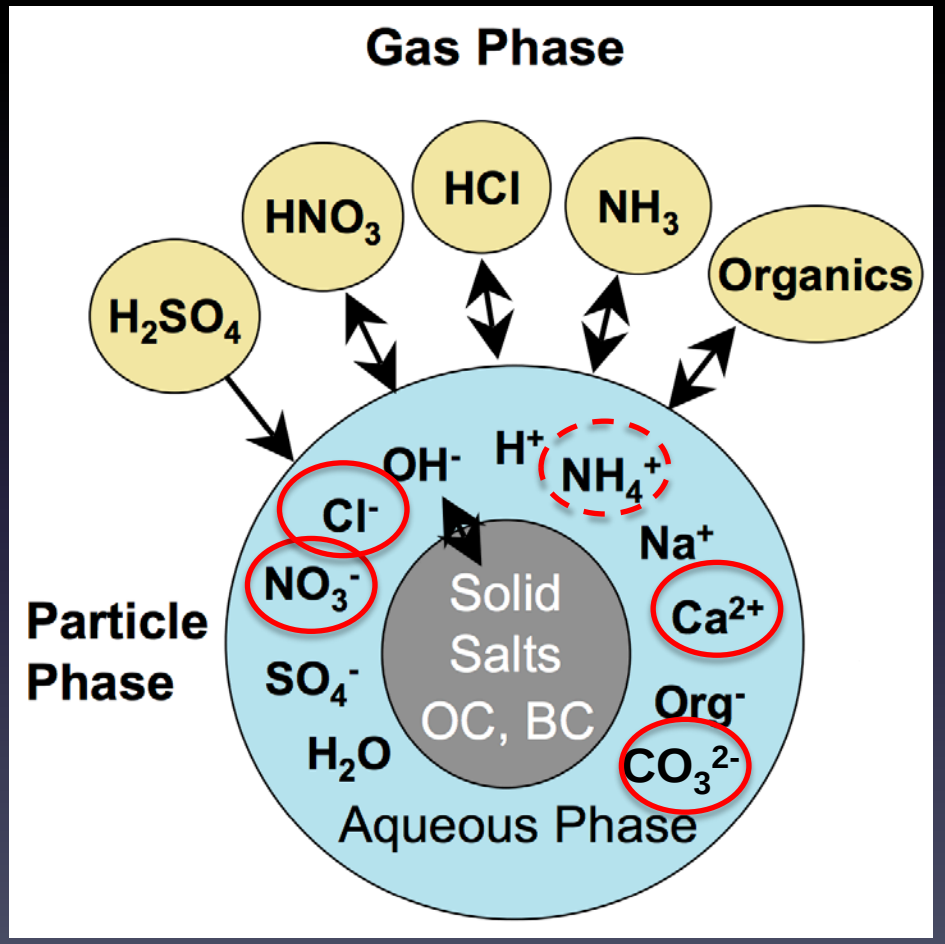
Red circles: new aerosol species

Modified based on the presentation by Zaveri, WRF tutorial, 2008

Introduction – new species in MOSAIC-MAM4

No.	Species	Accum.	Aitken	coarse	Primary Carbon
1.	BC	X			X
2.	POM	X			X
3.	SOA	X	X		
4.	SO4	X	X	X	
5.	NH4	X	X	X	
6.	NO3	X	X	X	
7.	Cl	X	X	X	
8.	Na	X	X	X	
9.	Dust	X		X	
10.	Ca	X		X	
11.	CO3	X		X	
Total		11	6	8	2

Total aerosol tracers = 27



Red circles: new aerosol species

Modified based on the presentation by Zaveri, WRF tutorial, 2008

Model and observation

- Model
  - CAM5.2.10 for six years (last five years for analysis)
  - 1.9×2.5 resolution
  - Cases: 1) MOSAIC-MAM7; 2) MOSAIC-MAM4; 3) MAM7 and 4) MAM4 (with MOZART chemistry)
- Observation (a special focus on NO3)
  - East Asia: EANET dataset (2005~2009)
  - North America: IMPROVE dataset (2000~2015)
  - Europe: EMEP (1986~1995, following Feng and Penner, 2007)
  - Global: Aerosol mass spectrometry, AMS (since ~2000)

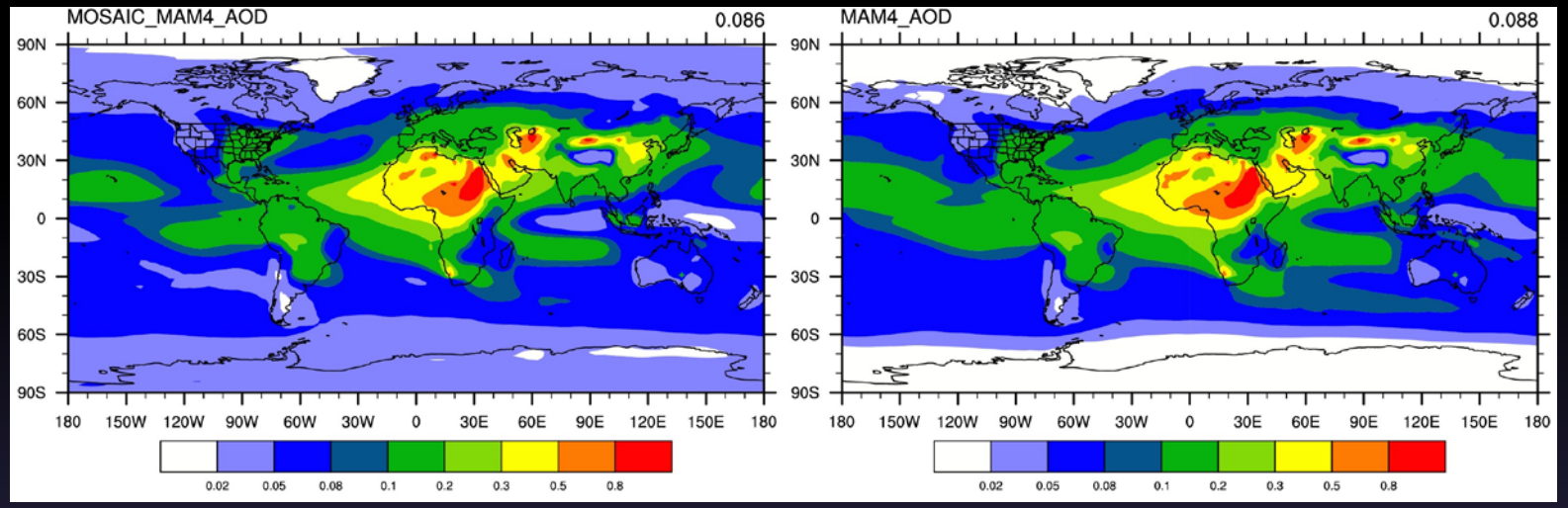
Results – computational coast

Cases	with MOZART	with MOZART & MOSAIC
MAM4	2.4h → 1 model year	3h → 1 model year
MAM7	3h → 1 model year	4.2h → 1 model year

- 512 CPUs on NCAR Yellowstone
- MOSAIC-MAM vs. MAM: 25% ~ 40% more computational cost
- MOSAIC-MAM7 vs. MOSAIC-MAM4: 40% more computational cost

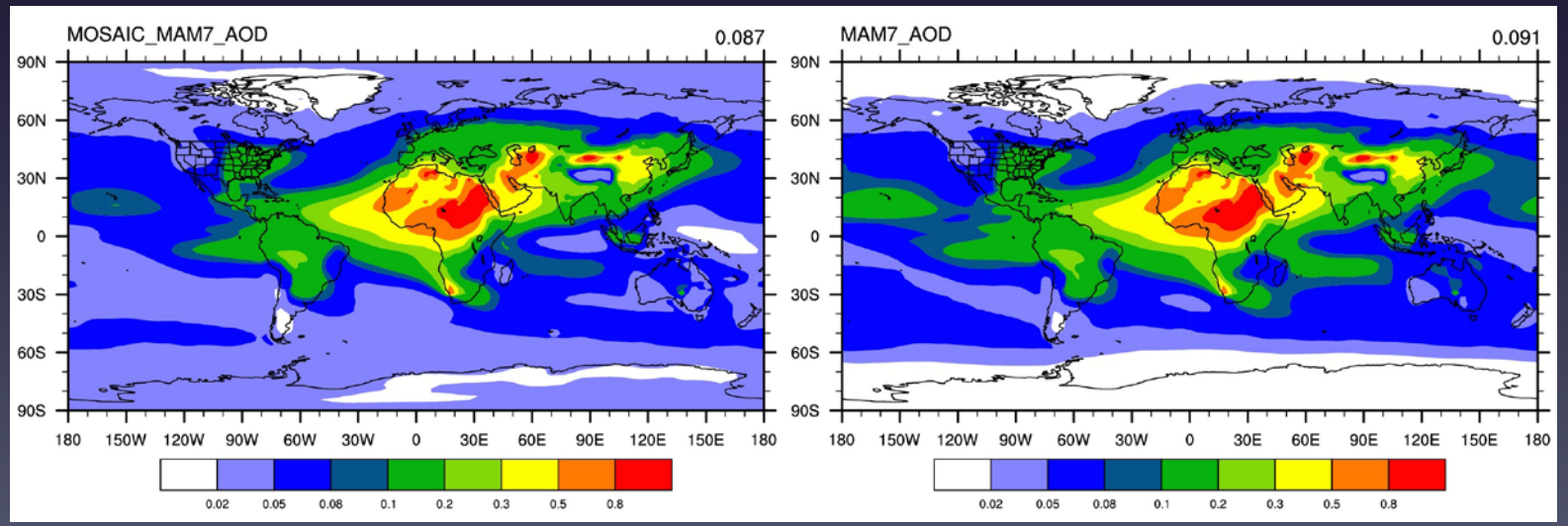
Results – AOD simulations

MOSAIC-MAM4 0.086



MAM4 0.088

MOSAIC-MAM7 0.087



MAM7 0.091

- Agreement between cases
- MAM7 case predicts highest AOD, because of largest dust concentrations
- MAM4 and MOSAIC-MAM4 predict higher AOD over ocean

Results – global budgets of chemical species

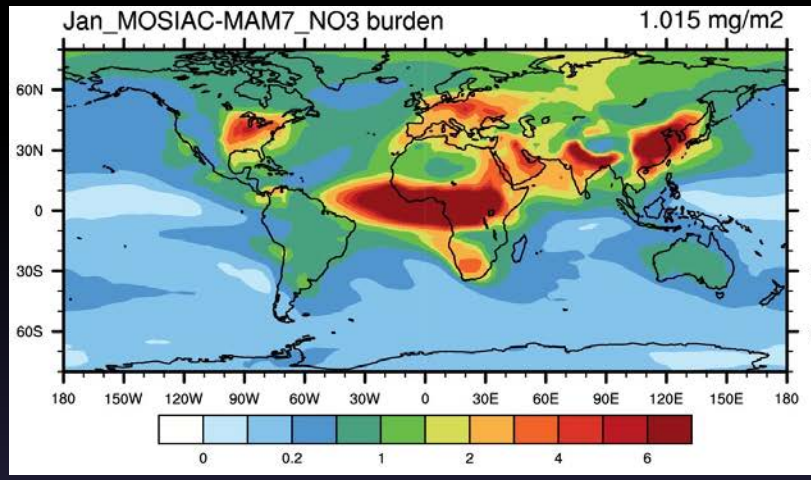
	Liu et al. (2012)	MAM7	MOSAIC-MAM7	MAM4	MOSAIC-MAM4
dms	0.067	0.147	0.144	0.143	0.139
so2	0.32	0.276	0.283	0.287	0.299
h2so4	4.2e-4	3.16e-4	3.22e-4	3.32e-4	3.67e-4
nh3	0.064	0.0826	0.0702	0.511	0.0833
nox	--	0.596	0.679	0.601	0.691
hno3	--	1.344	1.13	1.313	1.15
hcl	--	0.971	3.97	0.975	4.07
so4	0.47	0.551	0.694	0.553	0.706
nh4	0.24	0.304	0.292	--	0.286
no3	--	--	0.163	--	0.147
ncl	7.58	5.84	5.72	6.72	6.59
na	--	--	1.91	--	2.39
cl	--	--	3.13	--	3.41
dst	24.7	38.6	34.3	37.8	31.8
oin	--	--	32.84	--	30.48
ca	--	--	0.723	--	0.67
co3	--	--	0.762	--	0.722
bc	0.093	0.098	0.096	0.095	0.092
pom	0.68	0.731	0.712	0.729	0.676
soa	1.15	1.489	1.039	1.485	1.053

Tg S for dms, so2, h2so4, so4; Tg N for nh3, nh4, nox, hno3 no3; Tg for other species

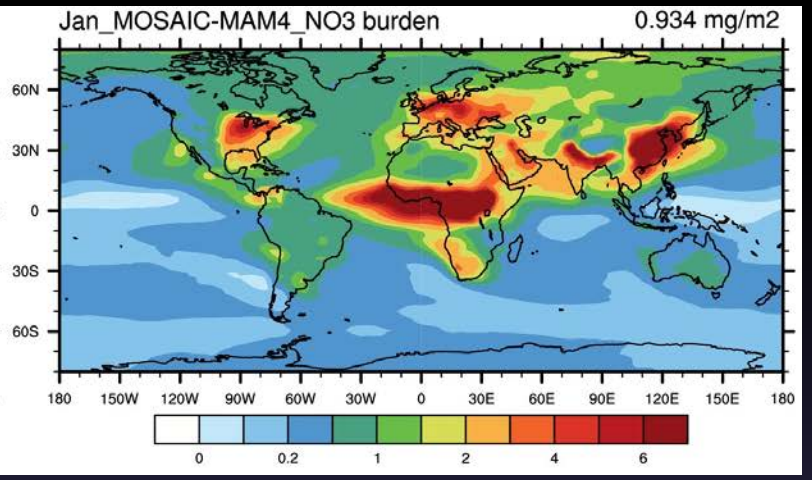
- MAM4 does not treat NH4
- MOSAIC cases treat NO3
- Sea-salt sulfate in MOSAIC cases
- Smaller σ_g in MAM4 -> weaker dry deposition
- More hydrophilic species in coarse or fine/coarse dust modes
- Condensation of SOA treated by MOSAIC

Results –NO3 modeled by MOSAIC-MAM7 and MOSAIC-MAM4

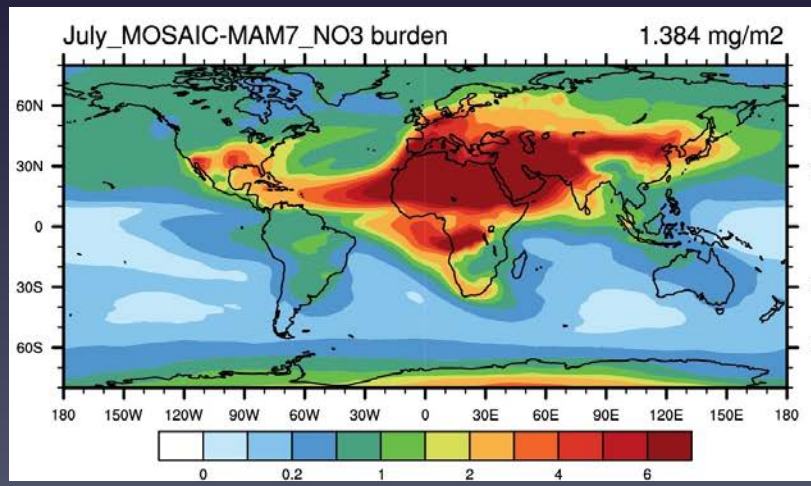
Jan. MOSAIC-MAM7



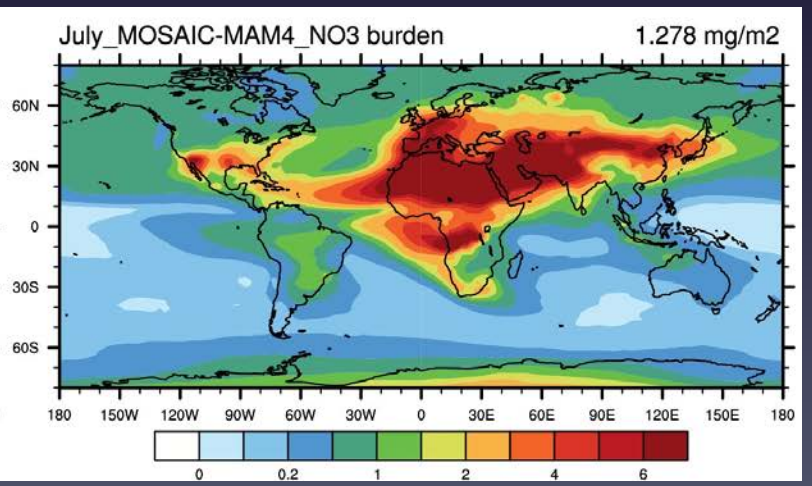
Jan. MOSAIC-MAM4



July MOSAIC-MAM7



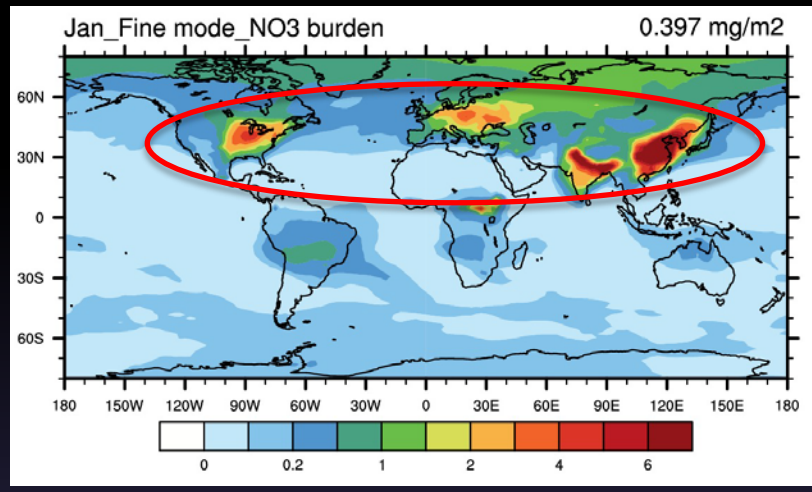
July MOSAIC-MAM4



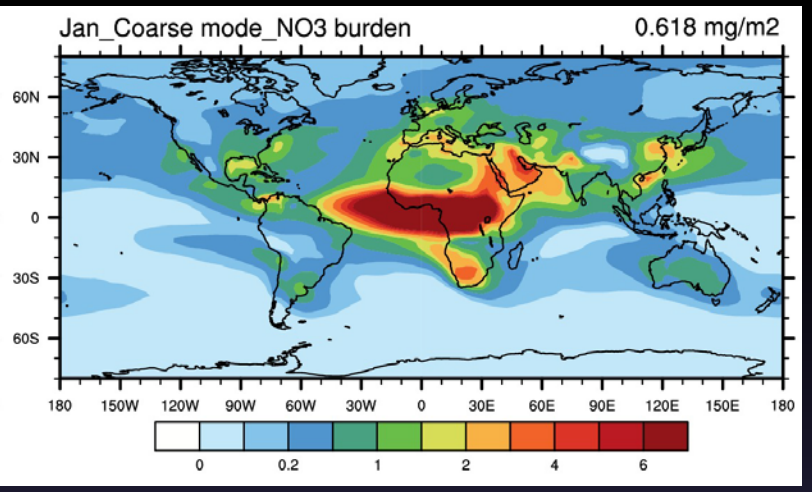
- In Jan., MOSAIC-MAM7 predicts 8.6% more NO3 than MOSAIC-MAM4
- In July, MOSAIC-MAM7 predicts 8.2% more NO3 than MOSAIC-MAM4

Results – NO3 modeled by MOSAIC-MAM7

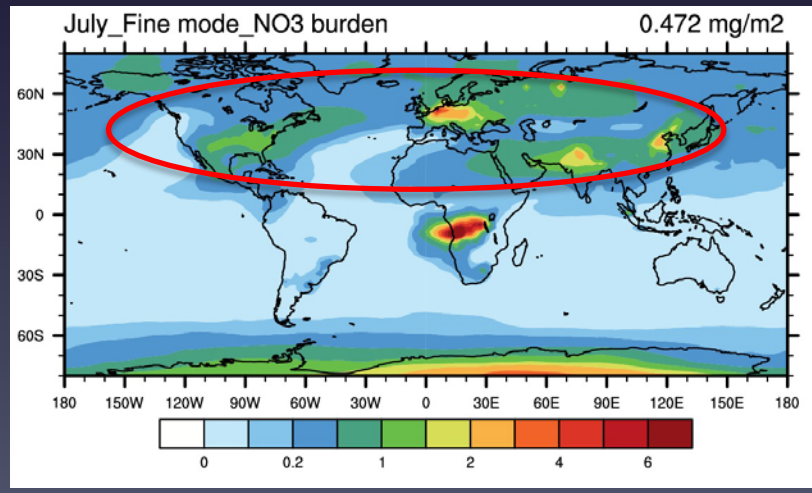
Jan. aitken + accumulation modes



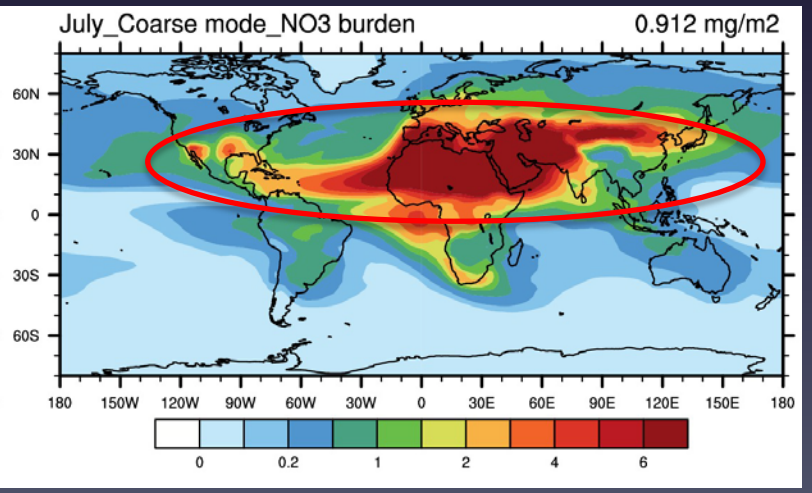
Jan. dust and sea salt modes



July aitken + accumulation modes



July dust and sea salt modes

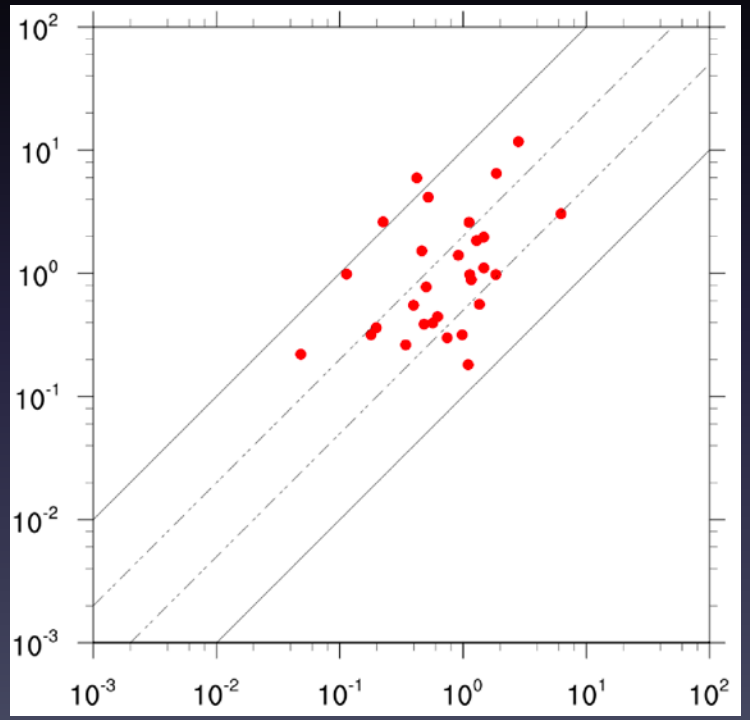


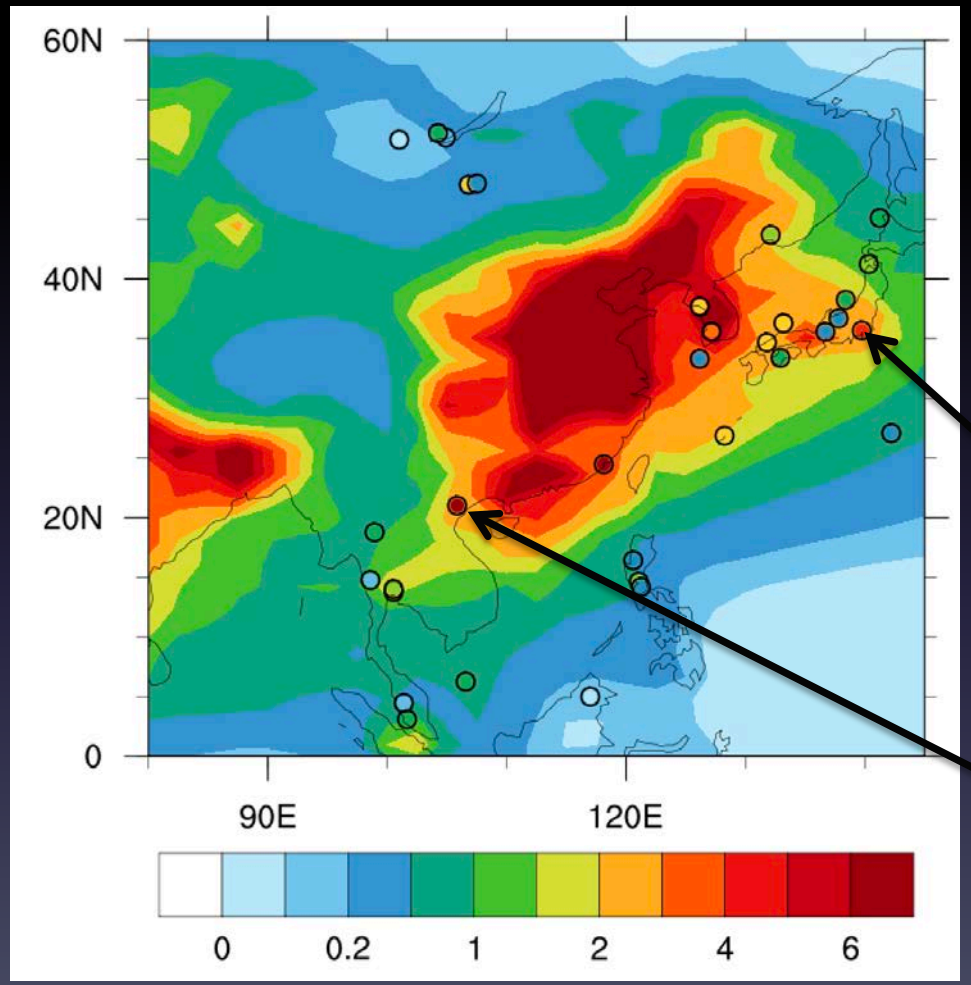
Northern hemisphere

- In Jan., large amount of NO3 in aitken and accumulation modes over polluted region.
- In July, only small amount of NO3 in aitken and accumulation modes, because of high temp.
- In July, large amount of NO3 condensed on fine/coarse dust modes

Results – comparison against EANET

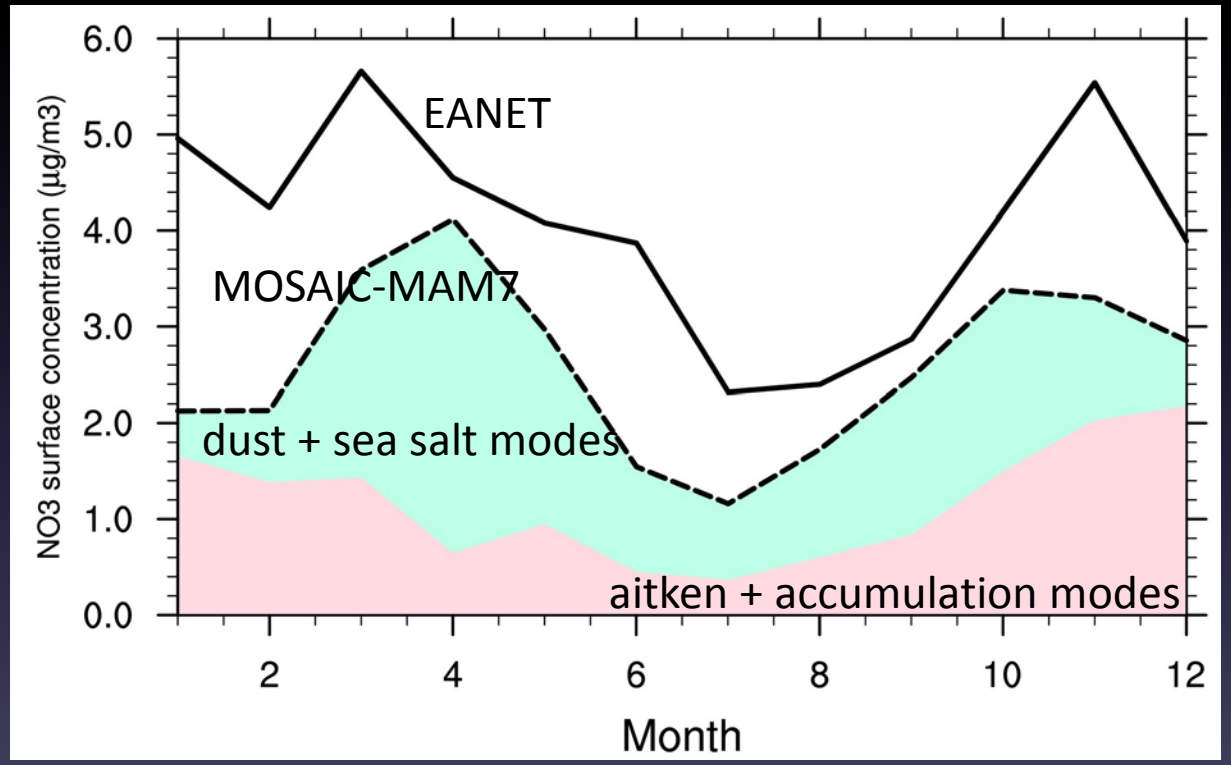
Correlation: 0.385
Model mean: 2.086 µg/m^3
EANET mean: 1.055 µg/m^3

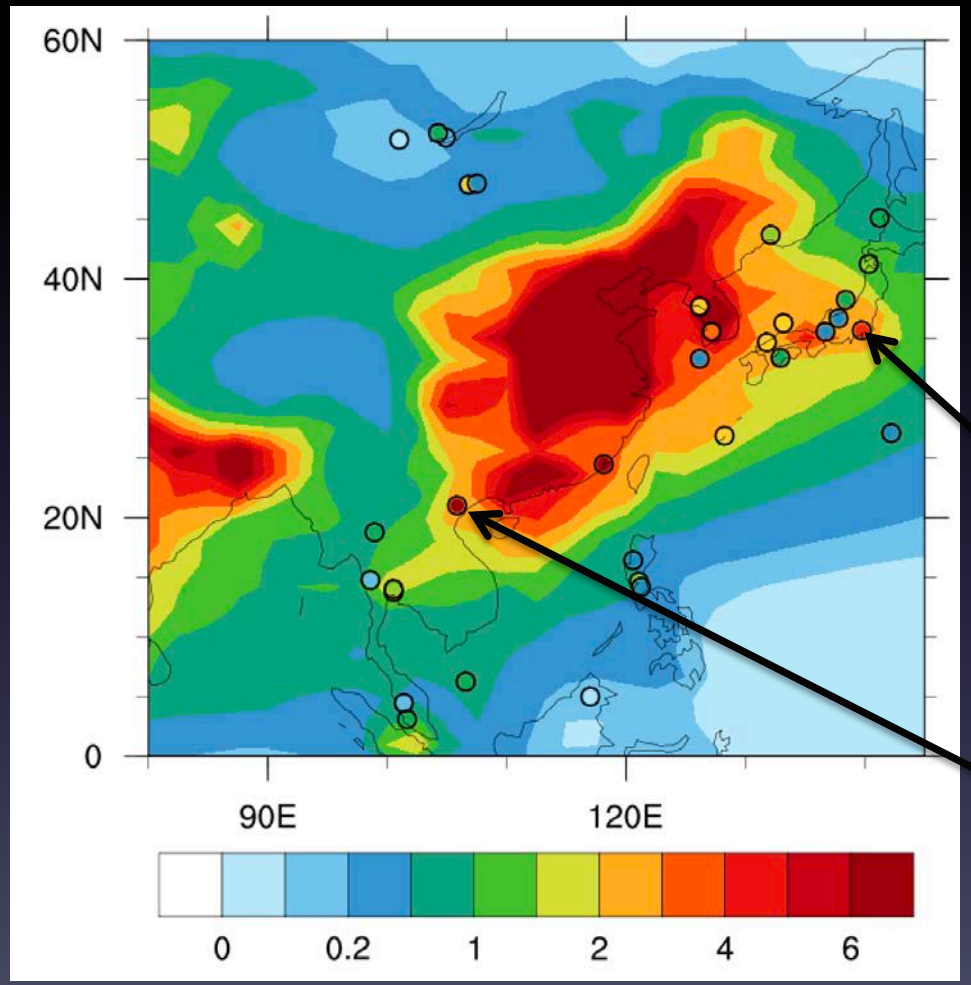




Results – comparison against EANET

Tokyo

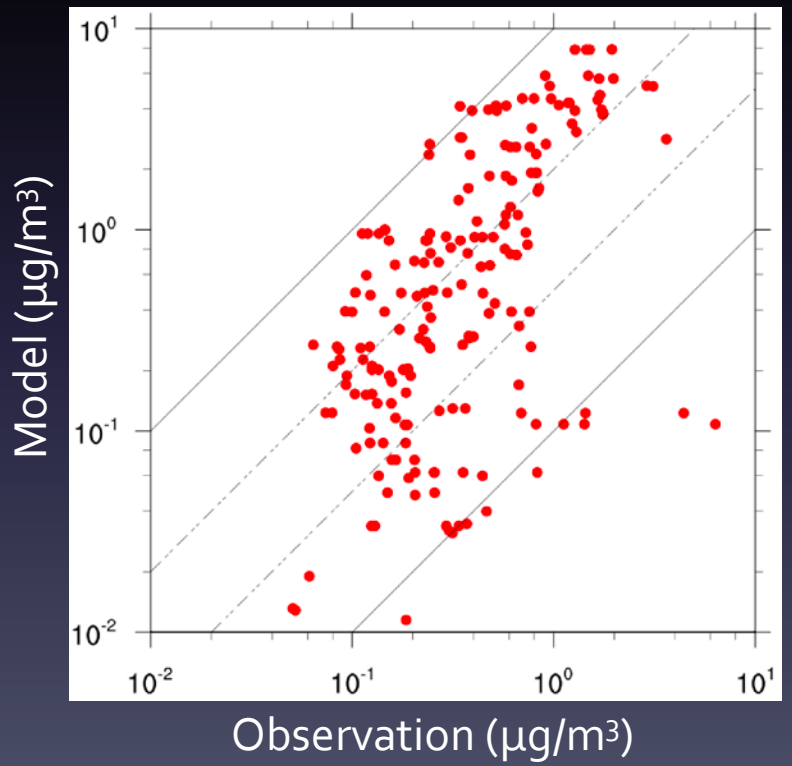




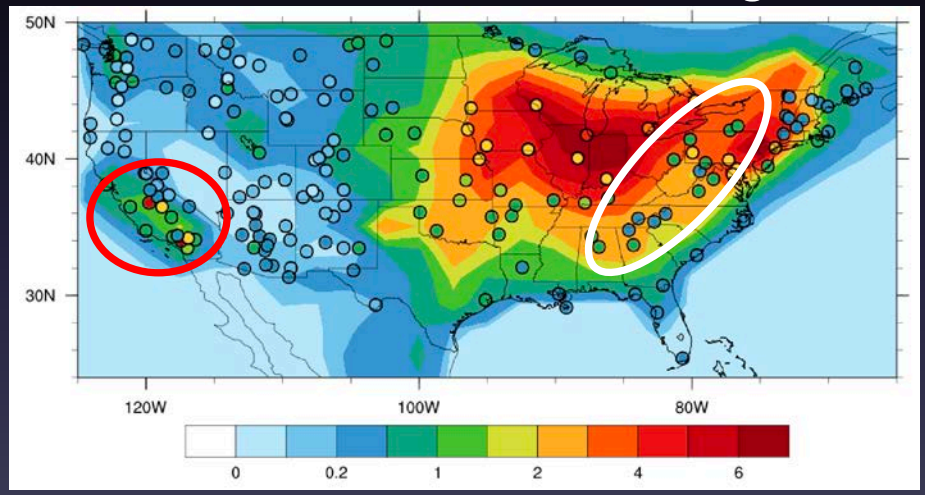
NO3 surface concentration (µg/m^3)

Results – comparison against IMPROVE

Correlation: 0.477
Model mean: 1.296 µg/m^3
IMPROVE mean: 0.559 µg/m^3



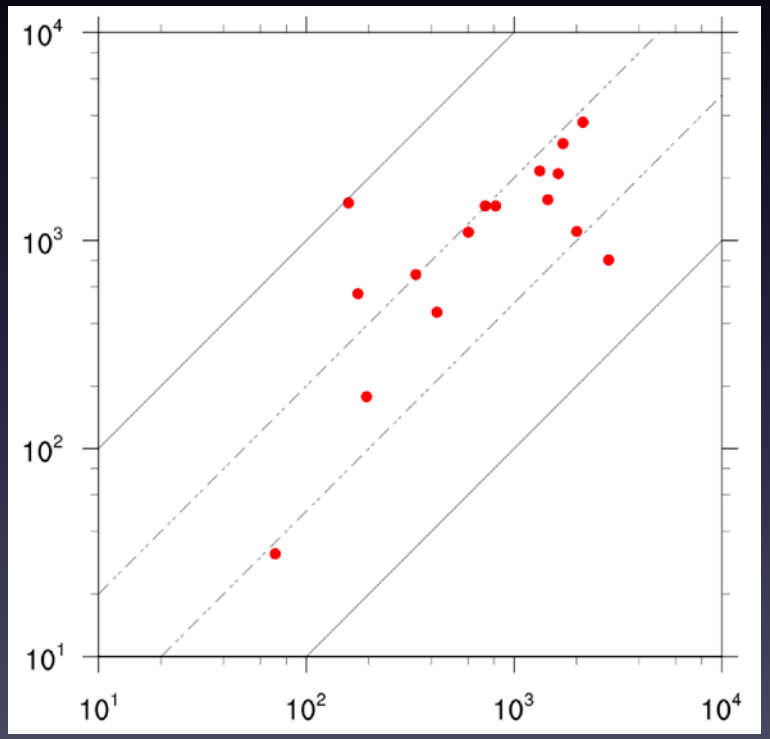
IMPROVE vs. annual average

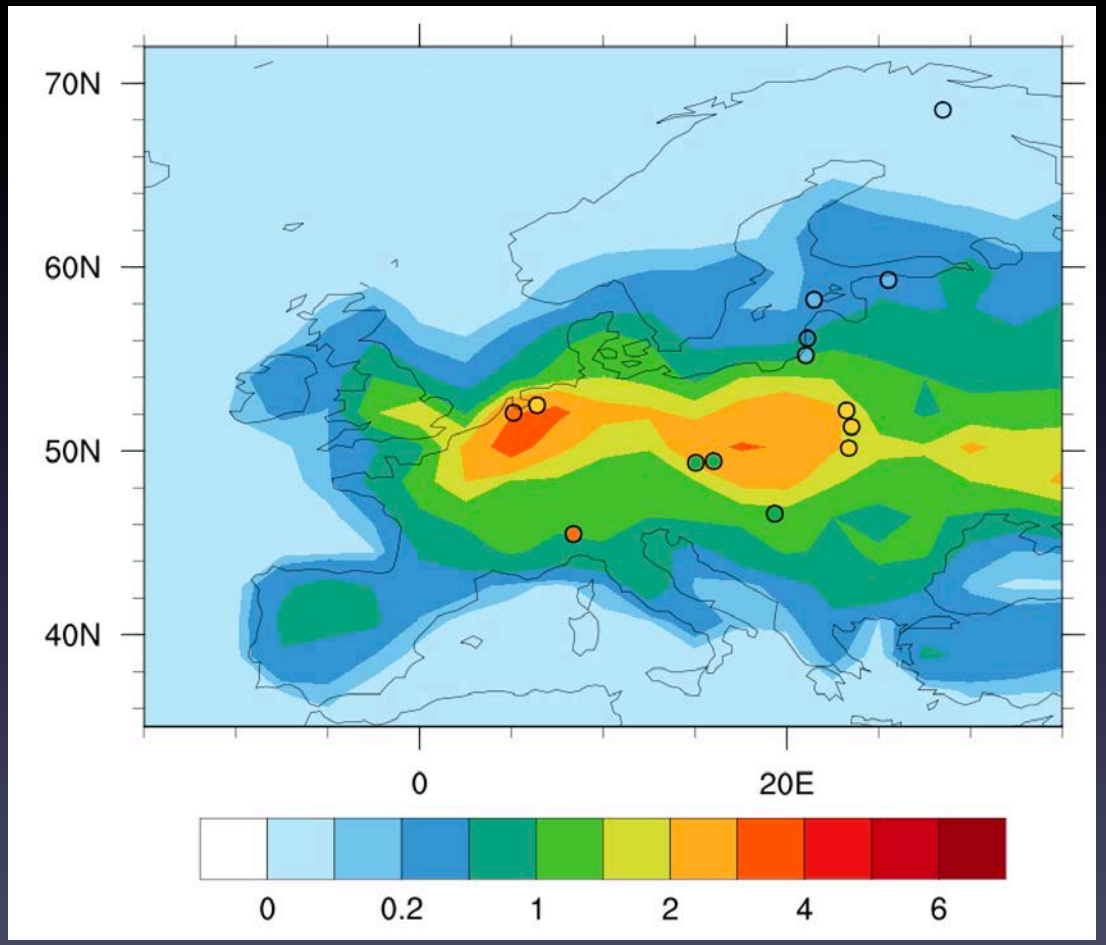


Fine mode nitrate(µg/m^3)

Results – comparison against EMEP

Correlation: 0.559
Model mean: 1363.5 pptv
EMEP mean: 1039.6 pptv

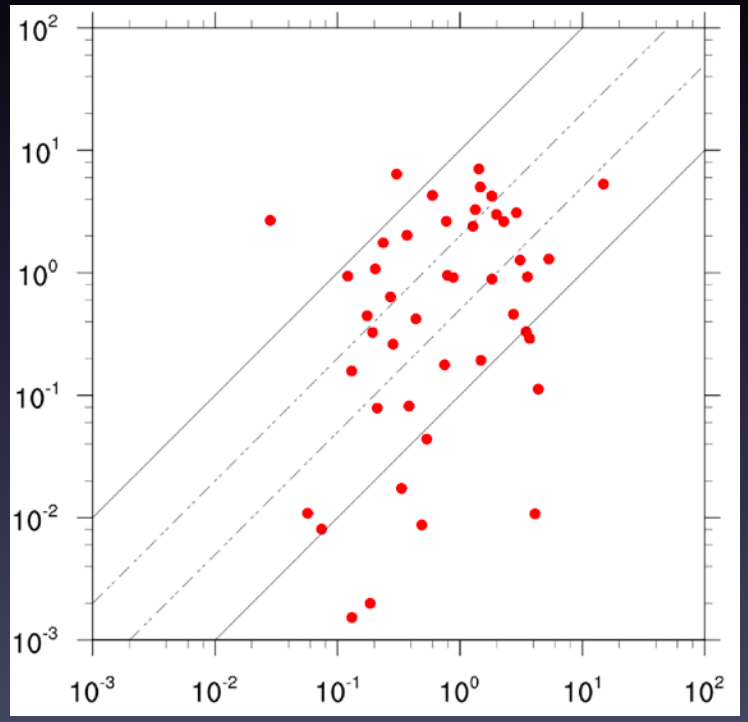


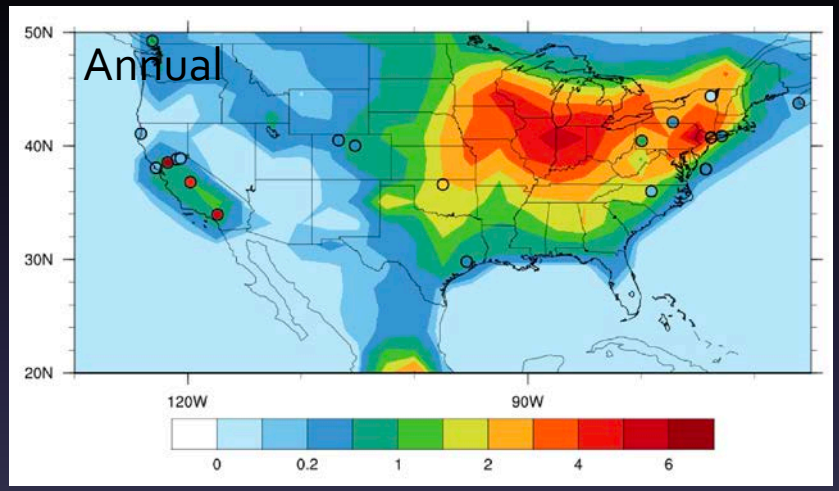


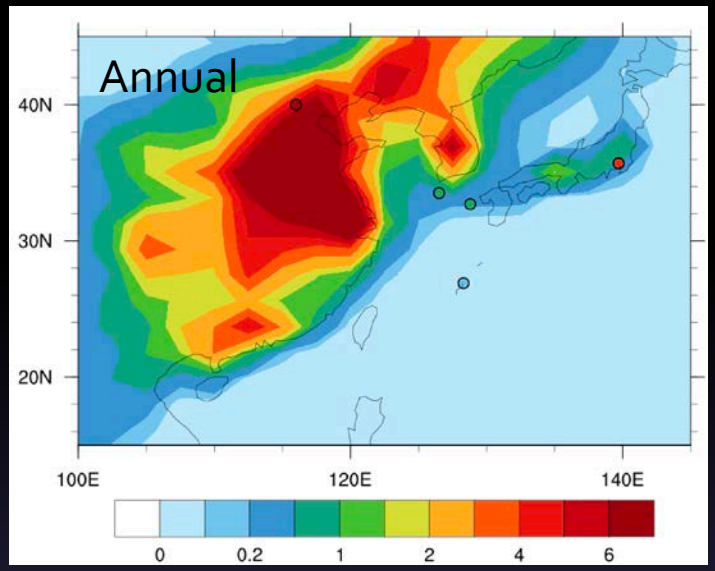
Equivalent gaseous volume mixing ratio (ppbv)

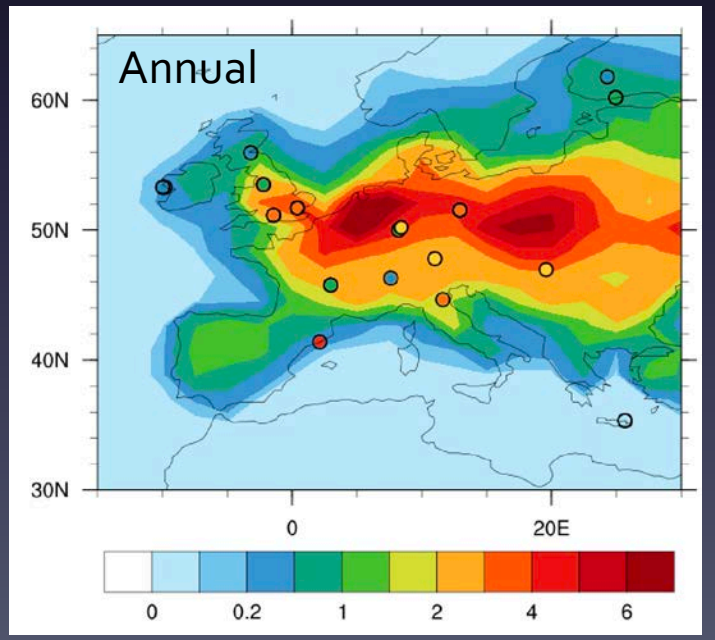
Results – comparison against AMS

Correlation: 0.291
Model mean: 1.417 µg/m^3
AMS mean: 1.515 µg/m^3









Conclusions

- MOSAIC aerosol module, coupled with MAM7 and MAM4 in CAM model, is used to simulate gas-aerosol exchange process.
- NO3 aerosols
  - exhibit significant seasonality, which is well captured by MOSAIC-MAM7
  - are overestimated by model if compared against filter-type of observations; and slightly underestimated by model compared against AMS
  - are usually underestimated by MOSAIC-MAM7 over highly polluted cities, indicating that additional work need to be done.

Results – computational coast

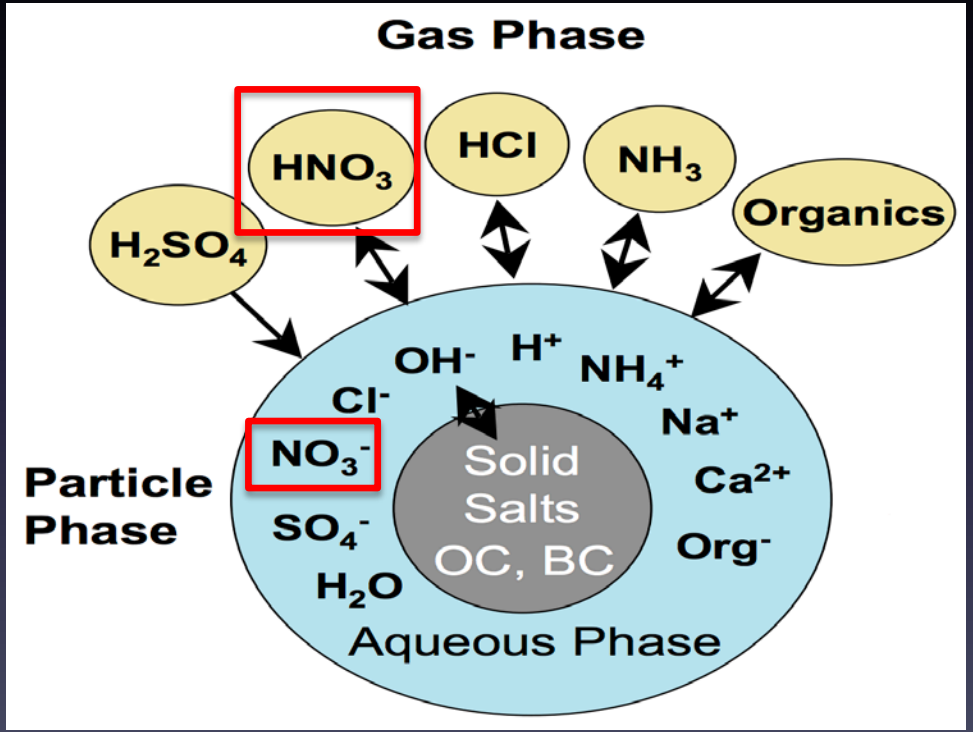
Cases	Without MOZART and MOSIAC	with MOZART	with MOZART & MOSAIC
MAM4	48 mins. → 1 model year	2.4h → 1 model year	3h → 1 model year
MAM7	1h → 1 model year	3h → 1 model year	4.2h → 1 model year

- 512 CPUs on NCAR Yellowstone
- MOSAIC-MAM vs. MAM: 25% ~ 40% more computational cost
- MOSAIC-MAM7 vs. MOSAIC-MAM4: 40% more computational cost

- MOSAIC module is developed by Zaveri et al. [2008], which treats many processes during the evolution of aerosol particles, such as nucleation, gas-aerosol exchange, coagulation, wet/dry removal processes.

- In the version of MAM coupled with MOSAIC, gas-aerosol exchange is treated by MOSAIC. The remaining processes are still treated by MAM

- Adaptive-step time-split Euler method is used for solving gas-aerosol exchange.



Source: presentation by Zaveri
WRF tutorial, 2008