

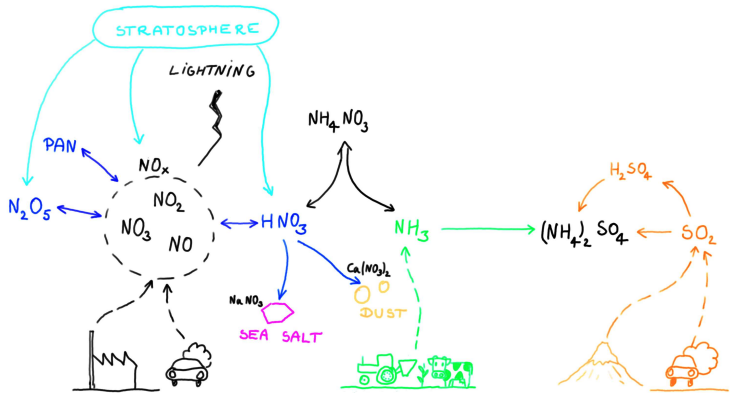
Implementation of nitrate in NorESM

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Boulder, 22 June 2017

- Motivation/introduction
- The aerosol scheme in NorESM
- Extending the aerosol scheme with nitrate
- Results – validation
- Conclusions

What is nitrate?



Why modelling nitrate?

Expected increased relative importance of nitrate aerosol in 21st century

Hauglustaine et al. [2014] (only direct radiative forcing)

		2000	2030	2050	2100
SO ₄	[W m ⁻²]	-0.315	-0.118	-0.094	-0.033
NO ₃	[W m ⁻²]	-0.056	-0.095	-0.102	-0.096

Air-quality models

Nitrate in climate models : Feng and Penner [2007], Bauer et al. [2007], Bellouin et al. [2011], Xu and Penner [2012], Hauglustaine et al. [2014]

Aerocom inter-comparison study : Bian et al. [2017, ACPD]

What is NorESM?

NorESM - Norwegian Earth System Model

Before 2007

- Atmosphere : development of aerosol module and study of indirect aerosol effect in various versions of CAM (CAM-Oslo)
- Ocean : development of BCC (Bergen Climate Model) including MICOM, with marine bio-geochemistry (HAMOCC) (ARPEGE as atmosphere model in BCC)

Since 2007 Working on development of NorESM – resulted in NorESM-1 based on CCSM-4

Current development of aerosol-scheme in CAM-Oslo

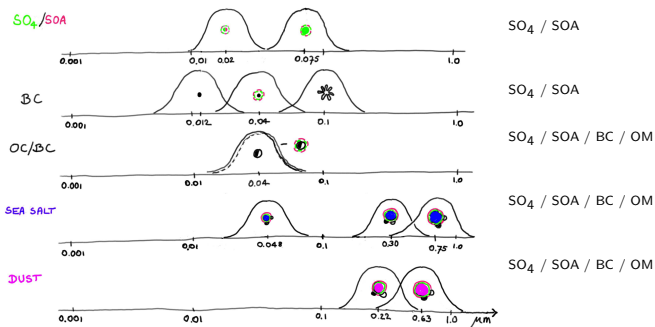
explicit SOA formation, aerosol nucleation, interactive emissions of DMS and OM from the ocean, new sea-salt emission parameterisation, nitrate aerosol

The CAM-Oslo aerosol scheme

Gas-phase species (8) : DMS, SO₂, H₂SO₄, H₂O₂, isoprene, mono-terpenes, semi-volatile SOA precursors, low-volatile SOA precursor

Oxidant climatologies (4) : OH, HO₂, NO₃, O₃ (+ daily cycle)

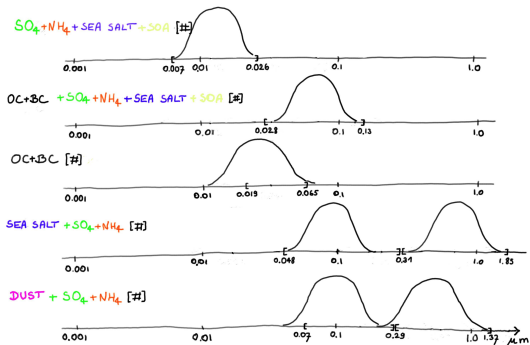
Aerosol species (12 modes – 20 tracers)



Remarks Explicit nucleation / Aging of particles / No evaporation of SOA / NH₄ implicit

Comparison with MAM7 aerosol scheme

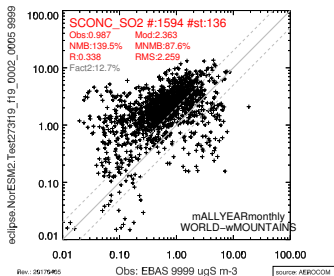
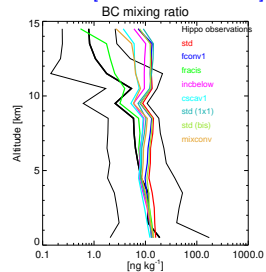
Liu et al. [2012]



Remarks Aerosol number, variable mode radius

Some issues with CAM-Oslo

BC [HIPPO, 2009–2011]



SO₂ [Aerocom]

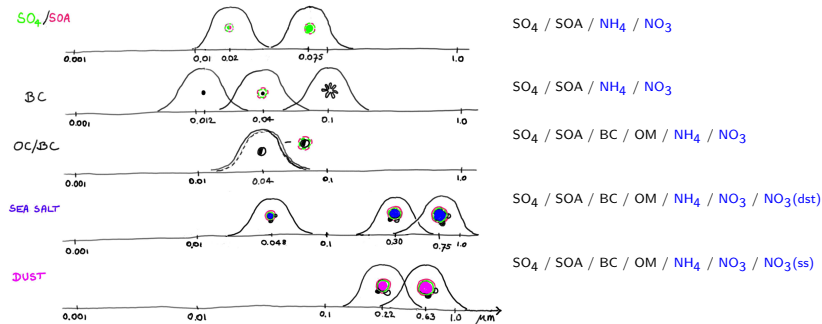
Ammonium/nitrate implementation

New gas-phase species HNO_3 , NH_3 / NO , NO_2 , NO_3 / N_2O_5 , PAN

NH_3 and HNO_3 can condensate on existing aerosol

- 1 NH_4 : ammonium (bi)sulfate : $(\text{NH}_4)_2\text{SO}_4$, $(\text{NH}_4)\text{HSO}_4$
- 2 NH_4 and NO_3 : equilibrium of $\text{NH}_3(\text{g}) + \text{HNO}_3(\text{g}) \leftrightarrow \text{NH}_4\text{NO}_3(\text{aerosol})$ [Ackermann et al., 1995; Hauglustaine et al., 2014; Bellouin et al., 2011]
- 3 $\text{NO}_3(\text{dst})$: irreversible condensation of HNO_3 on dust
- 4 $\text{NO}_3(\text{ss})$: irreversible condensation of HNO_3 on sea-salt

Aerosol tracers



How to validate?

Two issues

- 1 How well is nitrate represented?
- 2 Impact of the simplified NO_x chemistry?

Possible validation

- 1 Comparison with a full-chemistry version
- 2 Comparison with observations (aerocom-tool)
- 3 Comparison with other models

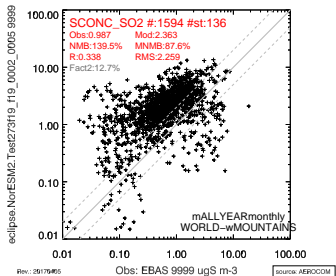
Simulations

- Simplified chemistry and full chemistry (both nudged to same meteorology)
- 5 years : averages over year 2–5 are shown
- Resolution : $1.9^\circ \times 2.5^\circ$, 30 levels
- Year 2000 conditions (emissions, GHG, ...)

Comparison with observations: SO₂ and SO₄

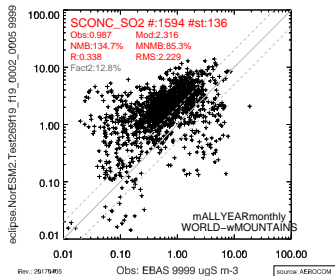
Surface observations

Simplified chemistry with nitrate

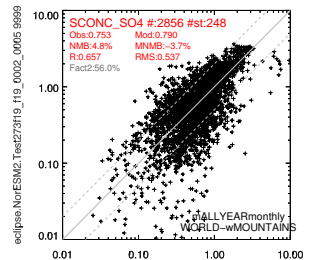


SO₂

Full-chemistry with nitrate

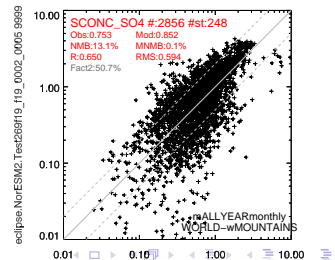


Simplified chemistry with nitrate



SO₄

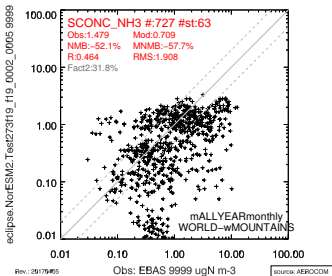
Full-chemistry with nitrate



Comparison with observations: NH_3 and NH_4

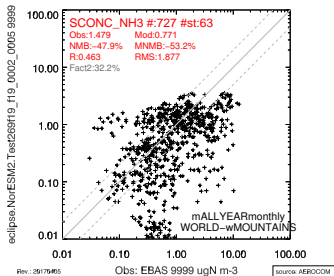
Surface observations

Simplified chemistry with nitrate

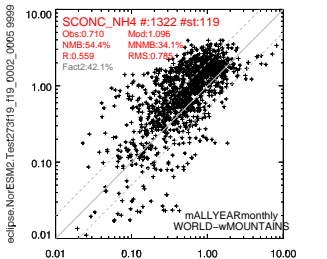


NH_3

Full-chemistry with nitrate

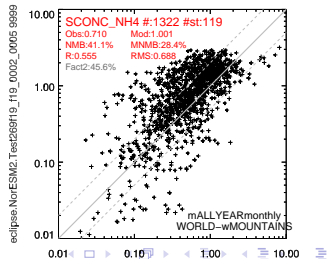


Simplified chemistry with nitrate



NH_4

Full-chemistry with nitrate



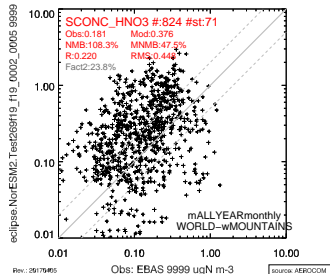
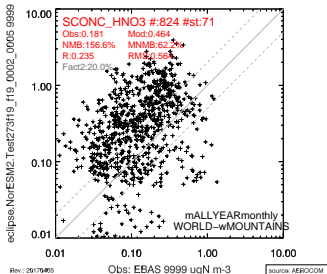
Comparison with observations: HNO_3 and NO_3

Surface observations

Simplified chemistry with nitrate

HNO_3

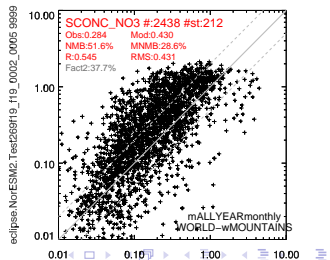
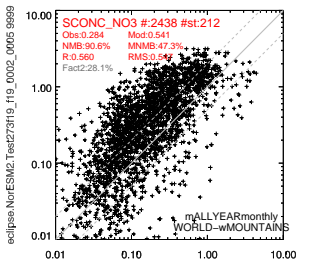
Full-chemistry with nitrate



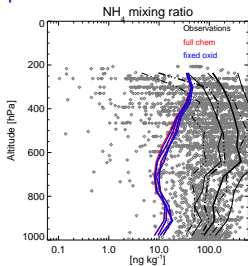
Simplified chemistry with nitrate

NO_3

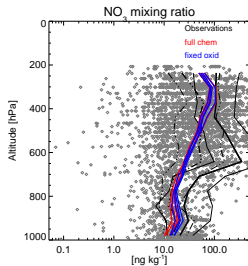
Full-chemistry with nitrate



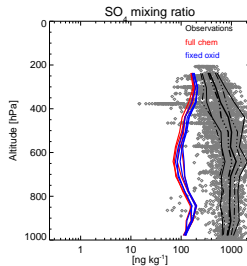
NH₄
April 2008



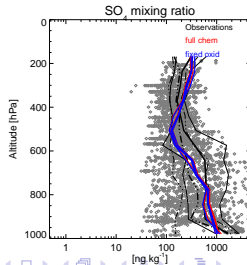
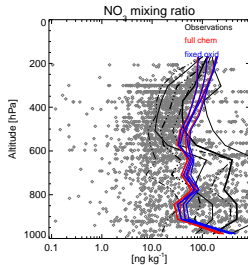
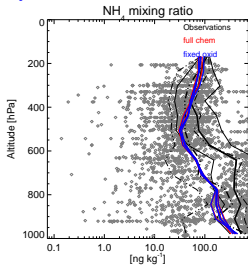
NO₃



SO₄



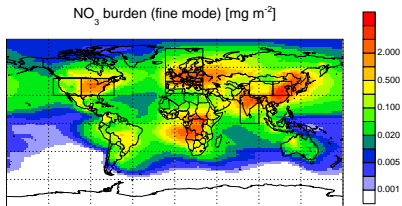
July 2008



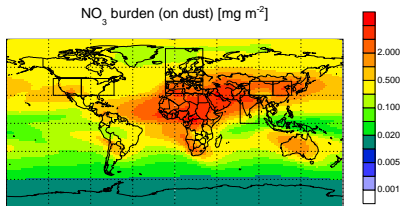
Nitrate column burden

Aerosol-only – annual mean

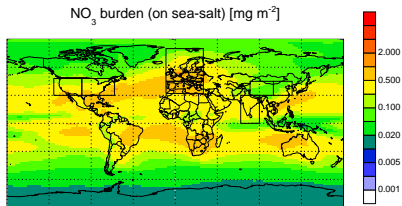
Nitrate (in NH_4NO_3) (0.12 Tg)



Nitrate on dust (0.44 Tg)



Nitrate on seasalt (0.13 Tg)



Ammonium and nitrate burdens

Global burden

		NorESM		Hauglustaine et al. [2014]	Bian et al. [2017]	
		full-chemistry	aerosol-only		avg.	med.
NH ₄	[Tg]	0.35	0.36	0.28 (0.39)	0.32	0.30
NO ₃	[Tg]	0.59	0.68	0.80 (0.79)	0.63	0.60
NO ₃ (a1)	[Tg]	0.10	0.12	0.22		
NO ₃ (dst)	[Tg]	0.38	0.44	0.31		
NO ₃ (ss)	[Tg]	0.10	0.13	0.27		

Neutralization

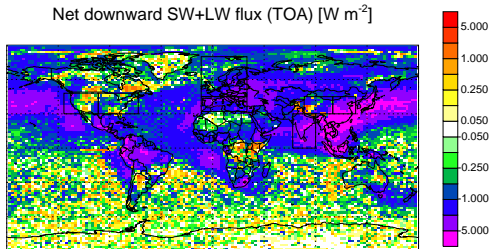
	full-chemistry	aerosol-only
$\frac{[\text{NH}_4]_{\text{vmr}}}{[\text{SO}_4]_{\text{vmr}}}$	1.25	1.30

Effective radiative forcing

Total : -1.145 W m^{-2}

		Longwave	Shortwave
Direct	$[\text{W m}^{-2}]$	0.032	-0.184
Indirect	$[\text{W m}^{-2}]$	0.076	-1.132
Surface albedo	$[\text{W m}^{-2}]$	0.057	0.006

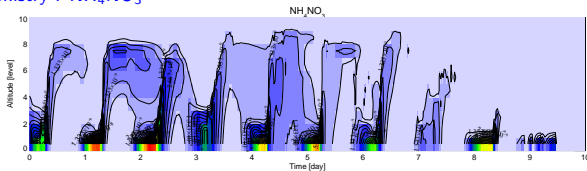
Geographical distribution (annual mean)



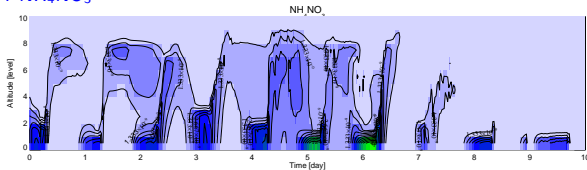
Simplified NO_x chemistry ...

Gridpoint in western Europe – June

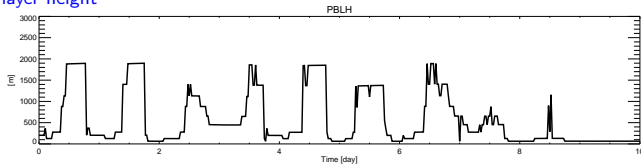
Simplified chemistry : NH_4NO_3



Full chemistry : NH_4NO_3



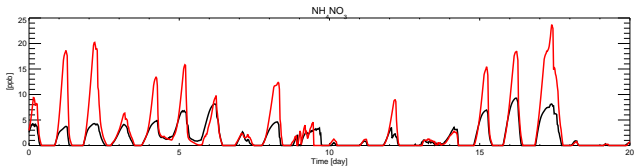
Boundary layer height



Simplified NO_x chemistry ...

Gridpoint in western Europe – June – lowest layer

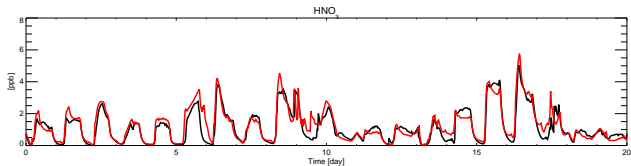
NH_4NO_3



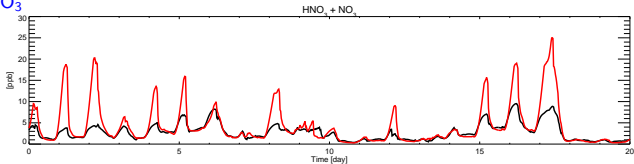
Full-chemistry with nitrate

Aerosol-only with nitrate

HNO_3

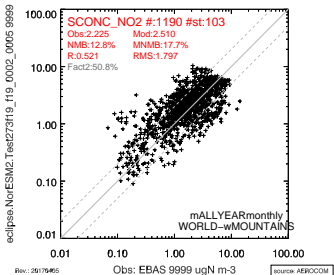


$\text{HNO}_3 + \text{NO}_3$

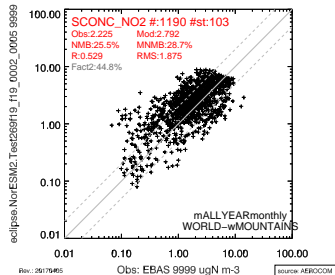


Comparison with observations: NO₂

Aerosol-only



Full-chemistry



Aerosol module now contains nitrate and ammonium

- 4 extra aerosol tracers : NH_4 , NO_3 , $\text{NO}_3(\text{dst})$, $\text{NO}_3(\text{ss})$
- 7 extra gas-phase species
- Aerosol-only version : 29 \rightarrow 40 tracers.
- Implemented both in aerosol-only as well as in full-chemistry version of NorESM.

Remaining issues

- Possibly too fast aerosol aging?
- Optimization of the simplified NO_x chemistry

Future

- Look at AOD
- Look at nitrogen deposition measurements
- Extend to more global observations
- (Daily cycle of emissions?)

The end

Thank you !