# Results from coupling the CAM-Oslo aerosol and MOZART chemistry schemes

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# Overview

- Introduction on NorESM
- CAM-Oslo: its aerosols and secondary aerosol formation
- Coupling wit Mozart
- Results
- Conclusions

# Introduction on NorESM

# The NorESM model

## Based on CCSM-4, CESM-1: modifications

- Atmosphere: based on CAM-4 but with different aerosol description

Primary emissions ↘ Aerosols
Precursor emissions → Secondary aerosol formation ↗ Aerosols

Aerosols ↗ CCN → CDNC → Indirect effect
Aerosols ↘ Direct effect

- Ocean: MICOM (instead of POP)

## Description

- T. Iversen: About NorESM, a model based on CCSM4 but with significant amendments (AMWG)
- A. Kirkevåg: Natural aerosols (CCWG)

# The NorESM model

## Participated in CMIP5

## Description

- Zhang et al. [2012, GMD]: Pre-industrial and mid-Pliocene simulations with NorESM-L
- Zhang and Yan [2012, GMD]: Pre-industrial and mid-Pliocene simulations with NorESM-L: AGCM simulations
- Kirkevåg et al. [2013, GMD]: Aerosol-climate interactions in the Norwegian Earth System Model NorESM
- Bentsen et al. [2012, GMDD]: The Norwegian Earth System Model, NorESM1-M – Part 1: Description and basic evaluation
- Iversen et al. [2012, GMDD]: The Norwegian Earth System Model, NorESM1-M – Part 2: Climate response and scenario projections
- Tjiputra et al. [2012, GMDD]: Evaluation of the carbon cycle components in the Norwegian Earth System Model (NorESM)

# CAM-Oslo: its aerosols and secondary aerosol formation

# Aerosols in CAM-Oslo

## 13 log-normal modes with fixed dry radius

| | | radius [$\mu$m] | | | |
|---|---|---|---|---|---|
| 1 | $SO_4$(n) | 0.0118 | | | |
| 2 | BC(n) | 0.0118 | | | |
| 3 | BC/OC(ni) | 0.04 | | | |
| 4 | BC(ax) | 0.1 | | | |
| | | | SO4(a1) | | |
| 5 | $SO_4$(na) | 0.04 | $SO_4$ | | |
| 6 | BC(a) | 0.04 | $SO_4$ | | |
| 7 | BC/OC(ai) | 0.04 | $SO_4$ | | |
| 8 | $SO_4$(pr) | 0.075 | $SO_4$ | | |
| | | | SO4(ac) | BC(ac) | OC(ac) |
| 9 | DU | 0.22 | $SO_4$ | BC | OC |
| 10 | DU | 0.63 | $SO_4$ | BC | OC |
| 11 | SS | 0.022 | $SO_4$ | BC | OC |
| 12 | SS | 0.13 | $SO_4$ | BC | OC |
| 13 | SS | 0.74 | $SO_4$ | BC | OC |
| | $SO_4$(aq) | | | | |

## Remark

- Number concentrations is a diagnostic based on mass

# Sulfate aerosol formation

## Reactions:

| | | | | | | |
|---|---|---|---|---|---|---|
| DMS | + | $NO_3$ | → | $SO_2$ | | |
| DMS | + | OH | → | 0.5 $SO_2$ | + | 0.5 MSA (→ POM) |
| DMS | + | OH | → | $SO_2$ | | |
| $SO_2$ | + | OH | → | $H_2SO_4$ | | |
| $SO_2$ | + | $O_3$ | → | $SO_4$ | (aqueous phase) | |
| $SO_2$ | + | $H_2O_2$ | → | $SO_4$ | (aqueous phase) | |

## Oxidants in CAM-Oslo:

| | |
|---|---|
| OH | Year 2000 climatology + daily cycle (no cloudiness impact) |
| $O_3$ | Year 2000 climatology |
| $H_2O_2$ | Relaxed towards year 2000 climatology (dependance on cloud cover) |
| $NO_3$ | Effective reaction rate |

(OH, $O_3$, and $H_2O_2$ climatologies come from a CTM simulation)

## Gas phase tracers in CAM-Oslo

DMS
SO2
($H_2O_2$)

# Secondary organic aerosol formation

## Emissions of hydrocarbons

| | |
|---|---|
| $C_{10}H_{16}$ | Monoterpenes (as $\alpha$-pinine) |
| $C_6H_5(CH_3)$ | Aromatics (as toluene) |
| $C_5H_{12}$ | Alkanes ($\#$ C $>$ 3) |
| $C_5H_8$ | Isoprene |

## Reactions with oxidants

$$
\begin{array}{lcccc}
C_{10}H_{16} & + & O_3 & \rightarrow & \text{less volatile species} \\
C_{10}H_{16} & + & OH & \rightarrow & \ldots \\
C_{10}H_{16} & + & NO_3 & \rightarrow & \ldots \\
C_6H_5(CH_3) & + & OH & \rightarrow & \ldots \\
C_5H_{12} & + & OH & \rightarrow & \ldots \\
C_5H_8 & + & OH & \rightarrow & \ldots
\end{array}
$$

## Secondary organic aerosol formation in CAM-Oslo

- SOA emitted as POA (climatology, coming from a CTM simulation)
- Emissions are limited to the surface, and assumed to be redistributed by turbulence and convection

# Coupling with Mozart

# MOZART-4

## Chemistry

- tropospheric chemistry
- 80 gas phase species
- 16 aerosol tracers

## Aerosol modes

| | | | |
|---|---|---|---|
| SO4 | | | |
| BC1 | BC2 | | |
| OC1 | OC2 | SOA | |
| DU1 | DU2 | DU3 | DU4 |
| SS1 | SS2 | SS3 | SS4 |
| NH4 | (NH4)NO3 | | |

## Remarks

- Aging of hydrophobic OC1 and BC1 to hydrophylic BC2 and OC2

# Modifications

Keep CAM-Oslo aerosol

Secondary aerosol formation

- Use the Mozart $H_2SO_4$ and $SO_4$ formation rates
- Use the Mozart SOA formation rate

$NH_4$ and $(NH4)NO_3$ in Mozart: remain

Heterogeneous chemistry in Mozart: use CAM-Oslo aerosols

# Results

# Simulations

## Model

- $2.5 \times 1.9$, 26 levels
- Prescribed observed sea-surface temperature and sea-ice extend
- Period: 2006-2009
- Biomass burning: GFED.v3.1 emissions
- Anthropogenic: RCP6.0 emission scenario

## Simplified setup – offline

- Cloud condensation nuclei concentration: prescribed
- Aerosol fields, $O_3$: monthly mean climatologies

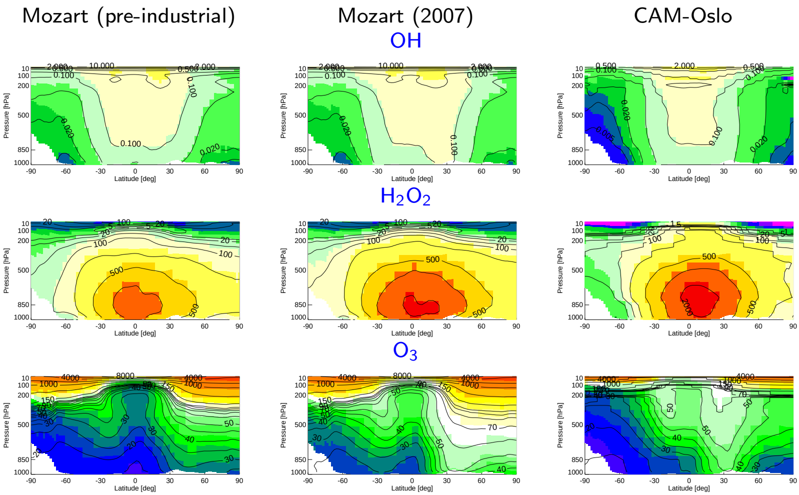
## Three setups

- Standard Mozart
- Standard CAM-Oslo
- CAM-Oslo/Mozart : coupled

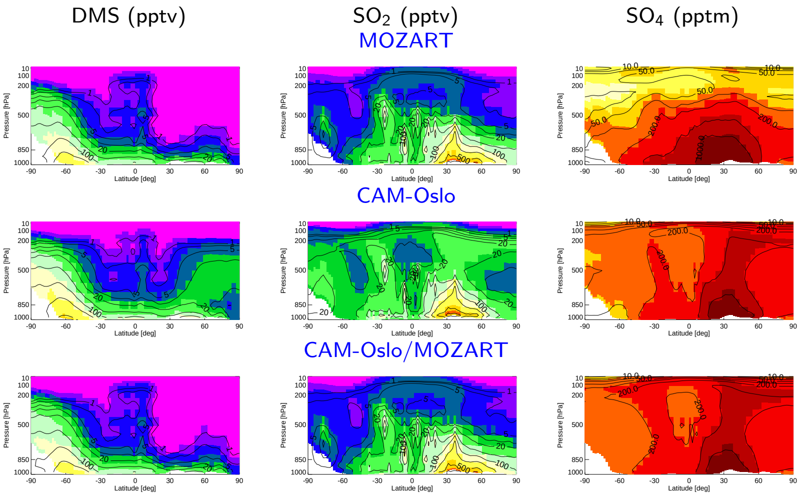
## Allows direct and indirect aerosol effect calculation

- Emissions: 2006-2009
- Emissions: no anthropogenic emissions

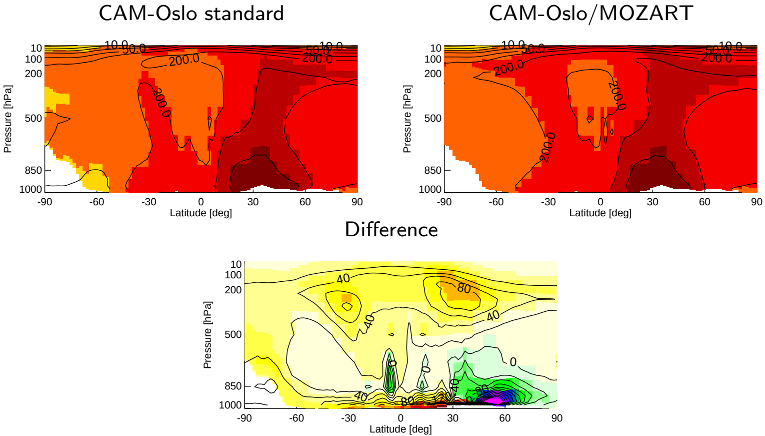
# Oxidant fields in sulphur cycle
## Annual mean



# Sulphur cycle
## Annual mean



# $SO_4$ (pptm)
## Annual mean



# Sulphur cycle: fluxes and burdens
## Annual mean

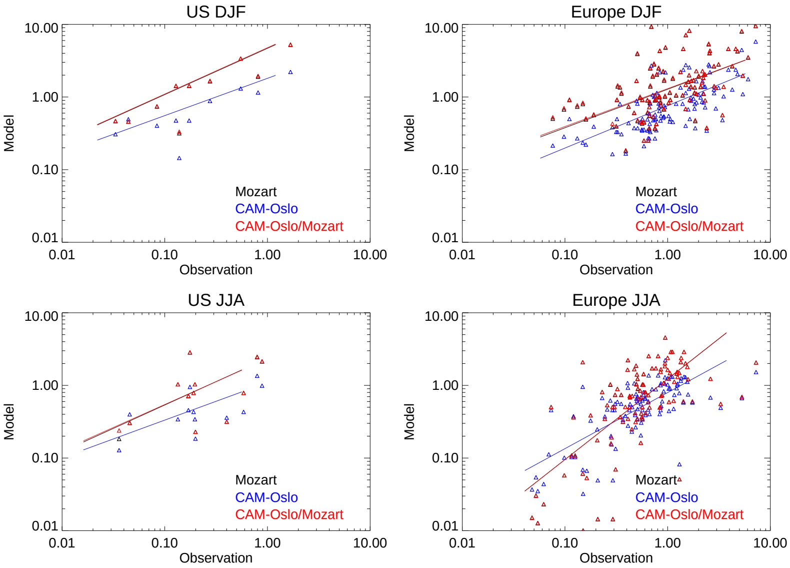
### Conversion rates (Tg[S]/yr) :

| | DMS → MSA | DMS → $SO_2$ | $SO_2$ → $H_2SO_4$ | $SO_2$ → $SO_4$ |
|---|---|---|---|---|
| Mozart | 3.64 | – | 8.93 | 42.98 |
| CAM-Oslo | 4.87 | 13.23 | 8.14 | 45.76 |
| CAM-Oslo/Mozart | 3.64 | – | 8.59 | 42.40 |

### Burden (Tg) :

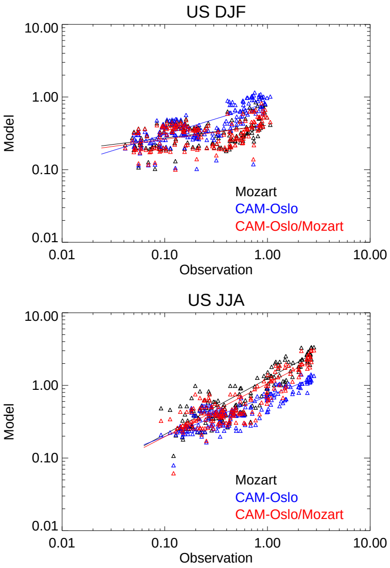
| | DMS | $SO_2$ | $SO_4$ | POM |
|---|---|---|---|---|
| Mozart | 0.16 | 0.43 | 1.83 | |
| CAM-Oslo | 0.25 | 0.52 | 1.80 | 2.38 |
| CAM-Oslo cpl. with Mozart | 0.16 | 0.44 | 1.93 | 2.05 |

# Comparison with observations
## $SO_2$

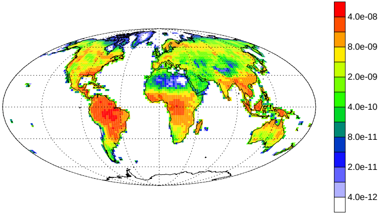


# Comparison with observations

## $SO_4$

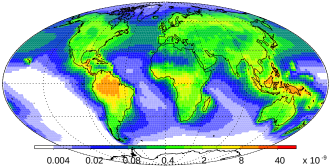


## Standard emission CAM-Oslo: 37.1 $\mathrm{Tg\,yr^{-1}}$



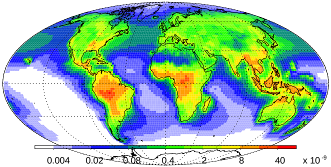

## SOA formation rate in Mozart

Standard



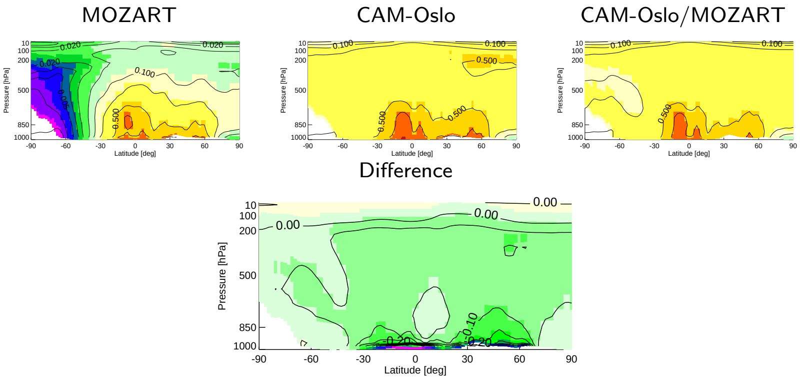

10.4 $\mathrm{Tg\,yr^{-1}}$

Including isoprene




19.4 $\mathrm{Tg\,yr^{-1}}$

# POM (ppbm)
## Annual mean



# Heterogeneous chemistry

## Surface area density

- Use CAM-Oslo aerosols

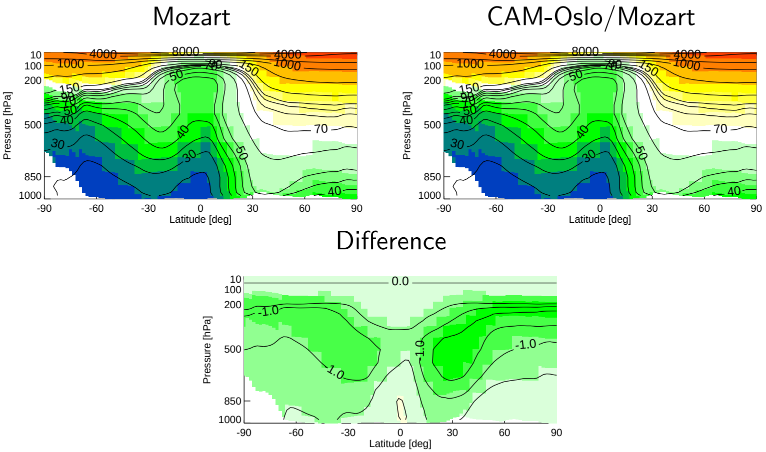
## Uptake coefficient $\gamma$

| Reaction | Aerosol | $\gamma$ |
|---|---|---|
| $N_2O_5 \rightarrow 2\,HNO_3$ | $SO_4$ | $f(RH, T)$ |
| | BC | 0.005 |
| | OC | $f(RH)$ |
| | mineral dust | $f(RH)$ |
| | sea salt | $f(RH)$ |
| $NO_3 \rightarrow HNO_3$ | wet aerosols | 0.001 |
| $NO_2 \rightarrow 0.5\,HNO_3 + 0.5\,HNO_2$ | wet aerosols | 0.0001 |
| $HO_2 \rightarrow 0.5\,H_2O_2$ | wet aerosols | 0.2 |

## Further specifications

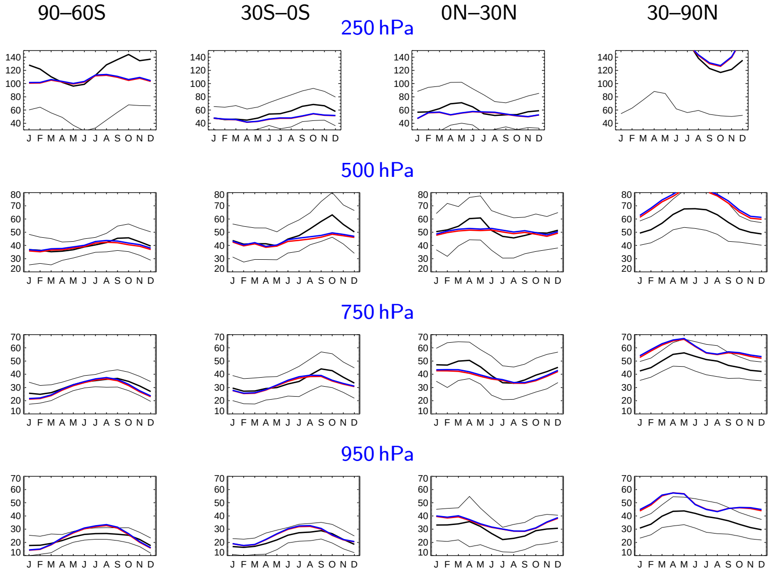
- Wet aerosols: if $RH > 50\,\%$
- Hygroscopic growth is taken into account
- Internally mixed aerosols: which fraction of surface is covered by which aerosol type

# $O_3$ distribution [ppbv]



# Ozone - impact on chemistry

## Comparison with $O_3$ climatology 1985–2011 [McPeters et al., 2007]



# Aerosol effect

## Comparison of two simulation

- No anthropogenic emissions
- 2006–2009 emissions

## Direct and indirect effect [W $m^{-2}$]

| | Direct effect | Indirect effect |
|---|---|---|
| CAM-Oslo | -0.043 | -0.901 |
| CAM-Oslo/Mozart | -0.058 | -0.921 |

# Conclusions

- $SO_2$ differs strongly between CAM-Oslo and CAM-Oslo/Mozart at surface and in upper troposphere
- $SO_4$ shows more agreement between CAM-Oslo and CAM-Oslo/Mozart
- Mozart SOA production differs strongly from climatology used in CAM-Oslo
- Direct and indirect aerosol effect is slightly stronger in CAM-Oslo/Mozart than in CAM-Oslo
- Possible large impact from description of emissions (surface/altitude) and (dry) deposition parameterizations
- It would be useful to compare with POM observations