The Atmospheric model CAM4-Oslo of the Norwegian Earth System Model (NorESM)

The main block of code in NorESM is the CCSM4 from NCAR, which includes the coupler CPL7 (J. Hurrel et al., pers. comm., see http://www.ccsm.ucar.edu/models/ccsm4.0/cam/).

The atmospheric component in NorESM (CAM4-Oslo) is modified from the CAM4 of CCSM4 for use in NorESM by updating the aerosol and aerosol-cloud interaction schemes originally developed for CAM-Oslo based on CAM3, and the most recent published version is described and discussed in Seland et al. (2008), Kirkevåg et al. (2008), Storelvmo et al. (2008), Hoose et al. (2009), and Struthers et al. (2011). The further updated CAM4-Oslo (Kirkevåg et al., 2011, in preparation), includes more realistic parameterizations, and a number of adjustments of uncertain parameters for realistic gross climate properties in long control simulations with NorESM. Relative to the published CAM-Oslo, the changes include:

- New fields of tropospheric oxidants (OH, O_3, H_2O_2) from Oslo-CTM2 (Berntsen and Isaksen, 1997), and a replenishment time which increases with the cloud volume fraction.
- The OM/OC (OM: organic matter; OC: organic carbon) ratio for biomass burning POM (primary organic matter) emissions has been increased to 2.6 (Formenti et al., 2003).
- A range of upgrades in the treatment of natural background aerosols:
  - The prescribed AeroCom sea salt emissions are replaced by prognostic (wind and temperature dependent) sea-salt emissions (Struthers et al., 2011).
  - MSA is included.
  - Oceanic emissions of POM - a “bio-aerosol” - are added (Spracklen et al., 2008).
  - Natural SOA production from vegetation is increased to 37.5 Tg/yr (Hoyle et al., 2007).
  - The in-cloud mineral scavenging coefficient has been reduced to 0.25.
- Gravitational particle settling is now calculated at all heights.
- Deposition of BC and mineral dust is coupled to the land and sea-ice models for calculation of surface albedo changes.
- The effective cloud droplet radius for light scattering is updated (Rotstayn and Liu, 2009).
- The relative humidity threshold for formation of low clouds is reduced to 90 %, and the critical droplet volume radius for onset of auto-conversion is increased to 14 µm.

The ocean component in NorESM is a developed version of MICOM based on the ocean model in the Bergen Climate Model (Furevik et al., 2003), thus replacing the POP2 used with CCSM4. This ocean model includes an interactive module for carbon (HAMOCC_v5; The Hamburg Ocean Carbon Cycle Model, developed by Ernst Maier-Reimer and Christoph Heinze at the Max-Planck-Institut fűr Meteorologie in Germany).

The land model in NorESM is the original CLM4 of CCSM4, including its own carbon cycle model as well as the SNow, ICe, and Aerosol Radiative (SNICAR) model (Flanner et al, 2007; 2009) which enable calculations of effects on radiation from snow darkening caused by deposited absorbing aerosols.

Also, effects of deposition of light-absorbing aerosols on the albedo of snow-covered and bare sea-ice are taken into account in **the sea-ice model** CICE4 (Holland et al., 2011).

For the AeroCom intercomparison study (*http://dataipsl.ipsl.jussieu.fr/AEROCOM/*), the CAM4-Oslo of NorESM has been set up to run with the “data ocean and sea-ice” models from CCSM4, and the snow albedo effect of deposited BC and mineral dust in the land model has been turned off. Runs of 7-year *off-line* simulations are made, using the latter 5 year of the data in the analysis.

While the “pre-industrial” and “present day” emissions used in CAM-Oslo (aka UIO_GCM_V2) were for the emission years 1750 and 2000 in the AeroCom Phase I emission data base (Dentener et al. 2006), the new emission years are 1850 (“pre-industrial”, PRE) and 2006 (“present-day”, CTRL) for use in CAM4-Oslo (aka CAM4-Oslo_Vcmip5) in AeroCom Phase II.

AeroCom simulations for year 1850 are done with SO2, POM and BC fossil-fuel, bio-fuel and biomass burning emissions and explicit BC emissions from aviation from the IPCC AR5 data sets (Smith et al., 2009, in preparation; update from Bond et al., 2007; Van der Werf et al., 2007; Schultz et al., 2008; Mieville et al., 2009; Buhaug et al., 2009; Eyring et al., 2009; Lee et al., 2009, in preparation). In the AeroCom 2006 simulations these emissions are replaced by the AeroCom Phase II emissions dataset valid for the year 2006. This dataset also include emissions estimates for SO2 and POM from aviation. 2.5% of the SO2 emissions are assumed to be directly emitted as sulphate particles, as in Seland et al. (2008).

Additionally, the model in all simulations use emissions from Aerocom B, Phase I, for DMS, SO2 from tropospheric volcanoes, and for mineral dust. Aerocom B also provide emissions of SOA from biogenic sources (treated as POM), but these are here scaled to the total value found in Hoyle et al. (2007). The new IPCC emissions for biomass burning aerosols are given as 2D fields, but we have assumed that these emissions have the same vertical profiles as the AeroCom emissions used in CAM-Oslo (Seland et al., 2008). We have also added a primary OM source from oceans, based on Spracklen et al. (2008). The sea-salt emissions are calculated explicitly in the model, using a modified version of the parameterization in Struthers et al. (2011).

Both CTRL and PRE simulations use GHG concentrations from year 2006, and both the anthropogenic aerosol direct (DRF) and the indirect radiative forcing (IndRF) since 1850 may be found from the difference CTRL – PRE. Results from these and other AeroCom simulations as well as a range of sensitivity experiments are presented and discussed in detail in Kirkevåg et al. (2011, in preparation).

References

Berntsen, T., and I. S. A. Isaksen, 1997: A global 3-D chemical transport model for the troposphere, 1, Model description and CO and Ozone results, J. Geophys. Res., 102(D17), 21239-21280, doi:10.1029/97JD01140.

Bond, T. C., E. Bhardwaj, R. Dong, R. Jogani, S. Jung, C. Roden, D. G. Streets, S. Fernandes, and N. Trautmann, 2007: Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850-2000. Glob. Biogeochem. Cyc., 21, GB2018, doi:10.1029/2006GB002840.

Buhaug, Ø., J. J. Corbett, Ø. Endresen, V. Eyring, J. Faber, S. Hanayama, D. S. Lee, D. Lee, H. Lindstad, A.Z. Markowska, A. Mjelde, D. Nelissen, J. Nilsen, C. Pålsson, J. J. Winebrake, W.¬Q. Wu, and K. Yoshida, Second IMO GHG study 2009; International Maritime Organization (IMO) London, UK, March, 2009.

Eyring, V., I. S. A. Isaksen, T. Berntsen, W. J. Collins, J. J. Corbett, O. Endresen, R. G. Grainger, J. Moldanova, H. Schlager, and D. S. Stevenson, 2009; Transport impacts on atmosphere and climate: Shipping, Atm. Env., doi:10.1016/j.atmosenv.2009.04.059.

Flanner, M. G., Zender, C. S., Hess, P. G., T., R. J., and Rasch, P. J.: Present-day climate forcing and response from black carbon in snow, J. Geophys. Res., 112, doi:10.1029/2006JD008003, 2007.

Flanner, M. G., Zender, C. S., Hess, P. G., Mahowald, N. M., Painter, T. H., Ramanathan, V., and Rasch, P. J.: Springtime warming and reduced snow cover from carbonaceous particles, Atmos. Chem. Physics, 9, 2481–2497, 2009.

Formenti, P., Elbert, W., Maenhaut, J., Haywood, S., Osborne, S., and Andreae, M. O.: Inorganic and carbonaceous aerosols during the Southern African Regional Science Initiative (SAFARI 2000) experiment: Chemical characteristics, physical properties, and emission data for smoke from African biomass burning, J. Geophys. Res., 108, 1–16, 2003.

Furevik, T., Bentsen, M., Drange, H., Kindem, I.K.T., Kvamstø, N.G., and Sorteberg, A., 2003: Description and evaluation of the bergen climate model: ARPEGE coupled with MICOM. *Climate Dynamics*, **21**, 27–51. DOI 10.1007/s00382-003-0317-5

Holland, M., Bailey, D. A., Briegleb, B., Light, B., and Hunke, E. 2011: Improved sea ice shortwave radiation physics in CCSM4: The impact of melt ponds and aerosols on Arctic sea ice. *Journal of Climate, CCSM4 Special Issue (accepted for publication).* doi: 10.1175/JCLI-D-11-00078.1.

Hoose, C., J. E. Kristjansson, T. Iversen, A. Kirkevåg, Ø. Seland, and A. Gettelman, 2009: Constraining cloud droplet number concentration in GCMs suppresses the aerosol indirect effect.*Geophys. Res. Lett.*, **36**, L12807, doi:10.1029/2009GL038568.

Hoyle, C. R., Berntsen, T., Myhre, G., and Isaksen, I. S. A.: Secondary organic aerosol in the global aerosol - chemical transport model Oslo CTM2, Atmos. Chem. Physics, 7, 5675–5694, 2007.

Iversen, T., A. Kirkevåg, Ø. Seland, J. Debernard, J.E. Kristjansson, C. Hoose, 2010: Assessing Impacts of Aerosol Processes on Equilibrium Climate Sensitivity. Air Pollution Modeling and Its Application XX. (Steyn and Rao, Eds), 493-497. Springer, ISBN: 978-90-481-3811-1.

Kirkevåg, A., T. Iversen, Ø. Seland, J.B Debernard,, T. Storelvmo, and J.E. Kristjánsson, 2008: Aerosol-cloud-climate interactions in the climate model CAM-Oslo. *Tellus*, **60A**, 492-512.

Kirkevåg, A., Iversen, T., Seland, Ø., Struthers, H., Hoose, C., and Nilsson, D.: Aerosols and their radiative effects on climate in CAM4-Oslo/NorESM. The importance of natural aerosols for estimates of anthropogenic impacts, In preparation, 2011.

Lee et al. (2009) in preparation (QUANTIFY Scenarios) Developed from the approach of Lee, D.S., et al., 2009: Aviation and global climate change in the 21st century, Atmospheric Environment, doi:10.1016/j.atmosenv.2009.04.024.

Mieville, A., C. Granier, C. Liousse, B. Guillaume, F. Mouillot, J. F. Lamarque, J. M. Grégoire, G. Pétron, 2009: Emissions of gases and particles from biomass burning during the 20th century using satellite data and an historical reconstruction, Atmospheric Environment, submitted.

Rotstayn, L. and Liu, Y.: Cloud droplet spectral dispersion and the indirect effect: Comparison of two treatments in a GCM., Geophys. Res. Lett., 36, L10 801, 2009.

Schultz, M. G., A. Heil, J. J. Hoelzemann, A. Spessa, K. Thonicke, J. Goldammer, A. C. Held, J. M. Pereira, M. van het Bolscher, 2008: Global Wildland Fire Emissions from 1960 to 2000. Global Biogeochem. Cyc., doi:10.1029/2007GB003031.

Seland, Ø., T. Iversen, A. Kirkevåg, and T. Storelvmo, 2008: Aerosol-climate interactions in the CAM-Oslo atmospheric GCM and investigations of associated shortcomings. *Tellus*, **60A**, 459-491.

Smith et al. (2009) in preparation (??); updated from Smith, Steven J., Pitcher, H., and Wigley, T. M. L., 2001: Global and Regional Anthropogenic Sulfur Dioxide Emissions. Global and Planetary Change 29/1-2, pp 99-119.

Spracklen, D. V., Arnold, S. R., Sciare, J., Carslaw, K. S., and Pio, C.: Globally significant oceanic source of organic carbon aerosol, Geophys. Res. Lett., 35, doi:10.1029/2008GL033359, 2008.

Storelvmo, T., J. E. Kristjansson, U. Lohmann, T. Iversen, A. Kirkevåg, Ø.Seland, 2008: Modeling the Wegener-Bergeron-Findeisen process – implications for aerosol indirect effects. *Environ. Res. Lett.* 3. 045001. DOI:10.1088/1748-9326/3/4/045001.

Struthers, H., A. M. L. Ekman, P. Glantz, T. Iversen, A. Kirkevåg, E. M. Mårtensson, Ø. Seland, and E. D. Nilsson, 2011: The effect of sea ice loss on sea salt aerosol concentrations and the radiative balance of the Arctic. *Atmos. Chem. Phys., 11, 3459-3477.*

Van der Werf, G., J. T. Randerson, L. Giglio, G. J. Collatz, P. S. Kasibhatla, and A. F. Arellano Jr., 2006: Interannual variability in global biomass burning emissions from 1997 to 2004. Atmos. Chem. Phys., 6, 3423-3441.