The Oslo-aerosol scheme implemented in CAM5.3

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Overview

- Motivation/introduction
- The CAM-Oslo aerosol scheme
- Updates in CAM5.3-Oslo
- Results – validation
- Conclusions

Remark : to avoid potential conflicts with an upcoming publication, we have removed the figures from this presentation. They will hopefully become soon available in Kirkevåg et al. [2018, GMDD].

Introduction

Role of aerosols : Climate change – uncertainty in climate sensitivity

CAM-Oslo

- Aerosol scheme – implemented in CCM2, CCM3, CAM2, CCSM3
- CAM4-Oslo in NorESM1 (based on CCSM4 (CAM4)) [Bentsen et al., 2013; Iversen et al., 2013; Kirkevåg et al., 2013]

NorESM based on CESM

- ocean : MICOM (instead of POP)
- ocean biogeochemitry : HAMOCC
- atmosphere : CAM-Oslo aerosol scheme, energy conservation, angular momemtum conservation, COARE flux parameterisation over ocean
- specifc modification in sea-ice model
- no land ice-sheets model, no wave model

CAM4-Oslo $\rightarrow$ CAM5.3-Oslo

- Harmonization process
- Specific modifications in CAM4-Oslo

The CAM-Oslo aerosol scheme

Aerosol BC, OM (including SOA), dust, sea-salt, sulphate

Gas-phase precursors

DMS, SO_2, H_2SO_4, H_2O_2

isoprene and monoterpenes $\rightarrow$ $SOAG_{LV}$ and $SOAG_{SV}$ ($\rightarrow$ SOA)

Condensation : H_2SO_4 and $SOAG_{LV}/SOAG_{SV}$

Distinction between background aerosol and condensate/coagulate/aqueous-phase-produced

NMR	Background	Condensate		Aq. phase			Coagulate
0.024	BC						
	↓						
0.024	BC	SO_4	SOA				
	↑						
0.062	BC						
0.040	BC/OM						
	↓						
0.040	BC/OM	SO_4	SOA				
0.012	SO_4/SOA	SO_4	SOA				
0.075	SO_4	SO_4	SOA	SO_4	BC	OM	SO_4
0.220	dust	SO_4	SOA	SO_4	BC	OM	SO_4
0.630	dust	SO_4	SOA	SO_4	BC	OM	SO_4
0.048	sea salt	SO_4	SOA	SO_4	BC	OM	SO_4
0.300	sea salt	SO_4	SOA	SO_4	BC	OM	SO_4
0.750	sea salt	SO_4	SOA	SO_4	BC	OM	SO_4

Aging

Loop-up tables : to estimate new NMR and σ after growth

Oxidants climatologies : OH, HO_2, O_3 and NO_3

Number concentration : not a prognostic variable

Evolution of CAM4-Oslo to CAM5.3-Oslo

Comparison with MAM3/MAM4/MAM7

	#modes	# aerosol tracers	# number tracers	# gas-phase tracers
OsloAero	10 (12)	21	–	H_2O_2, DMS, SO_2, H_2SO_4, isop, monot, $SOAG_{LV}$, $SOAG_{SV}$
MAM3	3	12	3	H_2O_2, DMS, SO_2, H_2SO_4, SOAG
MAM4	4	15	4	H_2O_2, DMS, SO_2, H_2SO_4, SOAG
MAM7	7	24	7	H_2O_2, DMS, SO_2, H_2SO_4, SOAG, NH_3

Harmonization of CAM-Oslo aerosol scheme with standard CAM

- emissions, gas-phase chemistry, oxidants (before from OsloCTM1/OsloCTM2), deposition (**pp_trop_mam_oslo**)
- #MODAL_AERO, #MODAL_AERO_3MODE, #MODAL_AERO_7MODE → additional #OSLO_AERO
- emissions of dust (before Aerocom, Dentener et al. [2006]) (however, different sizes)
- (stratiform) cloud micro-physics
- use of nudging

However still differences (**chemistry/oslo_aero** and **physics/cam/cam_oslo**)

- emissions of seasalt, marine OM, DMS
- coagulation, condensation, hygroscopic growth
- optics
- AeroTab/Look-up tables
- daily cycle on OH, HO_2, NO_3 radicals
- no aerosol number concentration as prognostic variable, but *process-tagged*

Highlight of CAM4-Oslo to CAM5.3-Oslo changes

Emissions

- DMS emissions : link to the surface ocean climatology of Lana et al. [2011] or Kettle et al. [2000]
- Marine OM emissions : link to the surface ocean climatology of chlorofyl-a
- Sea-salt emissions and emission size [Salter et al., 2015]
- Dust emissions (in this work prefactor 1/0.4)

SOA / nucleation

- SOA : ispoprene and monoterpenes $\rightarrow$ $SOAG_{LV}$, $SOAG_{SV}$ $\rightarrow$ SOA (no evaporation)
- Explicit nucleation by H_2SO_4 and organic vapours ($SOAG_{LV}$, $SOAG_{SV}$)

Other modifications

- Radius smallest BC mode : 12 $\rightarrow$ 24 nm
- 2x2, L26 $\rightarrow$ 1x1, L30
- Better climatology for NO_3 radical

Experimental setup

Main purpose : focus on aerosol climatology, aerosol-cloud interaction, and estimate of RF and ERF

Simulations

	SSTs/GHGs/Oxidants	Meteorogy	Emissions	Length
Free running	2000	free	2000	30 yr
	2000	free	1850	30 yr
Nudged	2000	ERA-Interim	2000	2004–2010
	2000	ERA-Interim	1850	2004–2010

Resolution : 1x1, L30

Oxidants (OH, O_3, HO_2, H_2O_2) : all 2000

Nudging to ERA-Interim : PS, U, V, $\tau = 6$ h.

Comparison with surface observations (1)

(plots of comparison between observed and modelled surface concentration for SO_2, SO_4, BC, and OA)

Comparison with surface observations (2)

(plots of comparison between observed and modelled surface concentration for dust and sea-salt)

BC – comparison with HIPPO campaigns

(plots of comparison between observed (HIPPO campaign) and modelled BC profiles)
HIPPO campaign [Wofsy et al., 2011; Schwarz et al., 2013]

Nudged

AMIP

Comparison with AeroNet observations

(plots of comparison between observed and modelled clear-sky optical depth and absorption optical depth at 550nm)

Global emissions / lifetimes / burdens

Emissions, lifetimes, burdens

	DMS	SO_2	SO_4	Dust	Sea salt	BC	OM
Emissions (Tg)	34.3 [34.6] (18.1)	65.0 [65.0] (66.3)	1.67 [1.67] (1.70)	3104 [2508] (1672)	1937 [2003] (6462)	7.93 [7.93] (7.70)	86.9 [87.4] (122)
Lifetime (days)	1.48 [1.50] (2.39)	1.35 [1.33] (1.11)	3.70 [3.65] (3.80)	1.92 [1.93] (2.55)	1.07 [1.04] (0.28)	4.98 [4.77] (8.12)	5.13 [4.84] (7.58)
Burden (Tg)	0.140 [0.143] (0.12)	0.357 [0.352] (0.24)	0.584 [0.579] (0.59)	16.3 [13.3] (11.7)	5.70 [5.72] (4.94)	0.108 [0.103] (0.17)	2.44 [2.26] (2.87)

Code

Numbers : nudged simulations
Squared brackets : AMIP
Round brackets : CAM4-Oslo [Kirkevåg et al., 2013], for comparison

Overview comparison with observations

Normalized mean bias

	CAM4-Oslo	CAM5.3-Oslo	
		Nudge	AMIP
SO_2	16	150	137
SO_4	-5	22	27
BC	-54	-28	-34
OA (OM)	108	122	125
sea salt	50	22	40
dust	-14	-39	-24
OD550 (clear sky)	-22	-16	
OD550	-8	15	
ABS550 (clear sky)	-32	-25	
ABS550	-33	-20	
ANG4487 (clear sky)		-17	
ANG4487	-19	-43	

Direct radiative forcing

Nudged to ERA-Interim

AMIP

(plots of LW and SW direct radiative forcing at TOA)

Cloud radiative forcing

Nudged to ERA-Interim

AMIP

(plots of LW and SW cloud radiative forcing at TOA)

RF and ERF

RF / ERF decomposition	**CAM4-Oslo** RF [W m^{-2}]	**CAM5.3-Oslo** ERF Nudge (AMIP) [W m^{-2}]	IPCC-AR5 RF [W m^{-2}]	IPCC AR5 ERF [W m^{-2}]
SW ARI	-0.10	-0.095 (-0.092)*	-0.35 (-0.85 to 0.15)	-0.45 (-0.95 to 0.05)
LW ARI		0.026 (0.026)*		
SW ACI	-0.91	-1.50 (-1.45)*	Not assessed	-0.45 (-1.20 to 0.0)
LW ACI	0.01	0.161 (0.155)*		
ARI + ACI	-1.00	-1.41 (-1.36)*	Not assessed	-0.9 (-1.9 to -0.1) -1.08 (-1.40 to -0.76)**
	Kirkevåg et al. (2013)	This work	Boucher et al. (2013)	Boucher et al. (2013)

(*) the semi-direct effect is here embedded in the ERF ACI term (Ghan, 2013), not in ERF ARI as in the IPCC AR5 estimates

(**) mean $\pm$ one standard deviation for CMIP5 and ACCMIP models for the period 1850–2000

Conclusions and perspective

Conversion CAM4-Oslo to CAM5.3-Oslo

- More embedded in the CESM-CAM structure (gain in synergy / loss in model diversity)
- Modifications in seasalt/dust/marine pom emissions + modifications in SOA description + modifications in nucleation + other changes
- Reduced bias in upper-troposphere BC – strong bias in surface SO_2 concentrations
- Estimate of ARI + ACI : -1.00 $W\,m^{-2}$ (CAM4-Oslo) $\rightarrow$ –1.41 $W\,m^{-2}$ (CAM5.3-Oslo)
- ERA-Interim (7 year mean) versus free-running AMIP (27 year mean) : comparable results (however, considerable impact on wind-driven emissions from sea-salt, dust)

Further focus

- Unidirectional SOA-scheme (only condensation, no evaporation), nitrate aerosol, full-chemistry
- OM / OC factor and comparison with observations

Further development CAM6.0-Oslo / NorESM2

The end

Thank you !

To be submitted soon to GMD :

A production-tagged aerosol module for earth system models – extensions and updates for CAM5.3-Oslo, A. Kirkevåg, A. Grini, D. Olivié, Ø Seland, K. Alterskjær, M. Hummel, I. H. H. Karset , A. Lewinschal, X. Liu, R. Makkonen, I. Bethke, J. Griesfeller, M. Schulz, T. Iversen