C2SM

Center for Climate Systems Modeling

Annual Report 2008 – 2009

C2SM Center for Climate Systems Modeling

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

C2SM Partners

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement des Innern EDI
Bundesamt für Meteorologie und Klimatologie
MeteoSchweiz

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Volkswirtschafts-
departement EVD
Forschungsanstalt
Agroscope Reckenholz-Tänikon ART

EMPA
Materials Science & Technology

C2SM
Center for Climate
Systems Modeling

Imprint

Publisher Center for Climate Systems Modeling (C2SM)
Editor Dr. Isabelle Bey
Layout null-oder-eins.ch
Print dokulink.ch
Circulation 50 Copies

Contact

Dr. Isabelle Bey (isabelle.bey@env.ethz.ch) – Executive director
Center for Climate Systems Modeling (C2SM)
ETH Zurich
Universitätstrasse 16
8092 Zürich, Switzerland
Tel: +41 44 632 79 15
www.c2sm.ethz.ch

Outline

Preamble

The Center for Climate Systems Modeling is a research center based at ETH Zurich. It is a joint initiative between ETH Zurich, MeteoSwiss, and Empa, with the main objective to improve the understanding of the Earth's climate system, and our capability to predict weather and climate. C2SM was founded in November 2008 and has been operational since March 2009. This document is the first annual report of C2SM and covers the period 2008–2009. It presents the working structure of the Center and describes the main achievements over this period as well as ongoing and planned activities.

About C2SM

Vision & objective

The Center for Climate Systems Modeling (C2SM) has been established to address the scientifically challenging and socially relevant issue of climate change. While there is a more widespread acceptance that anthropogenic activities are significantly influencing the Earth's climate, many uncertainties remain in our understanding of the complex processes involved in the climate system, including its atmospheric, oceanic, terrestrial, biospheric and cryospheric sub-components. The overarching goal of C2SM is to foster and coordinate the development and application of climate models operating at various scales to improve our capability to understand and predict the Earth's climate, including its weather systems, chemical composition and hydrological cycle. Established in fall 2008, C2SM is currently funded for a three-year period by the ETH-Foundation, ETH Zurich, MeteoSwiss, Empa, and Agroscope Reckenholz-Tänikon (ART). The core funding comes from a peer-reviewed CHIRP1 proposal (Collaborative, Highly Interdisciplinary Research Project) funded by ETH Zürich.

Research theme

Numerical models have become central elements of both research and service activities related to climate. They are now used for many applications including short-term weather forecast, seasonal climate prediction, climate projections (decades to centuries), process studies, and the testing of strategies to reduce and adapt to climate change. While climate models made rapid progress in the last decades, they still suffer from considerable limitations, for instance regarding the role of aerosols or the representation of the hydrological cycle.

A fundamental challenge faced by the modeling community is that climate and weather result from a large

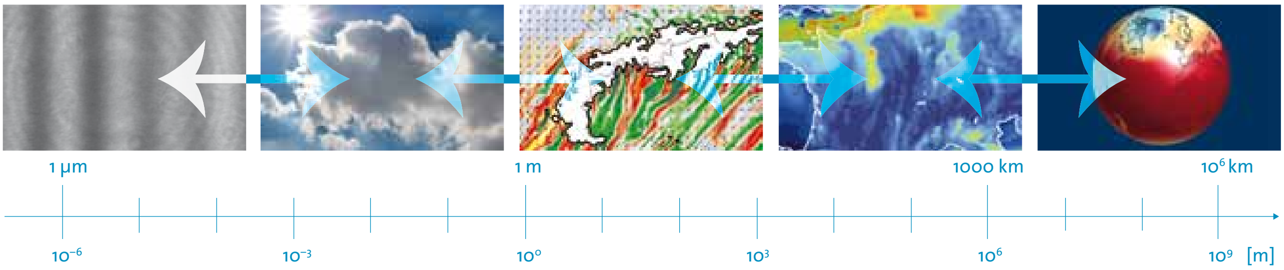

Figure 1. Range of scales investigated in the framework of C2SM, from a few micrometers (e.g. droplets) to the global scale (thousands of kilometers).

number of dynamical, physical, chemical, and biological processes that operate over a wide range of spatial and temporal scales and are interlinked in a complex manner. A particularly vexing problem is that the processes operating at the small scale strongly influence the phenomena at global scale and vice versa. C2SM's core research theme, i.e. "multi-scale interactions within the climate system" is geared towards explicitly addressing this problem (see Figure 1).

The main objectives of the Center are to develop and maintain the tools and methods necessary to bridge the gap between different spatio-temporal scales and between the different (atmospheric, hydrological, oceanographic and terrestrial) components of the climate system. In turn, this will increase our understanding and sharpen our predictive capability of climate variations and change on time scales from days to millennia.

Structure & organization of C2SM

The Center is a joint venture initiated by ETH, MeteoSwiss, and Empa. The Center currently includes 24 members, which are professors or senior scientists at ETH, MeteoSwiss, Empa, and ART. As such, the center encompasses the technical and scientific expertise of more than 200 persons.

Figure 2 summarizes the working structure of the Center and highlights the main responsibilities of the different C2SM bodies. The steering committee (SC) is elected by the members; it defines the strategy and oversees the operations. The Center is run by its executive director. The structure and organization of C2SM is described in greater detail in the Terms of Reference that can be downloaded from the C2SM website (www.c2sm.ethz.ch/about/docs).

In the following we provide further information on the composition of the different C2SM bodies.

C2SM members:

- Prof. Heinz Blatter, Institute for Atmospheric and Climate Science, ETH Zurich
- Prof. Stefan Brönnimann, Institute for Atmospheric and Climate Science, ETH Zurich
- Dr. Dominik Brunner, Laboratory for Air Pollution & Environmental Technology, Empa
- Prof. Nina Buchmann, Institute of Plant Science, ETH Zurich
- Prof. Harald Bugmann, Institute of Terrestrial Ecosystems, ETH Zurich
- Dr. Mischa Croci-Maspoli, Climate Services, Federal Office of Meteorology and Climatology MeteoSwiss

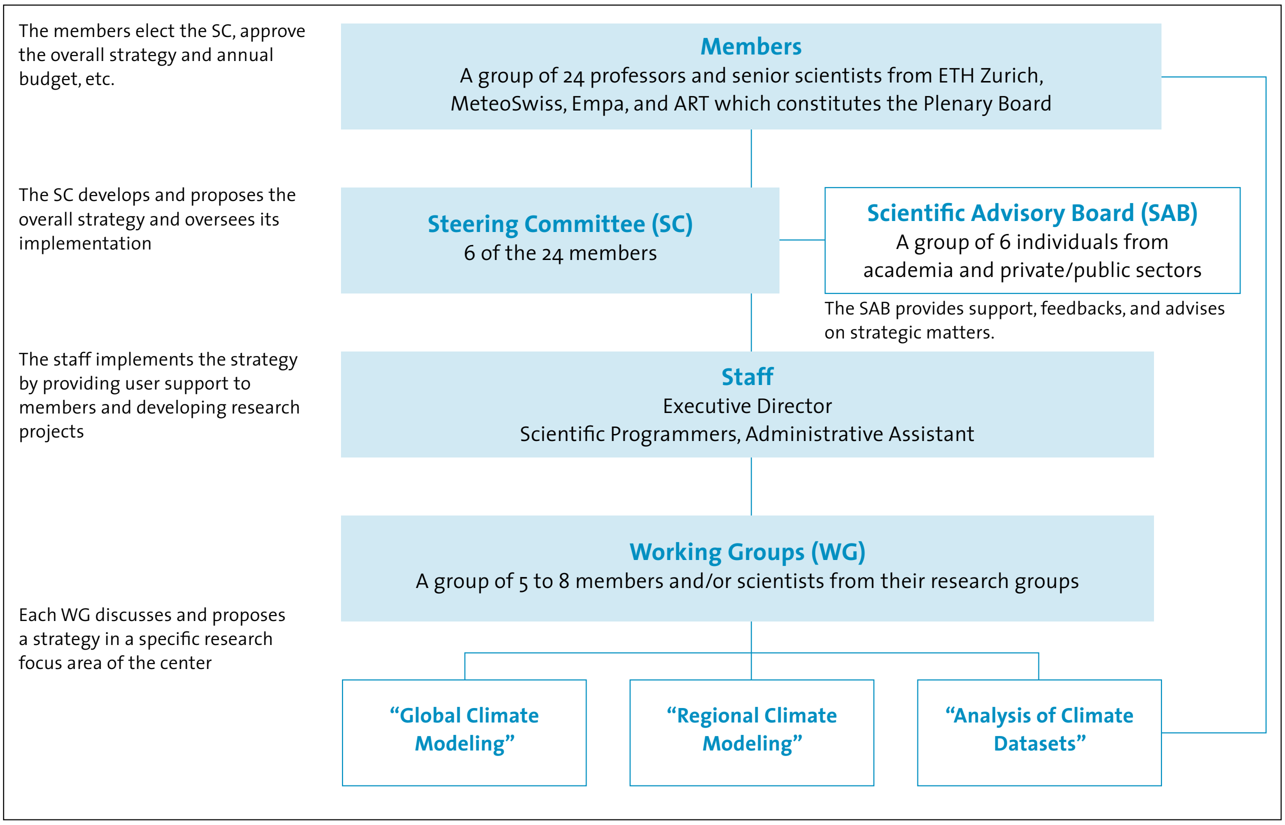

Figure 2. Working organization of C2SM.

- Prof. Andreas Fischlin, Institute of Integrative Biology, ETH Zurich
- Prof. Jürg Fuhrer, Agroscope Reckenholz-Tänikon Research Station
- Prof. Martin Funk, Laboratory of Hydraulics, Hydrology and Glaciology, ETH Zurich
- Prof. Reto Knutti, Institute for Atmospheric and Climate Science, ETH Zurich
- Dr. Mark Liniger, Climate Services, Federal Office of Meteorology and Climatology MeteoSwiss
- Prof. Thomas Peter, Institute for Atmospheric and Climate Science, ETH Zurich
- Dr. Mathias Rotach, Bio- and Environmental Meteorology , Federal Office of Meteorology and Climatology MeteoSwiss
- Prof. Sonia Seneviratne, Institute for Atmospheric and Climate Science, ETH Zurich
- Prof. Johannes Stähelin, Institute for Atmospheric and Climate Science, ETH Zurich
- Dr. Philippe Steiner, Modeling group, Federal Office of Meteorology and Climatology MeteoSwiss
- Prof. Helmi Weissert, Geological Institute, ETH Zurich
- Prof Heini Weinli, Institute for Atmospheric and Climate Science, ETH Zurich

Members of the Steering Committee:

- Prof. Christoph Schär, C2SM Chair, Institute for Atmospheric and Climate Science, ETH Zurich
- Dr. Christof Appenzeller, Climate Services, Federal Office of Meteorology and Climatology MeteoSwiss

- Dr. Brigitte Buchmann, Laboratory for Air Pollution & Environmental Technology, Empa
- Prof. Nicolas Gruber, C2SM Co-Chair, Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich
- Prof. Gerald Haug, Geological Institute, ETH Zurich
- Prof. Ulrike Lohmann, Institute for Atmospheric and Climate Science, ETH Zurich

Members of the Scientific Advisory Board

The SAB has been formed in 2009 and will have its first meeting in 2010. Its includes:

- Prof. Huw Davies (ETH, chairman)
- Dr. David Bresch (Swiss Re)
- Dr. Albert Klein Tank (KNMI)
- Prof. John Mitchell (University of Reading)
- Dr. Christoph Ritz (ProClim)
- Prof. Bjorn Stevens (MPI-Meteorology, Hamburg)

Center Staff

The Center 's staff includes an executive director, three scientific programmers, and an administrative assistant. The staff includes:

- Dr. Isabelle Bey, Executive director
- Rahel Buri, Administrative assistant (part time)
- Dr. Thierry Corti, Scientific programmer in charge of the focus area "Analysis of climate datasets" and communication officer
- Dr. Grazia Frontoso, Scientific programmer in charge of the focus area "Global climate modeling"
- Anne Roches, Scientific programmer in charge of the focus area "Regional climate modeling".

The Center's staff develops user support and research activities in three main scientific areas: Global Climate Modeling (GCM), Regional Climate Modeling (RCM), and Analysis of Climate Datasets (ACD). Three working groups, composed of 6 to 8 C2SM members or researchers from their groups meet, on a regular basis to define the strategy to be developed and the tasks to be performed in each of the three focus areas.

PhD students affiliated to C2SM

In addition, the Center provides funding for 4 PhD students who are working in different departments at ETH and Empa under the supervision of C2SM members.

- Ivy Frenger, Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich; Advisors: Nicolas Gruber and Reto Knutti
- Christoph Knote, Empa: Advisors: Dominik Brunner and Ulrike Lohmann
- Wolfgang Langhans, Institute for Atmospheric and Climate Science, ETH Zurich; Advisors: Christoph Schär and Philippe Steiner.
- Sara Nottelmann, Institute for Atmospheric and Climate Science, ETH Zurich; Advisors: Ulrike Lohmann

Overall achievements (Nov. 2008 – Dec. 2009)

During these first 14 months, the center has become fully operational and the first steps towards implementing the overall C2SM strategy have been taken. The Center has been staffed with an executive director and three scientific programmers. Four PhD students have started their projects, which focus on the multi-scale interactions in the ocean and atmospheric sub-components of the climate system. Working groups, which are constituted with C2SM members, have been established in order to refine the objectives in research and development in three focus areas, namely Global Climate Modeling, Regional Climate Modeling, and Analysis of Climate Datasets. As a result, first strategic decisions have been taken, which will be implemented in the coming years. C2SM staff and members have (co-) organized a series of scientific and outreach events. Finally, the Scientific Advisory Board has been established and a first meeting will be held in 2010.

Activities

Overview

The Center is active in several ways including research, user support, scientific animation, teaching, and outreach activities. The main objectives are:

- To maintain, improve, and make available to the Center's community a hierarchy of state-of-the-art climate and climate-related models. In particular, the Center seeks to refine and enhance a global and a regional climate model as well as the associated modules for, e.g., aerosol, (biogeo)chemistry, ocean, land surface, and clouds.
- To utilize climate models by conducting comprehensive simulations and diagnostics extending over a wide range of temporal and spatial scales.
- To exploit and disseminate key national and international data sets by providing a repository for them and by developing analysis and data management tools. A special emphasis will be given to the provision of future climate scenarios at scales relevant for impacts in Switzerland.
- To prepare for and exploit the next generation of high-performance computers and thereby continue to contribute at the highest level to climate system science.
- To foster the collaboration between research groups by facilitating scientific discussions and the preparation of joint proposals and to learn from environmental stakeholders who will exploit the Center's services.

Maintaining a regional and a global climate model

Climate models have become instrumental in the research activities pertaining to climate and weather. Our improved understanding of the climate and weather systems goes in parallel with the utilization of models of increasing complexity that are continuously developed and refined to include, for example, more advanced representations of relevant processes or new interactions and feedbacks among various sub-components of the climate system. The growing complexity renders the maintenance and application of climate models increasingly difficult for individual research groups. In addition, as an increasing number of research groups apply climate models, it becomes necessary to establish new working approaches to ensure that projects using a similar model are developed in a coherent manner and can benefit from each other.

In the framework of C2SM, we refine and maintain the regional climate model COSMO/CCLM and the global climate model ECHAM, thus covering a large spectrum of spatio-temporal scales in the climate system. Both models are used in many groups affiliated with the Center. Both the regional and global climate models are developed and maintained by international consortia. The involvement of C2SM in the further refinement of these models will thus serve a larger community beyond the Center and in the mean time, enhance the international visibility of the Center. A short description of the models is given in the following.

- *The COSMO/CCLM model:* The COSMO model is a non hydrostatic research and operational limited-area weather prediction model that is applied and further developed by several national weather services that form the COnsortium for Small scale MOdeling (COSMO). The COSMO-CLM or CCLM model corresponds to the COSMO model in CLimate Mode. The COSMO/CCLM model has been further coupled to additional modules to represent aerosol and trace gas chemistry (e.g., CCLM-M7 and COSMO-ART). Several projects led by C2SM members aim at further developing and applying the model and related sub-modules. The COSMO model is also developed and used operationally at MeteoSwiss. The long-term objective of using a similar model for both climate projections and weather forecasting is to build capacity to perform "seamless" predictions ranging from daily, weekly, seasonal, interannual, decadal to centennial timeframes. Two C2SM PhD projects (jointly supervised by researchers from ETHZ, Empa and MeteoSwiss) make use of the COSMO/CCLM model to investigate the issues of, for example, kilometer-scale climate modeling and chemistry-aerosol-climate interactions (see next section for details on these projects).

- *The ECHAM model:* The ECHAM general circulation model is a well-established climate model mainly developed by the Max-Planck Institute for Meteorology (MPI-Met) in Hamburg. Several complementary submodels have been implemented in ECHAM including, for example, an aerosol scheme (the HAM model) and a trace gas chemistry scheme (the MOZ model). This has resulted in the ECHAM5-HAMMOZ model, that is, a state-of-the-art fully unified aerosol-chemistry-climate model. Several groups affiliated to C2SM further develop and apply the ECHAM5 model and the associated sub-models. A strong focus is put on investigating the interactions between atmospheric constituents (aerosols and trace gases) with the climate (in particular clouds and radiation) in a coherent framework.

Two scientific programmers in charge of maintaining the COSMO/CCLM and ECHAM climate models, respectively, have been hired. Starting in 2010, their work will be geared towards contributing to the refinement of the models, providing support to the Center's groups, and facilitating the joint use of codes by different groups. In particular, they will be responsible for maintaining the codes (e.g., code version management and numbering, implementation and test of new parameterizations, etc.), and porting and optimizing the codes to exploit new high-performance computers.

In the framework of the RCM working group, first discussions have taken place between ETH, Empa and MeteoSwiss in order to strengthen the already existing collaboration with the objectives to maximize the developments and refinements to be performed in the COSMO/CCLM model and the related sub-modules. Similarly, discussions have taken place with MPI-Met and other institutions applying the ECHAM5-HAMMOZ model to develop a good working environment and information flow between the different groups involved.

In addition, in order to prepare for the next generation of computers, two proposals (including one conjointly with University of Berne) have been submitted to the High-Performance and High-Productivity Computing (HP2C) initiative (launched by the Swiss National Supercomputing Centre), which aims at developing applications to run efficiently on a very large number of computing nodes and make effective use of the next generation of supercomputers.

Exploiting climate models over a range of spatio-temporal scales

A large numbers of projects are ongoing in the frame of the Center, which aim at improving our quantitative understanding of the climate system in a broad sense. In the following we present PhD projects funded by C2SM and highlight studies from two of our members that have received a particularly strong resonance both in the research community and in the media.

- **On the potential role of eddies in the oceanic CO_2 uptake (PhD candidate: Ivy Frenger)**

Stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system requires a sound and quantitative understanding of the global carbon cycle. However, major uncertainties still remain in our understanding of this cycle, especially with respects to its interaction with some subcomponents of the climate system, notably the role of the CO_2-sinks as currently provided by the oceans and the terrestrial biosphere. Investigation of the global carbon cycle is usually performed with coupled, three-dimensional Earth System Models in which many critical processes of the climate system in general and of the carbon cycle in particular are represented in a simplified or parameterized manner. However, many important carbon-cycle processes are governed by factors operating at short temporal and small spatial scales (Figure 3). A good example is the parameterization of the effect of eddies in ocean carbon cycle modeling studies. Eddies are of fundamental importance for the transport of heat and momentum in the ocean and hence exert a profound influence on the oceanic general circulation but also play a critical role in controlling the ocean's productivity. However, the typical spatial scales of these eddies in the ocean is about 10 to 100 km, i.e. much smaller than the typical resolution of ocean models, which is of the order of 100 km or more. The goal of this PhD project is to investigate the potential role of eddies in the oceanic CO_2 uptake. The focus is placed on the Southern Ocean, which is responsible for nearly a third of the global oceanic uptake of anthropogenic CO_2, but may have recently undergone a weakening in its sink strength.

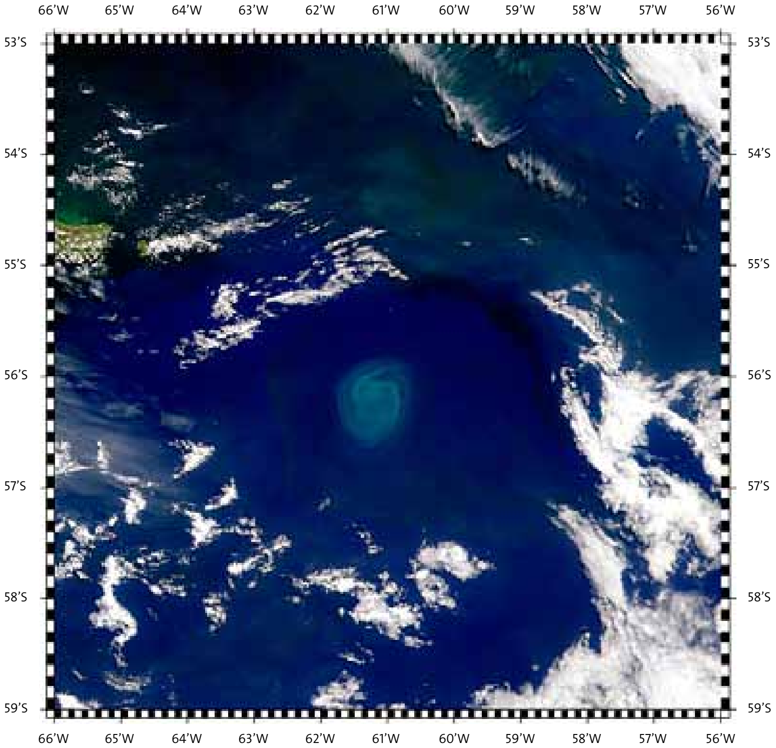

Figure 3. SeaWiFS image showing a well-defined eddy in the Drake Passage (Provided by the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE).

The focus of the first phase has been on analysis of sea surface anomaly and chlorophyll satellite data in the Southern Ocean for the period from 1997 until today with the objective to relate eddies with biological activity in different zones of the Southern Ocean. In addition, the set up of the ocean circulation model ROMS coupled to the biogeochemical-ecological model BEC (Biogeochemical Elemental Cycling) has been initiated in a high-resolution configuration (at least 1/6°). In the future, high-resolution simulations will be carried out for the Southern Ocean with this model system to examine the physical, biological and chemical processes linked to eddy activity and their sensitivities to climate change.

- **Towards kilometer-scale climate modeling (PhD candidate: Wolfgang Langhans)**

Atmospheric multiscale interactions at continental to regional scales are of a tremendous complexity and associated with a wide variety of fascinating processes and flow features. The interactions of these processes imply both downscale and upscale cascades of energy. The downscale cascade determines the regional climate in response to large-scale conditions. The upscale cascade encapsulates the aggregated effect of small-scale physical and dynamical processes onto the large-scale climate and thus strongly influences the mean large-scale structure of the atmosphere as well as the frequency of atmospheric circulation types. A rigorous approach to this problem thus requires an appropriate representation of both the downscale and upscale energy cascades in climate models. Due to computational constraints, current global and regional climate models (GCMs and RCMs) operate at grid spacings of 20-300 km. Many important processes can thus not explicitly be resolved and are parameterized instead. Although climate model parameterizations are sophisticated tools based on physical principles, they imply important limitations. Specific difficulties are well known for land-surface processes, moist convection, or turbulence and boundary layer processes over complex topography. These difficulties feed back with the upscale cascade to the whole climate system. As a matter of fact, much of the uncertainty about the sensitivity of the climate system with respect to greenhouse gas forcing is known to be associated with the treatment of moist convection and clouds.

The goal of the present project is thus to replace parameterizations of moist convection in RCMs by an explicit representation, and to refine other parameterizations using a higher spatial resolution of at least ~2 km. An updated version of the COSMO/CCLM model is being used with a focus on moist convection over the Alpine topography. Special attention is given to the horizontal resolution requirements for cloud-resolving simulations at this scale and the representation of turbulent processes in the model.

In the related PhD, which is jointly supervised by ETH and MeteoSwiss, ongoing work addresses the model set-up for high-resolution atmospheric simulations over the Alps, investigates numerical convergence at cloud-resolving resolution, and studies key processes in real- and idealized case studies to better understand the interactions between small-scale atmospheric circulations and the larger-scale flow (see Figure 4). The simulations use a horizontal grid spacing between 0.5 and 2.2 km. Some of this work also addresses specific numerical components such as the formulation of explicit numerical diffusion, which is used to suppress an upscaling of small-scale numerical noise to well-resolved scales. The work has already contributed to the provision of recommendations for an improved model set-up for cloud-resolving simulations. In the future, the impact of diurnal mountain circulations on summer-time convection will be also examined. In parallel, the dynamical processes that govern heavy convective precipitation events are investigated. Currently it is expected that the first multi-year climate simulations using a cloud-resolving model set-up will be started in 2010.

- **Chemistry-aerosol-climate interactions in a regional climate model (PhD candidates: Christoph Knote and Sara Nottelmann)**

An adequate understanding of aerosol-cloud-climate interactions is of major importance for our capability to reliably predict future climate. The representation of aerosol-cloud-climate interactions and feedbacks currently remains a large source of uncertainties in the climate prediction on decadal timescales with potential strong regional implications, and cloud feedbacks constitute a primary source of differences between simulated estimates of the equilibrium climate sensitivity for a CO_2 doubling. In addition, aerosol-cloud interactions are also closely linked to air pollution. Sulfate, black carbon, organic carbon and nitrate aerosols have a substantial anthropogenic component. Photochemical aging of particles and heterogeneous reactions of air pollutants on their surfaces can change the physicochemical properties of both natural and anthropogenic aerosols. In

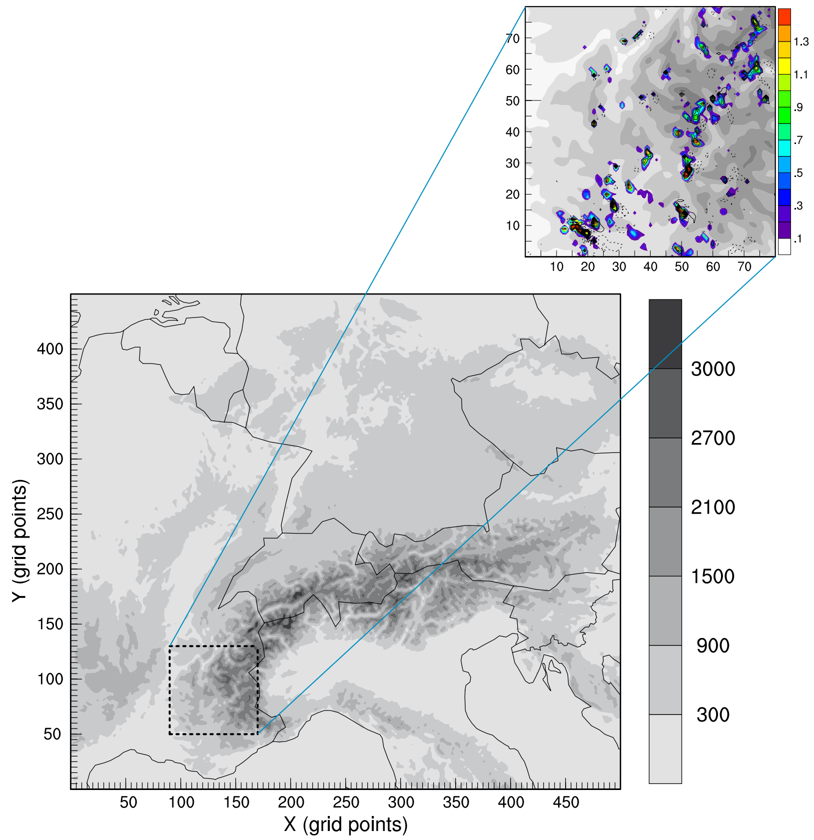

Figure 4. The larger figure depicts the domain over which the cloud-resolving simulations are performed together with the orography (gray shading); the x and y axis correspond to the 2.2 km-spaced grid points. The smaller figure shows a zoom over the dashed box of cloud liquid water (g/kg, color scale) and vertical velocity (black contour lines, every 1 m/s) at 4 km above mean sea level, 1600 UTC 17 July 2006.

addition, climate change is also expected to feed back on air quality in several important ways through e.g., emissions of biogenic VOCs. Interactions between chemistry, aerosol, cloud and climate are extremely complex and involve processes spanning a large range of spatial and temporal scales from the microscopic (e.g., cloud droplet nucleation) to the global scale (e.g., cloud radiation feedbacks). This implies that future changes in anthropogenic emissions of air pollutants will likely have a significant impact on cloud formation, cloud properties and precipitation, and hence on climate. The degree of details and resolution needed to adequately represent these processes in global models remains unclear.

The goal of this project is to investigate chemistry-aerosol-cloud-climate interactions using a multi-scale approach. In a first sub-project, a similar configuration of aerosol chemistry (M7 aerosol scheme) and aerosol-cloud interactions (double-moment cloud microphysics scheme) will be implemented in the regional climate model CCLM, similarly to what is done in the global climate model ECHAM (see Figure 5). So far, the main focus of this project has been placed on the implementation of an explicit and detailed treatment of cloud-borne aerosol particles in CCLM. The new scheme allows the representation of the cycling of aerosols in clouds. First simulations show that aerosol processing modifies the interstitial aerosol distribution in a significant way, with implications for the subsequent cloud formation. In the future, the process understanding and the model evaluation will be developed on the local and regional scale while the implications for future climate will be evaluated.

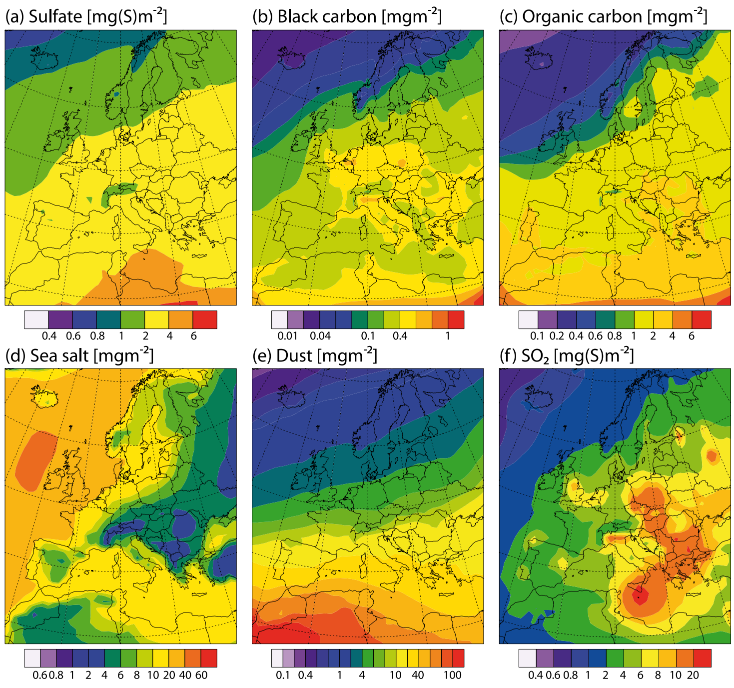

Figure 5. Annual mean burdens integrated within the model atmosphere for different aerosol species simulated within CCLM-M7.

Scientific highlight: Global brightening/dimming in solar surface radiation (Contributed by Martin Wild, IAC, ETH)

Solar radiation (sunlight) received at the earth surface is a key determinant of climate and the primary energy source for life on our planet. Variations in this quantity therefore profoundly affect the human and terrestrial environment and are a major driver of climate change. Recent studies present evidence that solar radiation reaching the earth surface has not been stable over time, but underwent significant decadal variations. These include a decrease of surface solar radiation ("global dimming") from the 1950s to the 1980s and a more recent partial recovery measured at widespread observation sites ("brightening"). Increasing air pollution and associated increase in aerosol concentration are considered as the major cause of the dimming up to the 1980s, while air pollution regulations and the breakdown of the economy in former communist countries are thought to be responsible for the more recent recovery. There is increasing evidence that the decadal variations in surface solar radiation have a considerable impact on various elements of the climate system, such as global warming, the components and intensity of the hydrological cycle, the carbon cycle as well as snow cover and glacier retreat. In order to reproduce these trends in climate models and estimate their impacts on other components of the climate system, the inclusion of sophisticated schemes of aerosol and cloud microphysics are essential. Such schemes are implemented in the latest versions of the ECHAM5 and COSMO/CLM climate models. Transient experiments are carried out with these extended modeling systems to investigate the origins, magnitude and impacts of global dimming and brightening. A recent special issue in the Journal of Geophysical Research has been devoted to this topic with heavy involvement of ETH.

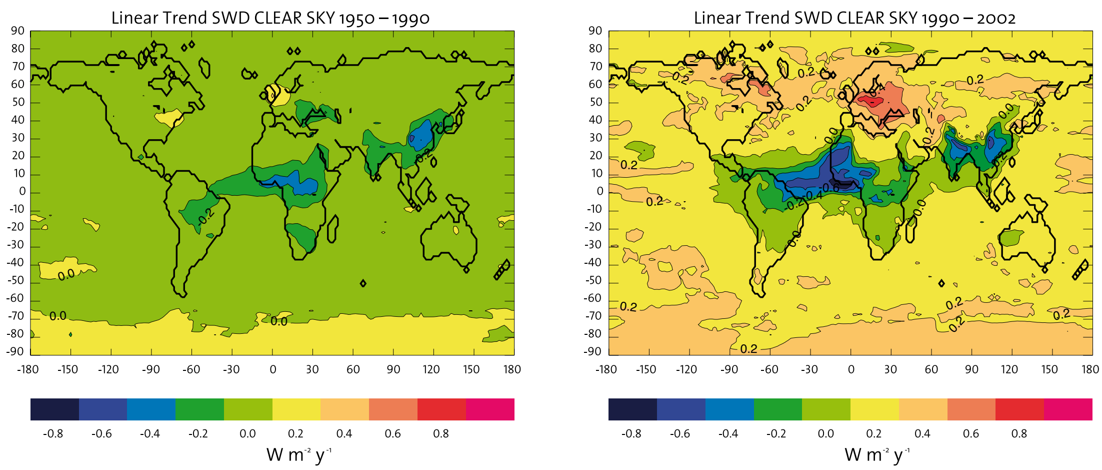

Figure 6. Trends in surface solar radiation (W m^{-2} y^{-1}) under cloud free conditions for the "global dimming" period 1950–1990 (left) and the "brightening" period 1990–2002, as simulated with the global climate model ECHAM5 HAM.

Scientific highlight: Which climate model should we trust? Contributed by Reto Knutti (IAC, ETH)

As our understanding of the processes relevant to climate change improves, and as computers get faster, we assume that our confidence in predictions from climate models increases. But this argument is more complicated that it seems. We trust a weather forecast mostly because it has repeatedly been verified by observations, not because we fully understand the underlying model. In the climate context, however, predictions for the year 2100 cannot be tested directly. Confidence into a climate model must therefore be established by testing the model on present day climate, it's variability, changes during the 20th century, on process evaluation and in paleoclimate applications. Which of these tests is most relevant to predicting future changes is not fully clear. For example, most models compare favorably to observations when simulating present day distribution of temperature (left part of figure). Their response to increasing greenhouse gases (right part of figure) is similar on the largest scales (polar regions and land warming more than tropics and oceans), but regional uncertainties can be several degrees Celsius still. Intuitively one would expect our confidence to increase as results from models agree, but many models are also based on the same assumptions and have to parameterize small-scale processes in similar ways. How to best synthesize the large amount of data produced by multiple models into information that is relevant for regional and local adaptation and decision making is an active area of research. The ability to run high resolution global climate models at ETH and CSCS is an important requirement for progress in this rapidly developing area, and C2SM provides the scientific and technical support for that activity.

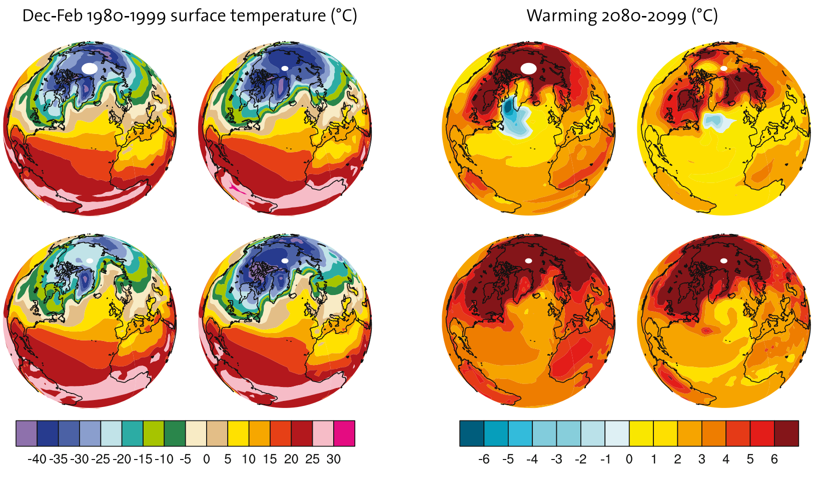

Figure 7. Simulated present day December to February surface temperature (left), and the projected warming 2080–2099 relative to 1980–1999 for the SRES A1B scenario (right) for four climate models. Modified from: Knutti, R., Should we believe model predictions of future climate change? Philosophical Transactions of the Royal Society A, 2008: p. doi:10.1098/rsta.2008.0169.

In a second sub-project, the model COSMO-ART, which incorporates detailed representation of tropospheric chemistry and aerosols, including their interactions with meteorology, is used up to the kilometer scale. So far, the model and the surrounding infrastructure have been implemented in the supercomputer at the Swiss National Supercomputing Centre. A first simulation has been performed over the European domain for the summer 2006. Preliminary results indicate that the COSMO-ART model represents accurately the variability of gas trace concentrations but underestimates the observed mass of fine particular matter at the surface. In particular, the secondary organics, sulfate and soot components appear to be underestimated. In the future, the effects of the improved description of aerosols on climate will be quantified, in close collaboration with the first sub-project.

Developing and disseminating climate datasets

As the use of climate models is increasing and the computing facilities enhanced (allowing for higher resolution and longer-term simulations, as well as large model ensemble and multi-model approaches), the amount of data generated for the analysis and prediction of climate change is continuously increasing. Storing, analyzing, and displaying these datasets becomes increasingly complex and therefore requires new approaches. The work of one of the three C2SM scientific programmers (who has started in October 2009) is geared towards the development of analysis and data management tools to facilitate the exploitation (e.g., production, management, display, and analysis) of large climate and model-generated datasets for past, current, and future climate. In particular, the objectives are to collect and document the main datasets (e.g., model simulations, meteorological re-analysis, observational datasets, etc.) used in the C2SM community, to facilitate their analysis through the development of a series of consistent tools, and to ensure their dissemination and exchange among the community.

In addition, in the coming months, a large effort will be devoted to the development and dissemination of new future climate scenarios at scales relevant for impacts in Switzerland (the so-called “Swiss Climate Scenarios CH2011” initiative). Over the last decade, climate change scenarios on the regional scale have become of prime interest to impact studies, to governmental bodies (e.g., BAFU, OcCC) and to the economic sector (e.g., construction, energy). The current climate change scenarios available for Switzerland (OcCC 2007, see www.occc.ch) need to be updated and extended. For example, they only consider seasonal averages for northern and southern Switzerland, and do not distinguish between different greenhouse gas scenarios, thus limiting their applicability from a user perspective. The gap between available scenarios and requests from the climate impact community is even wider if climate extremes are considered. Yet it is precisely those events that are probably most important to society. First steps towards the developments of new national climate scenarios have taken place under the auspices of ETH, MeteoSwiss, ART, C2SM, NCCR-Climate, and OcCC. With this objective in mind, C2SM together with the NCCR-Climate is organizing a workshop to provide information on the availability and usability of climate change scenarios for Switzerland (to be held on March 2, 2010). International and national speakers will discuss the needs in terms of future climate scenarios as well as the new available methodologies (e.g., statistical, downscaling, multi-model approaches) for the development of future climate scenarios at scales relevant for Switzerland.

Teaching, outreach and communication

Members from C2SM are actively involved in several bachelor and master programs of ETH Zurich, in particular the master in Atmospheric and Climate Science and the master in Environmental Sciences.

In addition, through the active participation of its members and their groups, C2SM has contributed to a number of outreach and scientific events indicated below.

- Nacht der Forschung 2009 – September 25, 2009. A C2SM stand was prepared by a number of volunteers. Visitors had the opportunity to learn about the climate system and the associated possible feedbacks through posters, measurements of albedo, and a very simple radiative model.
- AGS / ETH Sustainability / CCES workshop on "Effective Outreach for Sustainability" – October 15-16, 2009. AGS (Global Alliance for Sustainability) organized a workshop to discuss the following question: "How can universities and scientists outreach effectively to non-academic partners to seek and implement solutions to the sustainability challenge?". This question was debated with respect to different environmental issues. Nicolas Gruber and Isabelle Bey acted as the convener and the facilitator, respectively, for the discussion around "climate change".
- MeteoSwiss-C2SM COSMO users workshop – October 22, 2009. The goal of the workshop was to bring together the different users of the regional models COSMO and CCLM so that they can learn about the latest development performed in different groups using this model and also establish further collaborations.
- ETH Sustainability / CCES event on "Klimawandel – wohin steuert die Schweiz?" event – November 12, 2009. The goal of this event was to present the most recent results in climate research and to offer a panel discussion opened by Federal Councillor Leuenberger. Several C2SM members actively contributed to the organization and development of the event, including Ulrike Lohmann and Reto Knutti as speakers.

Other activities

Contribution to the development of the Climate-KIC

In 2008, the European Institute of Innovation and Technology (EIT) has created a new funding mechanism to boost innovation and technology transfer between academia and the private sectors in Europe, called Knowledge and Innovation Communities (KIC). ETHZ, together with fifteen other world class partners from academia and from the private and public sectors have developed and submitted a KIC in the area of climate adaptation and mitigation. The proposed "Climate-KIC" has been approved by the EIT board in December 2009, and is now being implemented in order to be up and running in June 2010. The main goal of the Climate-KIC is to make a step-change in Europe's innovation capacity to meet the climate change challenge. C2SM has contributed to the development of the Climate-KIC through its staff and several of its members, including, in particular, co-chairman Nicolas Gruber who has been the project leader at ETH and is now member of the interim executive committee of the Climate-KIC.

A look ahead to 2010

In the coming months and years, the Center will continue its effort to further develop the above-mentioned activities. In 2010, the focus will be placed on the following tasks:

- Maintenance of the global climate model ECHAM and associated sub-models: testing and refinement of the new version of the ECHAM model (so-called ECHAM6 version), which is being prepared by the ECHAM-HAMMOZ community to be used in the activities related to the 5th IPCC Assessment Report
- Maintenance of the regional climate model COSMO/CCLM and associated sub-models: development of an updated version of CCLM-M7 model, which will include the latest version of the CCLM model.
- Improvement of the collaboration and communication flow between the research groups and institutions involved in C2SM through, e.g., the development of new wiki pages, tools to facilitate the management of code versioning, etc.
- Contribution to the initiative "Swiss Climate Scenarios CH2011" through the development of improved climate scenarios and dedicated web server and web portal.

3. Publications

Here we list key selected publications from C2SM members published over the last two years:

Altenhoff, A., O. Martius, M. Croci-Maspoli, C. Schwierz, and H.W. Davies (2008), Linkage of atmospheric blocks and synoptic-scale Rossby waves: a climatological analysis, Tellus, 60, 1053-1063

Aschwanden, A., and H. Blatter (2009), Mathematical modeling and numerical simulation of polythermal glaciers, J. Geophys. Res., 114, F01027, doi:10.1029/2008JF001028

Bakke, J., Ø. Lie, E. Heegaard, T. Dokken, G. H. Haug, H.H. Birks, P. Dulski, and T. Nilsen (2009), Rapid oceanic and atmospheric changes during the Younger Dryas cold period, Nature Geosci., 2, 202-205 doi:10.1038/ngeo439

Beer, C., P. Ciais, M. Reichstein, D. Baldocchi, B. E. Law, D. Papale, J. F. Soussana, C. Ammann, N. Buchmann, D. Frank, D. Gianelle, I. A. Janssens, A. Knohl, B. Köstner, E. Moors, O. Roupsard, H. Verbeeck, T. Vesala, C. A. Williams, and G. Wohlfahrt (2009), Temporal and among-site variability of inherent water-use efficiency at the 1ecosystem level, Global Biogeochem. Cycles, 23, 2, doi:10.1029/2008GB003233

Begert, M., E. Zenklusen, C. Häberli, C. Appenzeller, and L. Klok (2008), An automated procedure to detect discontinuities; preformance assessment and application to a large European climate data set, Meteorol. Z.,17, 663-672, DOI: 10.1127/0941-2948/2008/0314

Brauer, A., G. H. Haug, P. Dulski, D. M. Sigman, and J. F. W. Negendank (2008), An abrupt wind shift in western Europe at the onset of the Younger Dryas cold period, Nature Geosci., 1, 520-523, doi:10.1038/ngeo263

Brönnimann, S. (2009), Early twentieth-century warming, Nature Geosci., 2, 735-736

Brönnimann, S., et al. (2009), Exceptional atmospheric circulation during the "Dust Bowl", Geophys. Res. Lett., 36, L08802, doi:10.1029/2009GL037612

Brönnimann, S., et al. (2009), Variability of large-scale atmospheric circulation indices for the Northern Hemisphere during the past 100 years, Meteorol. Z., 18, 379-396

Buser, C.M., H. Künsch, D. Lüthi, M. Wild, and C. Schär (2009), Bayesian multi-model projection of climate: Bias assumptions and interannual variability, Clim. Dyn., 33, 849-868, DOI 10.1007/s00382-009-0588-6

Corti, T., and T. Peter (2009), A simple model for cloud radiative forcing, Atmos. Chem. Phys., 9, 5751-5758

Corti, T., V. Muccione, P. Köllner-Heck, D. Bresch, and S.I. Seneviratne (2009), Simulating past droughts and associated building damages in France, Hydrol. Earth Syst. Sci., 13, 1739-1747

Croci-Maspoli, M., and H. C. Davies (2009), Key Dynamical Features of the 2005/06 European Winter, Mon. Weather Rev., 137, 664-678

Croft, B., U. Lohmann, R. V. Martin, P. Stier, S. Wurzler, J. Feichter, R. Posselt, and S. Ferrachat (2009), Aerosol size-dependent below-cloud scavenging by rain and snow in the ECHAM5-HAM, Atmos. Chem. Phys., 9, 4653–4675

Della-Marta, P. M., H. Mathis, C. Frei, M. A. Liniger, J. Kleinn and C. Appenzeller (2009), The return period of wind storms over Europe, Int. J. Climatol., 29, 437-459, DOI: doi:10.1002/joc.1794

Fischer, A. M., M. Schraner, E. Rozanov, P. Kenzelmann, C. Schnadt Poberaj, D. Brunner, A. Lustenberger, B. P. Luo, G. E. Bodeker, T. Egorova, W. Schmutz, T. Peter, and

S. Brönnimann (2008), Interannual-to-decadal variability of the stratosphere during the 20th century: Ensemble simulations with a chemistry-climate model, Atmos. Chem. Phys., 8, 7755-7777

Fischer, E. M., and C. Schär (2009), Future changes in daily summer temperature variability: driving processes and role for temperature extremes, Clim. Dyn., 33, 917-935, DOI 10.1007/s00382-008-0473-8

Fuhrer, J. (2009), Ozone risk for crops and pastures in present and future climates, Naturwissenschaften 96, 173-194

Fuhrer, J., and K. Jasper (2009), Bewässerungsbedürftigkeit von Acker- und Grasland im heutigen Klima, AgrarForschung, 16(10), 396-401

Grant, A., S. Brönnimann, and L. Haimberger (2008), Recent Arctic warming vertical structure contested, Nature, 455, E2-E3, doi:10.1038/nature07257

Gruber, N. (2009), Fickle trends in the ocean, Nature, 458, 155-156

Gruber, N., M. Gloor, S. E. Mikaloff Fletcher, S., C. Doney, S. Dutkiewicz, M. Follows, M. Gerber, A. R. Jacobson, F. Joos, K. Lindsay, D. Menemenlis, A. Mouchet, S. A. Mueller, J. L. Sarmiento, and T. Takahashi (2009), Oceanic sources, sinks, and transport of atmospheric CO_2, Global Biogeochem. Cycles, 23, GB1005, doi:10.1029/2008GB003349

Hastings, A. F., M. Wattenbach, W. Eugster, C. Li, N. Buchmann, and P. Smith (2009), Uncertainty propagation in soil greenhouse gas emission models: An experiment using the DNDC model and at the Oensingen cropland site, Agriculture, Ecosystems and Environment, 136, 97-110, DOI: 10.1016/j.agee.2009.11.016

Haug, G. H., and M. S. Daniel (2009), Polar twins, Nature Geosci., 2, 91-92

Hohenegger, C., P. Brockhaus, C. S. Bretherton and C. Schär (2009), The soil moisture-precipitation feedback in simulations with explicit and parameterized convection, Journal of Climate, 22, 5003-5020

Jaeger, E. B., I. Anders, D. Lüthi, B. Rockel, C. Schär, and S.I. Seneviratne (2008), Analysis of ERA40-driven CLM simulations for Europe, Meteorol. Z., 17 (4), 349-367

Jaeger, E. B., R. Stöckli and S. I. Seneviratne (2009), Analysis of planetary boundary layer fluxes and land-atmosphere coupling in the Regional Climate Model CLM, J. Geophys. Res., 114, D17106

Joos, H., P. Spichtinger, and U. Lohmann (2009), Orographic cirrus in a future climate, Atmos. Chem. Phys., 9, 7825-7845

Jouvet, G., Huss, M., Blatter, H., Picasso, M., and Rappaz, J. (2009), Numerical simulation of Rhonegletscher from 1874 to 2100, J. Comput. Phys., 228, 6426-6439

Kloster, S., F. Dentener, J. Feichter, F. Raes, U. Lohmann, E. Roeckner, and I. Fischer-Bruns (2009), A GCM study of future climate response to air pollution reductions, Climate Dynamics, 33, doi:10.1007/s00382-009-0573-0

Knote, C., G. Bonafe, and F. Di Giuseppe (2009), Leaf Area Index Specification for Use in Mesoscale Weather Prediction Systems. Mon. Weather Rev., 137, 3535-3550

Knutti, R. (2008), Should we believe model predictions of future climate change? Triennial Issue Earth Science of Philosophical Transactions of the Royal Society A, 366, 4647-4664, doi:10.1098/rsta.2008.0169

Kress, A., M. Saurer, U. Büntgen, K. S. Treydte, H. Bugmann, and R. T. W. Siegwolf (2009), Summer temperature dependency of larch budmoth outbreaks revealed by Alpine tree-ring isotope chronologies, Oecologia 160, 353-365

Lazzarotto, P., P. Calanca, and J. Fuhrer (2009), Dynamics of grass-clover mixtures – An analysis of the response to management with PROductive GRASSland simulator (PROGRASS), Ecol. Modell., 220, 703-724

Liang, J.-H., J. C. McWilliams, and N. Gruber (2009), High-frequency response of the ocean to mountain gap winds in the northeastern tropical Pacific, J. Geophys. Res., 114, C12005, doi:10.1029/2009JC005370

Lovenduski, N.S., N. Gruber, and S. C. Doney (2008), Toward a mechanistic understanding of the decadal trends in the Southern Ocean carbon sink, Global Biogeochem. Cycles, 22, GB3016, doi:10.1029/2007GB003139

Mahlstein, I., and R. Knutti (2009), Regional climate change patterns identified by cluster analysis, Clim. Dyn., published online, doi: 10.1007/s00382-009-0654-0

Masson, D. and R. Knutti, Spatial scale dependence of climate model performance in the CMIP3 ensemble, Journal of Climate, submitted

Posselt, R., and U. Lohmann (2009), Sensitivity of the total anthropogenic aerosol effect to the treatment of rain in a global climate model, Geophys. Res. Lett, 36, L02805, doi:10.1029/2008GL035796

Rotach, M. W., P. Ambrosetti, F. Ament, C. Appenzeller, M. Arpagaus, H. S. Bauer, A. Behrendt, F. Bouttier, A. Buzzi, M. Corazza, S. Davolio, M. Denhard, M. Dorninger, L. Fontannaz, J. Frick, F. Fundel, U. Germann, T. Gorgas, C. Hegg, A. Hering, C. Keil, M. A. Liniger, C. Marsigli, R. McTaggart-Cowan, A. Montani, K. Mylne, R. Ranzi, E. Richard, A. Rossa, D. Santos-Muñoz, C. Schär, Y. Seity, M. Staudinger, M. Stoll, H. Volkert, A. Walser, Y. Wang, J. Werhahn, V. Wulfmeyer, M. Zappa (2009), MAP D-PHASE: Real-time Demonstration of Weather Forecast Quality in the Alpine Region, Bull. Am. Meteorol. Soc., 90, 1321–1336, DOI:10.1175/2009BAMS2776.1

Schraner, M., E. Rozanov, C. S. Poberaj, P. Kenzelmann, A. M. Fischer, V. Zubov, B. P. Luo, C. R. Hoyle, T. Egorova, S. Fueglistaler, S. Bronnimann, W. Schmutz, and T. Peter (2008), Technical Note: Chemistry-climate model SOCOL: version 2.0 with improved transport and chemistry/microphysics schemes, Atmos. Chem. Phys., 8, 5957-5974

Schwalm, C., C. Williams, K. Schaefer, A. Arneth, D. Bonal, N. Buchmann, J. Chen, B. Law, A. Lindroth, S. Luyssaert, M. Reichstein and A. Richardson (2009), Assimilation exceeds respiration sensitivity to drought: A FLUXNET synthesis. Global Change Biol., 16, 657-670, 10.1111/j.1365-2486.2009.01991.x

Schwierz, C., P. Heck, E. Zenklusen, D. N. Bresch, C. Schär, P. L. Vidale, and M. Wild (2009), Modelling European winter storm losses in current and future climates, Clim. Change, published online, doi:10.1007/s10584-009-9712-1

Sillmann, J. and M. Croci-Maspoli (2009), Present and future atmospheric blocking and its impact on European mean and extreme climate, Geophys. Res. Lett., 36, L10702, doi:10.1029/2009GL038259

Solomon, S., G.-K. Plattner, R. Knutti, and P. Friedlingstein (2009), Irreversible climate change due to carbon dioxide emissions, PNAS, 106, 1704-1709, doi/10.1073/pnas.0812721106

Storelvmo, T., U. Lohmann, and R. Bennartz (2009), What governs the spread in shortwave forcings in the transient IPCC AR4 models? Geophys. Res. Lett., 36, L01806, doi:10.1029/2008GL036069

Struthers, H., G. E. Bodeker, J. Austin, S. Bekki, I. Cionni, M. Dameris, M. A. Giorgetta, V. Grewe, F. Lefevre, F. Lott, E. Manzini, T. Peter, E. Rozanov, and M. Schraner, M. (2009), The simulation of the Antarctic ozone hole by chemistry-climate models, Atmos. Chem. Phys., 9, 6363-6376

Teuling, A. J., M. Hirschi, A. Ohmura, M. Wild, M. Reichstein, P. Ciais, N. Buchmann, C. Ammann, L. Montagnani, A. D. Richardson, G. Wohlfahrt, and S. I. Seneviratne (2009), A regional perspective on trends in continental evaporation, Geophys. Res. Lett., 36, L02404, doi: 10.1029/2008GL036584

Teuling, A. J., R. Uijlenhoet, B. van den Hurk, and S. I. Seneviratne (2009), Parameter sensitivity in LSMs: An analysis using stochastic soil moisture models and ELDAS soil parameters, J. Hydrometeor., 10, 751-763, doi:10.1175/2008JHM1033.1

Verschuren, D., J. S. S. Damsté, J. Moernaut, I. Kristen, M. Blaauw, M. Fagot, G. H. Haug and CHALLACEA project members (2009), Half-precessional dynamics of monsoon rainfall near the East African Equator, Nature, 462, 637-641, doi:10.1038/nature08520

Weigel, A. P., D. Baggenstos, M. A. Liniger, F. Vitart, and C. Appenzeller (2008), Probabilistic verification of monthly temperature forecasts, Mon. Weather Rev., 136, 5162-5182

Weigel, A.P., M.A. Liniger, and C. Appenzeller (2009), Seasonal ensemble forecasts: Are recalibrated single models better than multi-models? Mon. Weather Rev., 137, 1460-1479

Wiacek, A., and T. Peter (2009), On the availability of uncoated mineral dust ice nuclei in cold cloud regions, Geophys. Res. Lett., 36, L17801, doi:10.1029/2009GL039429

Wild, M., 2009: Global dimming and brightening: A review., J. Geophys. Res., 114, D00D16, doi:10.1029/2008JD011470

Wulfmeyer, V., A. Behrendt, H. S. Bauer, C. Kottmeier, U. Corsmeier, A. Blyth, G. Craig, U. Schumann, M. Hagen, S. Crewell, P. Di Girolamo P, C. Flamant, M. Miller, A. Montani, S. Mobbs, E. Richard, M. W. Rotach, M. Arpagaus, H. Russchenberg, P. Schlüssel, M. König, V. Gärtner, R. Steinacker, M. Dorninger, D. D. Turner, T. Weckwerth, A. Hense, and C. Simmer (2008), The Convective and Orographically-induced Precipitation Study: A Research and Development Project of the World Weather Research Program for improving quantitative precipitation forecasting in low-mountain regions, Bull. Am. Meteorol. Soc., 89, 1477-1486, DOI:10.1175/2008BAMS2367.1

Zappa, M., M. W. Rotach, M. Arpagaus, M. Dorninger, C. Hegg, A. Montani, R. Ranzi, F. Ament, U. Germann, G. Grossi, S. Jaun, A. Rossa, S. Vogt, A. Walser, J. Wehrhan, and C. Wunram (2008), MAP D-PHASE: real-time demonstration of hydrological ensemble prediction systems, Atmos. Sci. Lett., 2, 80-87, DOI: 10.1002/asl.183

Zumbrunnen, T., H. Bugmann, M. Conedera, and M. Bürgi (2009), Linking forest fire regimes and climate – a historical analysis in a dry inner Alpine valley, Ecosystems, 12, 73-86