**CCSM Chemistry-Climate Working Group Meeting Report**
**Thursday, 22 June 2006**
**The Village at Breckenridge, Breckenridge, Colorado**

The Chemistry-Climate Working Group (ChemWG) met from 8:30 AM -12 PM on 22 June 2006 at the CCSM workshop. The meeting consisted of 6 talks and a general discussion and review of the state of the chemistry modeling within CCSM. This review is summarized below.

The focus of the ChemWG is on the coupling between the climate system (including the biosphere), aerosols, atmospheric composition, and chemistry. Atmospheric composition and photochemistry have been profoundly changed by anthropogenic activities through the emissions of aerosols and chemically active gases. This has impacted the radiative balance of Earth's atmosphere, cloud processes, and land surface, changed the atmospheric circulation, and modified the hydrological cycle. In addition, atmospheric chemical species and aerosols impact the carbon dioxide cycle through the oxidation of hydrocarbons by modifying the availability of light and water to various ecosystems, and by damaging plant tissue.

The ChemWG identified two main goals at its first meeting held 22-26 March 2006. The first goal is the development of a state-of-the art chemistry model within CCSM. This goal has largely been accomplished through the incorporation of the latest version of the offline chemical transport model, Model for Ozone and Related Trace Species (MOZART), developed in ACD (in collaboration with GFDL and the Max-Planck Institute for Meteorology) into CCSM. This version of CCSM, with highly evolved chemistry, will be used as a benchmark for other versions of CCSM where the chemistry is simplified to evaluate model simulations against current measurements and to quantify the impact of changes in climate on chemistry and air quality. Improvements to most aspects of this model are in the planning stages.

The second goal of the ChemWG is to develop a version of CCSM with chemistry for use in climate studies and in IPCC simulations. This version will be designed to represent the climatic impacts of chemistry and aerosols in a cost effective manner. To accomplish the second goal, the working group has defined the chemistry and aerosol processes that should be considered for inclusion in CCSM. For each process (see below) we have also defined a number of implementation options. By late 2008 the ChemWG will give the SSC the simulation costs for each option, the importance and impact of each option, and a recommendation as to the best option. The recommendation will be justified in terms of climate impact, science, computational cost, and needs of the community. Both versions of CCSM with chemistry can be run using offline winds (e.g., from the National Center for Environmental Prediction, NCEP) to facilitate comparison with episodic measurements.

The ChemWG has defined five processes to consider for including chemistry within a climate version of CCSM: the representation of aerosols, the link between aerosols and microphysics including a formulation of the indirect effect, the representation of the chemistry and chemical mechanisms, the interactions between chemistry and the biosphere, and the representation of the stratosphere. For each of these processes we define a fall-back position, which we feel gives an adequate representation of the process and can be implemented with a minimum of development.

- *Aerosols*. The working group has identified a number of candidate aerosol schemes for the next generation model. All of these schemes will represent the "semi-direct," whereby aerosols act to stabilize the atmosphere and inhibit cloud formation. In addition, all these schemes can be used to represent to the indirect effect, although the "fall-back position" requires rather severe approximations on the size distribution and the mixing state of the aerosols. Interaction between aerosol properties and the new radiation components of CAM is required, but is being postponed until the schemes are better formulated.
  - The fall-back position is the prognostic aerosols scheme currently implemented in CAM (by P. Rasch and N. Mahowald) with minor modifications. The aerosol number distribution is diagnosed from the aerosol mass, and only external aerosol mixtures are allowed. Ammonium nitrate and secondary organic aerosols are not currently represented. This scheme requires 15 transported aerosol species.
  - S. Ghan is currently implementing a 7 mode aerosol scheme into CAM. In this scheme each mode is composed of an internal mixture of multiple aerosol components, with the mass of each component and the total number of each mode predicted. This scheme requires between 25 and 33 advected aerosol species. Both nucleation and impact aerosol scavenging would be accounted for in this implementation.
  - S. Ghan will also abbreviate the above scheme to 4 modes for inclusion into CAM.
  - Plans include the implementation of a complex sectional aerosol scheme (e.g., the Community Aerosol Research Model, CARMA) to be used for testing purposes.
- *Linking aerosols and cloud microphysics.* See white paper at: http://www.cgd.ucar.edu/ csm/working_groups/Chemistry: "Aerosol effects on clouds, energy, and the hydrologic cycle." Aerosols form the nuclei for cloud droplets and ice crystals subsequently affecting cloud albedo and precipitation. While ad-hoc parameterizations of this interaction can be introduced using the "fall-back" aerosol and cloud physics parameterizations, a more physically based parameterization requires: 1) a treatment of aerosol activation, which accounts for the competition between aerosols of different compositions and sizes in cloud updrafts; and 2) a treatment of mass and number concentration of cloud particles, with a proper treatment of microphysical sources and sinks. A CAM microphysics development group (chaired by Gettleman, Ghan, Hess, and Mitchell) has been organized to develop a new microphysics scheme in CAM (see http://www.cgd.ucar.edu/csm/meetings/microphys/index.html). Again the interaction with CAM radiation schemes is postponed until the formulation becomes more definitive.

  - The fall-back position is marginal improvements with the existing CAM microphysics framework including the incorporation of a parameterization for representing the indirect effect.
  - Presently a two moments (mass and size distribution), 4 class scheme (droplets, cloud ice, rain, and snow) is being implemented into CAM. A decision on further development of this scheme will be made in fall 2006.
- *Chemical species and reactions*. Three types of chemistry representations have been proposed.
  - The fall-back position is to use chemistry input from offline tapes for the oxidation of aerosol-precursor species for the calculation of radiative fields and for input to the CLM. This is similar to the scheme currently used in CAM based on Rasch et al., 2001.
  - A more complete chemical mechanism from MOZART has been implemented into CAM-chem involving on the order of 100 species.
  - Abbreviated chemical mechanisms have been proposed by J.F. Lamarque and P. Cameron-Smith and are currently being tested. These mechanisms reduce the chemistry by approximately 50%. The selection will be based on an analysis of the performance of the simplified schemes against the full mechanism (for a variety of emission regimes, such as pre-industrial, present-day, and future) and against observations.
- *Interactions between chemistry and the biosphere.* See white papers at http://www.cgd.ucar.edu/csm/working_groups/Chemistry: "Atmospheric chemistry impacts and feedbacks on the global carbon cycle" and "Atmospheric chemistry impacts on the land biosphere." The goal of the working group is to implement interactions between chemistry and the biosphere, so as to include an accurate representation of biogenic emissions on the chemistry and the impact on the uptake of $CO_2$ by the terrestrial biosphere due to atmospheric ozone, nitrogen, and acid rain.
  - The ability of the CLM to incorporate and respond to nitrogen fluxes from the atmosphere has been developed in the Biogeochemistry and Land Model Working Groups. The fall-back position is to incorporate the nitrogen fluxes from offline tapes or online chemistry calculations.
  - The response of the biosphere to ozone has not yet been incorporated into the CLM and is not well understood by the wider community. Sensitivity tests will be conducted as to its importance. The sensitivity of the response to light will also be tested.
  - Fluxes of biogenic species and NOx from the biosphere are important to the simulation of atmospheric chemistry. Parameterizations of these fluxes are currently being implemented into the CLM.
- *Inclusion of a stratosphere*. Reasons for including a stratosphere in climate simulations are the inclusion of solar forcing and volcanoes in historical simulations; inclusion of ozone forcing; inclusion of fingerprints of climate change in a coupled model; inclusion of dynamical coupling between the stratosphere and troposphere; inclusion of changes in the mean and variability of the coupled state; and sensitivity of the mean coupled state to climate change.

- The fall-back position is to simply incorporate the stratosphere as an upper boundary condition as currently implemented.
- An alternative is to include the stratosphere and necessary chemistry into the next version of CAM. The WACCM group is currently investigating the importance of the stratosphere. Its possible inclusion should be a rather simple extension of their model development.

The ChemWG is also examining three issues not directly related to the development of the release version of CCSM4: 1) historical emissions from 1860–2000, 2) the relation between climate and air quality, and 3) improvements in the state-of-the art chemistry model within CCSM. An estimate of historical emissions is necessary for control simulations of the late 19$^{th}$ and 20$^{th}$ centuries. Anthropogenic and biomass burning emissions of $CO_2$, $CH_4$, ozone precursors, $SO_2$, and black and organic carbon are currently being developed within a collaboration between the Service d'Aéronomie in Paris, France, the Laboratoire d'Aérologie in Toulouse, France, and the Chemical Sciences Division of NOAA in Boulder in conjunction with C. Granier. Future emissions are still in the planning stage and will be decided on in an international forum.

An important future health issue is the impact of climate and emission changes on air quality (see http://www.cgd.ucar.edu/csm/working_groups/Chemistry, "Hemispheric Pollution to Regional Air Quality: An Issue of Resolution"). This issue can be addressed using the state-of-the art chemistry model within CCSM and downscaling the results to the regional scale using WRF-chem (Weather Research Forecast model with chemistry).

Necessary improvements in the state-of-the-art chemistry climate model include: 1) the parameterization of convective and large-scale rainout of chemical species, 2) the representation of aerosols, 3) the specification of interactive emissions for biogenic species and $NO_x$, 4) the deposition of chemical species, and 5) an improved online photolysis scheme. These improvements are either currently being implemented into CAM with chemistry or are in the planning stages.

The following table gives the options the ChemWG is considering for input into CCSM:

| | Microphysics | Aerosols | Chemistry | Biogeochemistry | Stratosphere |
|---|---|---|---|---|---|
| Fall-back | Present Scheme with Modifications | Prescribed | None | Nitrogen input From Tape | None |
| 1$^{st}$ option | 2 moment 4 class | Simple Diagnostic | Simple | Nitrogen input From Chemistry | Included |
| 2$^{nd}$ option | | 4 modes | Full | Nitrogen and Ozone from Chemistry | |
| 3$^{rd}$ option | | 7 modes | | | |

Jean-Francois Lamarque gave a talk on plans for historical emissions that he and Claire Granier are formulating in collaboration with the Service d’ Aeronomie in Paris, France, the Laboratoire d’ Aerologie in Toulouse, France, and the Chemical Sciences Division of NOAA in Boulder, Colorado. These emissions are expected to be available for the period from 1860-2000. It was suggested in the discussion that American colleagues, such as Steve Smith and Tami Bond, are also consulted in the development of these emissions. Fabrizio Sassi gave a talk on the plans in the WACCM group for determining the effect of the stratosphere on climate and particularly on climate sensitivity. Steve Ghan discussed his scheme for incorporating the indirect effect into CAM using very simple aerosol schemes. Andrew Gettleman gave an update on progress using the proposed new microphysics scheme for CAM, which would allow a more consistent representation of the aerosol budget and the indirect effect. Philip Cameron-Smith and Jean-Francois Lamarque gave presentations of there representations of reduced chemistry mechanisms within CAM. Finally, Jon Egill Kristjansson gave a presentation of the modeling effort at the University of Oslo focussing on the indirect effect.

**Attendees:**

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| Ammann | Caspar | NCAR |
| Anderson | Donald | NASA HQ |
| Arellano, Jr. | Avelino | NCAR |
| Bacmeister | Julio | NASA GMAO / UMBC GEST |
| Barahona | Donifan | Georgia Institute of Technology |
| Bardeen | Charles | University of Colorado-Boulder |
| Bretherton | Christopher | University of Washington |
| Cameron-Smith | Philip | Lawrence Livermore National Laboratory |
| Carpenter | Ilene | SGI |
| Collins | William | NCAR |
| Deng | Yi | University of Texas-Austin |
| Dennis | John | NCAR |
| Elliott | Scott | Los Alamos National Laboratory |
| Emmons | Louisa | NCAR |
| English | Jason | University of Colorado-Boulder |
| Erickson | David | Oak Ridge National Laboratory |
| Fein | Jay | National Science Foundation |
| Fung | Inez | UC Berkeley |
| Garcia | Rolando | NCAR |
| Gettelman | Andrew | NCAR |
| Ghan | Steven | Pacific Northwest National Laboratory |
| Guan | Bin | University of Maryland-College Park |
| Hakkarinen | Charles | |
| Heald | Colette | University of California-Berkeley |
| Hess | Peter | NCAR |
| Hoffman | Forrest | Oak Ridge National Laboratory |
| Holland | Elisabeth | NCAR |
| Huang | Yan | Georgia Institute of Technology |

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|---|---|---|
| Jacob | Daniel | Harvard University |
| Kelly | Rory | NCAR |
| Kristjansson | Jon Egill | University of Oslo |
| Lamarque | Jean-Francois | NCAR |
| Liu | Xiaohong | Pacific Northwest National Laboratory |
| Moore | Jefferson | University of California-Irvine |
| Nair | Ramachandran | NCAR |
| Patadia | Falguni | University of Alabama-Huntsville |
| Pierazzo | Elisabetta | Planetary Science Institute |
| Raeder | Kevin | NCAR |
| Rasch | Philip | NCAR |
| Sassi | Fabrizio | NCAR |
| Schimel | David | NCAR |
| Shields | Christine | NCAR |
| Thornton | Peter | NCAR |
| Tribbia | Joseph | NCAR |
| Vitt | Francis | NCAR |
| Wang | Minghuai | University of Michigan |
| Zhang | Yongxin | Los Alamos National Laboratory |