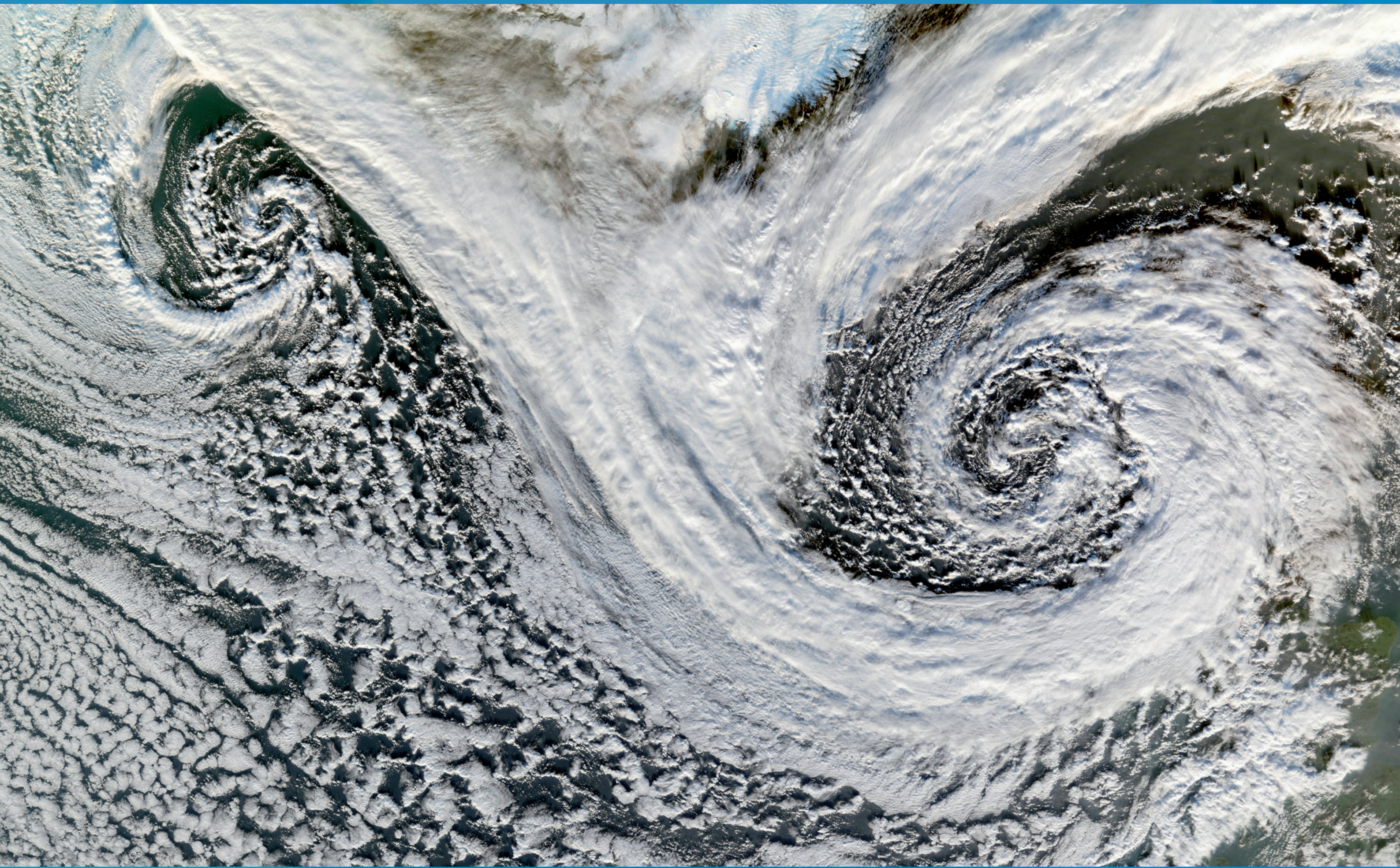
C2SM

Center for Climate Systems Modeling

Annual Report 2010



C2SM Center for Climate Systems Modeling

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

C2SM Partners

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Swiss Federal Institute of Technology Zurich

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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 (C2SM) is a research center based at ETH Zurich. It is a joint initiative between ETH Zurich, MeteoSwiss, Empa, and Agroscope Reckenholz-Tänikon with the main objective to improve the understanding of the climate system and strengthen the predictive skill of climate models on time scales from months to millennia. This document is the second annual report of C2SM. It highlights the main achievements obtained in 2010 as well as ongoing and planned activities.

About C2SM

Vision

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 Center for Climate Systems Modeling (C2SM) has been established to address the scientifically challenging and socially relevant issue of climate change. The overarching goal of C2SM is:

- To improve the understanding of the climate system and strengthen the predictive skill of climate models on time scales from days to millennia, taking into consideration natural climate variability and global climate change;
- To strengthen and coordinate activities of the partner institutions and additional partners of C2SM in Switzerland in the area of climate modeling;
- To provide an entry point in the area of climate modeling for national and international contacts.

Established in fall 2008, C2SM is funded by the ETH-Foundation, ETH Zurich, MeteoSwiss, Empa, and Agroscope Reckenholz-Tänikon (ART).

Research theme

Numerical models have become central tools of research and service activities related to climate change. 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

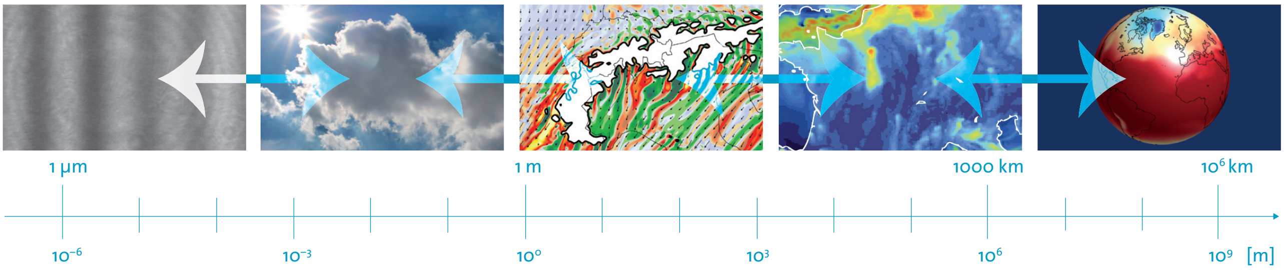

Figure 1. Range of scales investigated in the framework of C2SM, from a few micrometers (e.g. droplets) to the global scale (thousands of kilometers).

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 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 difficult 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).

Objectives & activities

The Center aims 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. Specific objectives include:

- 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., aerosols, (biogeo)chemistry, oceans, 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 the exploitation of the next generation of high-performance computers and thereby continue to contribute at the highest level to climate system science.

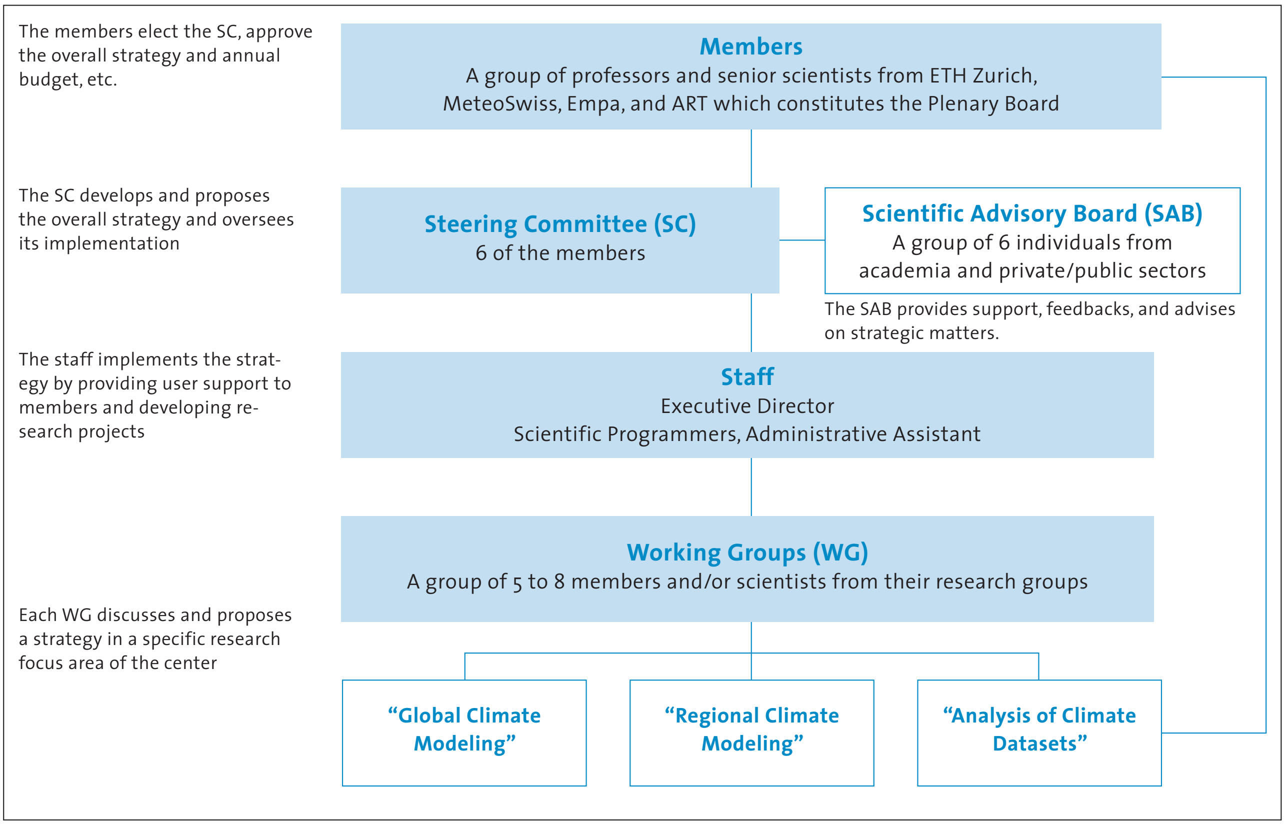

Figure 2. Working organization of C2SM.

- To foster the collaboration between research groups by facilitating scientific discussions, by coordinating joint research proposals and by learning from environmental stakeholders who will exploit the Center's services.

The Center is active in research, user support, scientific coordination and management, teaching, and outreach activities as further detailed in the following sections.

Structure & organization of C2SM

The Center is a joint venture initiated by ETH, MeteoSwiss, and Empa. The Center currently includes 23 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 structure and organization of C2SM is described in greater detail in the Terms of Reference that can be downloaded from the C2SM website (http://www.c2sm.ethz.ch/about/docs).

C2SM Constitutive Bodies and Staff:

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

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

Regular Members:

- Prof. Heinz Blatter, 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
- 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
- Prof Hans Rudolf Künsch, Seminar für Statistik, 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
- 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

Former Members:

- Prof. Stefan Brönnimann, now at University of Berne
- Prof. Mathias Rotach, now at University of Innsbruck

Members of the Scientific Advisory Board:
The SAB has been formed in 2009 and had its first meeting in fall 2010. The SAB has the mandate to advise the Centre on strategic matters and in particular to provide feedback regarding the achievements as well as the planned developments. It includes:

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

Center Staff and PhD students affiliated to C2SM:
The Center ‘s staff includes an executive director, three scientific programmers, a post-doctoral fellow, and an administrative assistant, namely

- Dr. Isabelle Bey, Executive Director
- Rahel Buri, Administrative Assistant (part time)
- Dr. Thierry Corti, Scientific Programmer and Communication Officer
- Dr. Grazia Frontoso, Scientific Programmer
- Dr. Xavier Lapillonne, post-doctoral fellow
- Anne Roches, Scientific Programmer.

The executive director runs the Center while the scientific programmers provide user support in three main focus 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, meet on a regular basis to discuss and propose the strategy to be developed and the tasks to be performed in each of the three focus areas. The post-doctoral fellow specifically contributes to the HP2C COSMO-CLM project (see “Scientific highlights” section).

In addition, the center provides funding for 4 PhD students who are working in different research groups 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

Budget and 2010 expenses

Table 1 and 2 summarize the different sources of funding for the period from 2008 to 2011 as well as the expenses for 2010, respectively.

Income (2008-2011)	Amount (kCHF)
ETH-Foundation (1)	570
ETH CHIRP-1 & carry over (1)	930
ETH UWIS department (2)	100
MeteoSwiss (3)	350
Empa (4)	175
ART (5)	40
Total	**2'165**

(1) One-time contribution at the beginning of the project; (2) Support provided for 2011; (3) Annual contribution of 100 kCHF from mid-2008 until end of 2011; (4) Annual contribution of 50 kCHF from mid-2008 until end of 2011; (5) Annual contribution of 10 kCHF from 2008 to 2011.

Table 1. C2SM funding sources for the period 2008-2011 as of 01.01.2011.

Expenses (2010)	Amount (kCHF)
Operational cost	**339**
Core staff salaries (1)	300
Other expenses (2)	39
Research activities	**261**
PhD students and post-doctoral fellows (1)	244
Other expenses (3)	17
Total	**600**

(1) The core staff salaries include salaries from the executive director and a fraction of the salary of the 3 scientists in charge of climate model analysis regional and global climate modeling systems, communication and outreach. Saleries of the PhD students and the remaining fraction of the three scientist's salaries is taken care through research projects (e.g., CHIRP-1); (2) "Other expenses" include expenses related to scientific workshops, training of scientist staff, travels, conferences etc.; (3) "Other expenses" include expenses related to research projects (e.g., CHIRP–1 PhD student training, travels to conferences, publications).

Table 2. C2SM expenses for 2010.

Scientific highlights

In this section we report on two particularly relevant scientific projects from C2SM members (the prediction of European heatwaves and the ash cloud from the Eyjafjallajökull volcano) as well as on two key projects directly managed by C2SM (the development of new Swiss climate scenarios and of new high-performance computing capabilities for weather and climate models).

Consistent patterns of projected heatwaves in Europe

Climate change may lead to more frequent and intense summer heatwaves, with potentially serious impacts to human health. The most severe impacts arise from extended heatwaves associated with warm nights and high relative humidity Heat combined with high humidity can cause heat cramps, heat exhaustion, heat strokes, and in extreme cases lead to death. For instance, about 70,000 additional deaths were recorded in the devastating summer of 2003 across Europe.

Different climate models give a wide variety of results regarding the severity of future heatwaves. The geographical patterns however are remarkably consistent and give a firm indication as to where the probability of health-adverse conditions would be most affected. Low lying river basins and coastal areas in the Mediterranean would be hit hardest by the projected increase in European heatwaves (Figure 3). The reasons as to why the geographic distribution of the future affected areas is consistent in all models: firstly, due to the low altitude these regions experience particularly high temperatures; secondly, the comparatively high absolute humidity amplifies the health impacts during heatwaves.

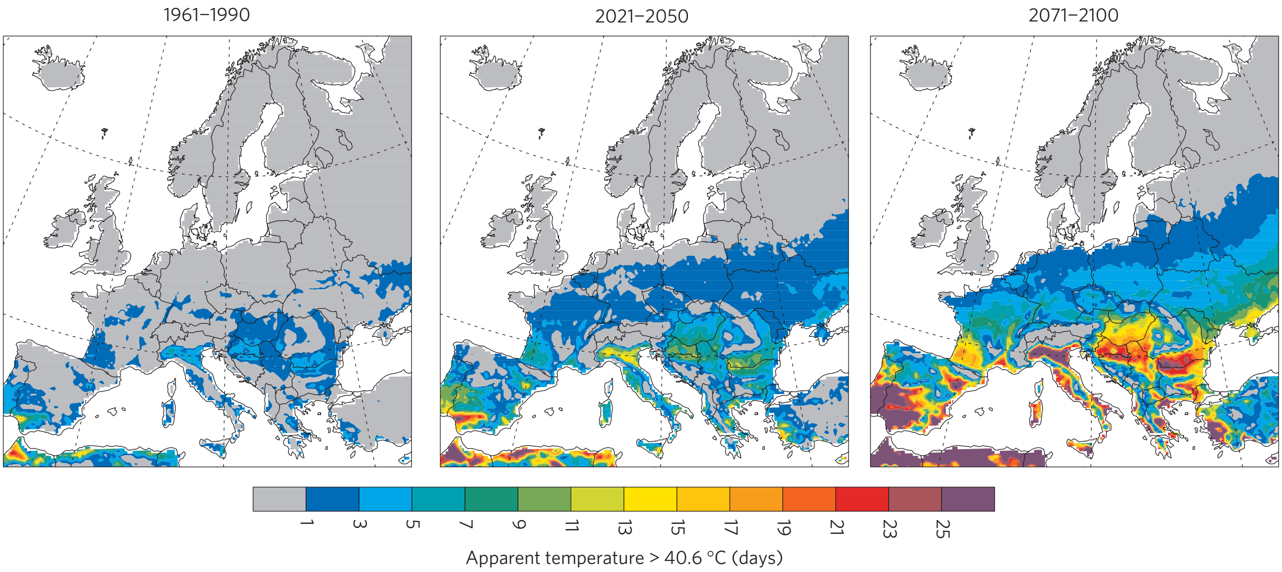

Figure 3. Average number of summer days exceeding the apparent temperature (heat index) threshold of 40.6 °C (105 °F) from six simulations of the ENSEMBLES project. Reproduced from Fischer and Schär (2010).

By the end of the century, some regions could experience 40 or more extremely warm days, with the combined effects of heat and humidity exceeding the threshold declared as "dangerous health conditions" by the US National Weather Service. In comparison, these conditions occurred with an average of just two days between 1961 and 1990.

These projections are cause for concern since some of the most densely populated European regions would experience the severest changes in health indicators. The health risk might even be underestimated, since the study does not account for the confounding effects of air pollution (typically high in urbanized regions) and for the amplifying effects of urban heat islands (cities cool off less effectively at night than the open land).

Measuring and modeling ashes from the Eyjafjallajökull volcano

In April 2010, the Icelandic volcano Eyjafjallajökull erupted, which resulted in a shutdown of air traffic in Europe for several days. Shortly after the beginning of the eruption, C2SM members contributed to measure the concentrations of volcanic ash particles and to simulate their dispersion in the northern hemisphere.

During several days, the group of Thomas Peter at ETH released balloons equipped with special aerosol backscatter sondes and an aerosol lidar from the roofs of the ETH building. These balloons, after penetrating the cloud of volcanic ashes traveling over the Zurich area, measured enhanced concentrations of aerosols between 4 to 5 km of altitude (up to several folds in comparison to those usually found close to the ground). The observations revealed that ash concentrations reached about 1 mg m-3, i.e. half of the later accepted threshold value for air traffic. With such high loads of aerosols, the shutdown of the Swiss air space was justified at that time, given that a threshold value had not yet been defined. Even now our current understanding of the impact of aerosols on aircraft engines continues to remain weak.

Extensive simulations of the dispersion of the volcanic plume were performed by the group of Brigitte Buchmann at Empa using the Lagrangian Particle Dispersion Model FLEXPART. A major uncertainty in these simulations was the exact timing of the eruptions and the initial injection heights of the ash in the volcanic eruption column. An improved source term was therefore derived using a combination of a sophisticated volcanic plume model, dispersion model simulations, and satellite observations (Stohl et al., 2011). Figure 4 compares a FLEXPART simulation using this optimized source term with satellite observations of the volcanic plume. The good similarity between simulation and observation demonstrates the success of the model in accurately tracking the multi-day dispersion of the plume. This lends confidence in the predictive capabilities of such models and their application for decision regarding the closing of the European airspace, a point that was disputed by policy makers and the airline industry

Forecasts were made available to the Federal Office of Civil Aviation (BAZL) to support their decision making on closing and re-opening of the Swiss air space.

The new CH2011 Swiss climate change scenarios

Future climate scenarios are needed for climate change impact studies and for the elaboration of effective, scientifically sound, adaptation strategies to climate change. Climate projections at scales relevant for Switzerland were published in 2007 by the Swiss climate research community under the umbrella of the OcCC and

ProClim (Climate Change and Switzerland 2050; OcCC and ProClim, 2007). However, as our understanding of the climate system and as climate models continuously progress, there was a potential to improve these climate projections in several manners.

As a result, in 2009, a group of scientists from MeteoSwiss, ETH, NCCR-Climate, ART, OcCC and C2SM decided to engage into the development of an updated set of future climate scenarios for Switzerland. These climate projections are based on the latest climate information available including the most recent IPCC Report (Fourth Assessment Report, AR4, IPCC, 2007a, IPCC, 2007b, IPCC, 2007c) and regional climate model outputs from a large European research project (the ENSEMBLES project; Linden and Mitchel, 2009). In addition, new statistical methods were developed to enable a better quantification of uncertainties in climate projections (e.g., Buser et al., 2009) and an improved downscaling of climate variables at specific sites (Bosshard et al., 2011).

In early 2010, C2SM conducted a survey throughout its community and beyond to assess the needs of end-users in terms of climate scenarios data (e.g., quantities to be provided, spatial and temporal resolution required). Throughout 2010, the scientists involved in the CH2011 initiative developed and compiled the future scenario data and wrote a detailed report that describes the future climate scenarios and provides recommendations on the usage of the CH2011 data. The report (CH2011, 2011) has undergone extensive national and international review and is currently approaching publication. The report and associated scenario data will be released in fall 2011 and will be disseminated through the C2SM website.

It is expected that the new CH2011 scenarios will have a

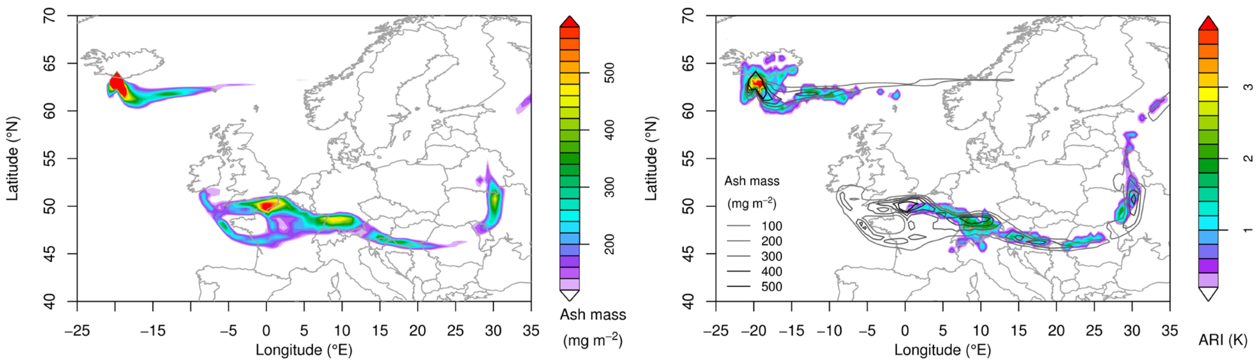

Figure 4. Comparison of simulated and satellite-derived ash concentrations of the Eyjafjallajökull volcanic ash plume on 17 April 2010 at 10 UTC. The left panel shows FLEXPART-simulated ash columns (courtesy of S. Henne, Empa) based on a simulation including several million particles released proportional to emission strengths. The right panel shows satellite-derived ash radiance index (courtesy of L. Clarisse, Université Libre de Bruxelles). ARI data is from the Infrared Atmospheric Sounder Interferometer (IASI) and is approximately proportional to ash column mass. Reproduced from Lin et al. (2011) by permission of American Geophysical Union. Copyright [2011] American Geophysical Union.

major impact, as they will serve as a basis for a variety of climate change impact studies ranging from health, agriculture, water resources, to glacier retreats. They should also guide decision making that many stakeholders and environmental planners at different political levels are currently facing and will further face in coming years.

The HP2C COSMO-CLM project

Currently, the underlying hardware architectures are changing dramatically and it is expected that new computer architectures will be substantially different from current ones, i.e., they will include a larger number of cores per processor and possibly also new types of computing processors such as Graphics Processing Units (GPU). This will result in a growing computational power, which may allow addressing the challenge of climate and weather models becoming increasingly complex and being used at increasingly higher resolution.

However, one challenge currently faced by climate scientists is that existing numerical weather prediction and climate codes need to be adapted for efficient usage of these new architectures. To meet this challenge, C2SM has coordinated a project proposal in the framework of the High Performance and High Productivity Computers (HP2C) initiative. This proposal ("Regional climate and weather modeling on the next generations high performance computers: Towards cloud-resolving simulations", 930'000 CHF, 01.01.2010-31.12.2012) encompasses the expertise of 8 C2SM members together with researchers from the Swiss Center for Scientific Computing (CSCS) and the German weather service (DWD).

The main objective of the project is to prepare the regional climate and weather forecast model COSMO for the next generation of super computers with the overall goal to enhance our capabilities in high-resolution cloud-resolving climate and weather simulation. The project is the first Swiss project of its kind that attempts to exploit the computational power of GPUs in weather/climate models. Funding through the HP2C project is available to hire expert software engineers and post-doctoral fellows who work closely together with scientists at MeteoSwiss, CSCS, DWD, and ETH under the coordination of C2SM. The consortium also includes a collaboration with a private supercomputing company (Supercomputing Systems AG, Zurich). The work is organized around three interrelated tasks including:

- Task (1) aims at the near-term development of high-resolution cloud-resolving climate modeling capability by extending the versatility of the COSMO-CLM model, and to apply this new tool for the generation of climate change scenarios.
- Task (2) addresses the refactoring of the COSMO-CLM model to better exploit current hardware architectures. For example, the current code will be enhanced with a hybrid MPI/Open MP parallelization and parallel data input/output strategies.
- Task (3) involves a more aggressive shift toward future technologies. We plan to rewrite the dynamical core of the COSMO-CLM model to improve the data layout for emerging architectures and employ state-of-the-art software engineering to ensure that the resulting code can be easily ported to emerging hardware.

Core Activities

In this section, we report on the achievements obtained in the three focus areas, that is, "Global climate modeling", "Regional climate modeling", "Climate data analysis". Technical and scientific support is provided by the Center's core staff for two modeling families (including the global chemistry-aerosol-climate model ECHAM-HAMMOZ and the regional climate/weather prediction model COSMO-CLM and its related extensions), and for the collection, analysis and visualization of large data sets.

Global Climate Modeling (GCM)

GCM activities at C2SM are centered around the global climate model ECHAM although other global models such as the National Center for Atmospheric Research (NCAR) Community Atmosphere Model (CAM) are also used in some groups. ECHAM is a comprehensive general circulation model that has been originally developed and is currently maintained and distributed by the Max Planck Institute for Meteorology (MPI-M) in Hamburg. Over the years, several groups in the European community (e.g., Dr. Philip Stier at Oxford University, Dr. Martin Schultz at Forschungszentrum Jülich) have contributed to couple ECHAM to complementary modules to represent specific components and processes of the Earth climate system. In particular, an aerosol module (HAM) and a trace gas chemistry module (MOZ) have been coupled to ECHAM, leading to the formation of the fully coupled aerosol-chemistry-climate model ECHAM-HAMMOZ. Since fall 2008, these different research groups (the so-called HAMMOZ community) have organized themselves by forming a Steering Committee that is chaired by C2SM member Prof. Ulrike Lohmann. Among other things, the Steering Committee is in charge of overseeing the model development by deciding upon the new processes or features to be included in the coupled model.

The establishment of the HAMMOZ Steering Committee and support provided by C2SM has resulted in ETH/C2SM becoming the hosting institution of ECHAM-HAMMOZ for the growing international HAMMOZ consortium that currently includes research groups in the U.K, Germany, Finland, and Italy. As such, C2SM is in charge of archiving, maintaining, and releasing the different versions of ECHAM-HAMMOZ within its community and to any other potential user.

Within C2SM, a large number of scientists and students are involved in the continuous development of the ECHAM model and of the related modules. The model is also applied in many different configurations. For example, strong emphasis is put on further developing the coupling between aerosols and clouds or on investigating to what extent the model can be used to quantify the different processes underlying the observed brightening/dimming in solar radiation at the Earth's surface

The work of Dr. Grazia Frontoso (the scientific programmer in charge of the GCM activities at C2SM) aims at facilitating the refinement, maintenance, application, and dissemination of the ECHAM-HAMMOZ model. Over the last years, the model has undergone a substantial re-structuring in order to achieve full modularity and to include new technical and scientific features. In addition, the core component ECHAM is kept in synchronization with the latest ECHAM6 version that is being prepared by MPI-M for contributing to the up-coming IPCC Fifth Assessment Report (AR5). In 2010, in collaboration with the HAMMOZ community, C2SM has focused on refining and testing the latest version of the ECHAM6-HAMMOZ model, which will be released later in 2011. Dr. Frontoso has also developed a series of post-processing tools to facilitate the analysis of model outputs and contributed to port the model onto the Swiss supercomputing facilities.

Regional Climate Modeling (RCM)

The COSMO model is a limited-area atmospheric model developed by the Consortium for Small-Scale Modeling (COSMO), including MeteoSwiss and other European meteorological services. The model, which can be used in CLimate Mode (COSMO-CLM), is also further refined and applied in several groups at ETH, Empa and in the international "Climate Limited-area Modelling" Community. Over the years, the COSMO model has been coupled to different modules dedicated to tropospheric chemistry, aerosol, aerosol-cloud interactions and land-atmosphere interactions, allowing for the investigation of additional processes relevant for the climate system. In particular, the COSMO-ART version including a detailed representation of atmospheric chemistry and aerosols, the COSMO-M7 version including a multi-modal representation of aerosols, and the COSMO-CLM2 version coupled to a more detailed representation of the land surface component (i.e., the Community Land Model (CLM)) are used within the C2SM community.

The work of Anne Roches (the scientific programmer in charge of the RCM activities) is geared towards refining the COSMO model, providing user support, and facilitating the joint use of COSMO and related codes. In 2010, she has focused on setting up a code repository for COSMO. The main goal of this development was to facilitate the code maintenance by enhancing the traceability and coherence of the many versions used within and beyond the C2SM community. The repository has become available to all members in September 2010 and a training session was held in October for all potential users.

The development of this unified source code management system has considerably strengthened the links between the three institutions (ETH, MeteoSwiss, and Empa) applying COSMO in different configurations. This was also a precondition for the development of the collaborative HP2C project. Finally, this development has also enhanced the ties to the source code development in the COSMO consortium (coordinated by the German Weather Service) and the CLM community (coordinated by the University of Cottbus), and as such enhanced the visibility of the Zurich researchers in these two communities.

Refinement of the model was also performed through, for example, the implementation of an original tracer scheme. Indeed, in the current model, every model configuration handles tracer transport in a different manner. This makes the maintainability of the code more complex (e.g., some pieces of code are redundant) and the introduction of a new tracer rather tedious, even though an increasing number of applications require such features (e.g., the consideration of water isotopes). Adding such a feature to the model may also provide new ventures for applications and collaborations within the C2SM community and beyond, and as such, would be very welcome by the entire COSMO and CCLM communities.

Climate Dataset Analysis

A survey was conducted in 2010 by Dr. Thierry Corti in order to better understand the needs of the C2SM community in terms of support for climate datasets. The survey indicated that a variety of tools are used for analyzing large datasets. For instance, the Climate Data Operators (cdo) ranked among the most popular data processing tools and NetCDF was first among data formats. The survey has resulted in the development of:

- A climate data directory and data dissemination facility. This directory is progressively being populated with large datasets that are used by several C2SM groups and are also subject to changes (i.e. regular retrievals are necessary in order to keep the data up-to-date). In particular datasets (especially multi-model or multi-experiment outputs) such as those provided by the ENSEMBLE European project, or the up-coming Fifth IPCC assessment are retrieved and maintained there.
- A collaborative website to assemble tools, manuals and scripts on data analysis and management, such as instructions on format conversion including sample scripts in often used programming languages.

The survey also revealed that, while many different programming tools/packages are used within the C2SM community, a large group of users is interested in learning and using the NCAR Command Language (NCL), that is, a new post-processing and plotting package that is becoming increasingly popular in the climate community. As a result, three developers of NCL were invited in Zurich to train interested users. In an attempt to harmonize post-processing tools used within the C2SM community, C2SM has strongly encouraged scientists to make use of NCL by providing individual support and developing missing but relevant features for the NCL package which are then passed back to the original developers and shared among the users through the C2SM collaborative website.

PhD Projects

In the following we briefly describe the progress achieved by the C2SM-funded PhD students.

On the potential role of eddies in the oceanic CO_2 uptake

The PhD of Ivy Frenger (jointly supervised by the groups of Prof. Nicolas Gruber and Prof. Reto Knutti) aims at investigating the role of mesoscale oceanic eddies for ocean biogeochemistry and air-sea CO_2 fluxes. This research topic is driven by the recognition that these mesoscale processes are known to be important for ocean dynamics, but their impact on ocean biogeochemistry is poorly understood. The area of interest is the Southern Ocean, which is crucial with respect to air-sea CO_2 exchange and which is also responsible for almost a third of the global oceanic uptake of anthropogenic CO_2 (Gruber et al. 2009). The Southern Ocean is also a region characterized by very intense mesoscale activity.

During the first phase of the PhD work, the relationship between phytoplankton activity and mesoscale eddies was examined on the basis of satellite data south of 30°S. Over 120 000 eddies were identified on the basis of the Okubo-Weiss parameter method using observations of sea level anomaly (Aviso, http://www.aviso.oceanobs.com/) for the period from 09/1997 through 03/2010. The corresponding Chlorophyll-a concentrations were then inferred from ocean color observations (GlobColour Project, http://www.globcolour.info/). The eddies were tracked over time with a correspondence-based approach. The largest amplitudes (> 50 cm) and diameters (> 200 km) of eddies occur in regions of high sea surface gradients in the Antarctic Circumpolar Current and north of the Subtropical Front in the western ocean basins. Nearly one third of the detected eddies lived for one month or more and slightly more eddies were anti-cyclonic than cyclonic (Figure 6).

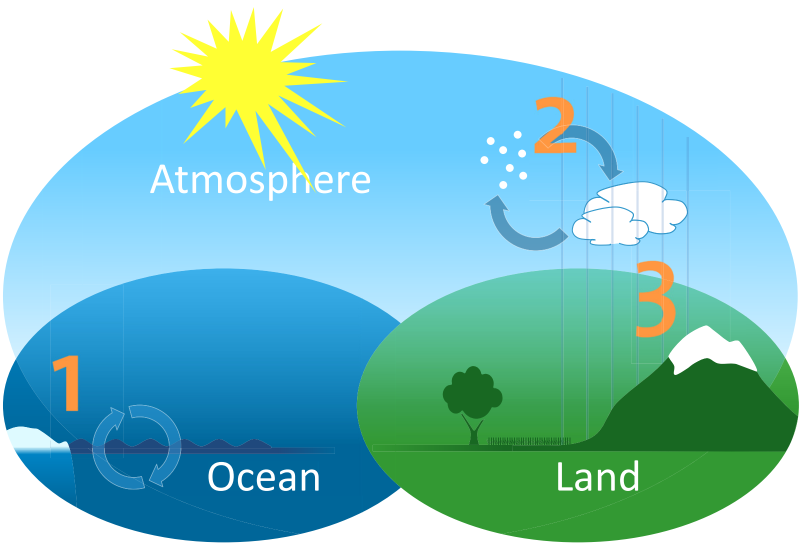

Figure 5. Research projects of PhD students funded by C2SM: (1) On the potential role of eddies in the oceanic CO_2 uptake, (2) Chemistry-aerosol-climate interactions in a regional climate model, (3) Towards kilometer-scale climate modeling.

The results revealed a distinct but spatially variable signal in chlorophyll related to eddies. Overall, eddies contribute about 15% to the total chlorophyll in most of the Antarctic Circumpolar Current and more than 30% in the regions where eddies are largest and most intense. Cyclonic eddies have enhanced chlorophyll concentrations (relative to the background chlorophyll) e.g. north of the Subtropical Front, but reduced concentrations e.g. between the Subtropical and the Polar Fronts. Anticyclonic eddies have the opposite pattern, so that the overall effect of eddies on Southern Ocean chlorophyll is nearly zero. One possible hypothesis is that the spatially heterogeneous imprint of eddies on chlorophyll is caused by the different geneses and dynamics of cyclonic and anticyclonic eddies in concert with differences in bottom-up limitation of phytoplankton by light and nutrients. These findings support the idea that eddies modulate biological productivity and hence carbon fluxes in the Southern Ocean through biophysical interactions. As a result, current work now focuses on applying the regional ocean model ROMS coupled to the biogeochemical-ecological model BEC to investigate the causes of the relations between eddies and biological activity, to quantify the associated carbon fluxes, including air-sea CO_2 fluxes, and to examine their sensitivities to climate change.

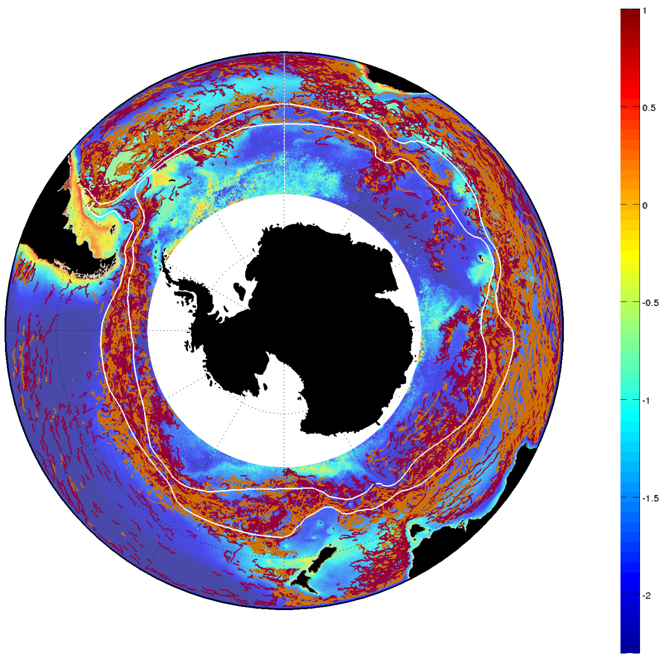

Figure 6. Tracks of cyclonic (orange) and anticyclonic (red) eddies with life spans greater than three months plotted on top of the natural logarithm of mean annual chlorophyll (climatology of 1998 -2009 in mg/mﬃ). The white lines mark the two main fronts of the Southern Ocean, the Polar (inner circle) and the Subantarctic (outer circle) Fronts, which comprise most of the transport of the Antarctic Circumpolar Current. Courtesy I. Frenger, ETH Zurich.

Towards kilometer-scale climate modeling

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. This implies well-known limitations for weather and climate simulations, for instance related to moist convection and complex topography. Through up-scale energy cascades, these limitations feed back to the larger-scale flow and may ultimately contaminate well-resolved scales. For instance, moist convection acting at kilometer scale affects large-scale cloud cover and thereby the sensitivity of the climate system with respect to greenhouse gas forcing.

The overarching goal of the PhD project of Wolfgang Langhans (jointly supervised by Prof. Christoph Schär and Dr. Philippe Steiner's group at MeteoSwiss) is to replace parameterizations of moist convection in an RCM by an explicit representation, using high spatial resolution of at least ~2 km. To this end a version of the COSMO-CLM model is being used and further developed. A key difficulty with this approach is that the spectrum of resolved motions is truncated near scales where convection is active, i.e. an "energy gap" does not exist between resolved and unresolved motions. Thus convective plumes remain under-resolved, and the treatment of small-scale numerical and turbulent diffusion becomes important. The main objective of the PhD is thus to investigate the role of the spatial truncation on the convergence of cloud-resolving simulations in a real-case model set-up.

In a first phase, the role of numerical diffusion and turbulence upon the simulation of convection over the Alps has systematically been investigated. A large set of simulations was conducted and the resulting energy spectra computed and analyzed to follow the propagation of energy across the spectrum. It is found that numerical diffusion indeed influences the simulated convection, even when considering Alpine-scale properties (such as diurnal cycle of precipitation or Alpine-scale overturning of the atmosphere). The study however shows that the contamination of well-resolved scales can be minimized by an appropriate formulation of numerical diffusion (Langhans et al. 2011). The complexity of the associated motions is visualized in Figure 7.

Current work is addressing the numerical convergence of month-long real-case simulations at resolutions between 500 m and 4 km, i.e. it poses the fundamental question to what extent these highly complex modeling systems become independent of key numerical choices. The investigated summer period is marked by strong radiative heating, the development of thermally driven mountain circulations, and the formation of diurnal convection. Preliminary results indicate that the simulations converge in terms of bulk (Alpine scale) fluxes. This would confirm our hypothesis that kilometer-scale simulations are highly useful despite the limited representation of individual convective plumes. A corresponding publication is currently in preparation.

This work contributed towards other cloud-resolving modeling activities at ETH and MeteoSwiss, and has influenced the model set-up in many other studies and simulations, including the PhD project of Linda Schlemmer. Her work is addressing the role of summer convection in an idealized cloud-resolving framework and the role of climate change on convective feedbacks (Schlemmer et al. 2011a, 2011b). Results from the PhD of Wolfgang Langhans have also been used for defining the set-up of the COSMO-CLM model in climate change scenario simulations, which are about to start (funded at a level of 2 PhD students by a SNF project).

Chemistry-aerosol-climate interactions in a regional climate model

Another topic addressed is the interactions between climate, clouds and air pollutants (in particular aerosols), which are 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. This project encompasses two partly funded Ph.D. projects.

The main objective of one Ph.D. project (Christoph Knote, jointly supervised by Dr. Dominik Brunner and Prof. Ulrike Lohmann) is to further develop and evaluate the regional climate model COSMO coupled to a detailed chemistry and aerosol modules, which allows examining the many linkages between air pollutants and climate at a regional level (focusing over Europe and Switzerland). An extensive evaluation of the coupled system revealed that the spatial and temporal variability of observed concentrations of trace gases and aerosols are well captured (Figure 8). Clearly identified deficiencies of the model are a general underestimation of sulfates and secondary organic aerosols but an overestimation of nitrate aerosols (Figure 8). The sulfate and nitrate issues are currently being addressed by introducing a new comprehensive scheme for wet deposition of trace gases and aerosols. A

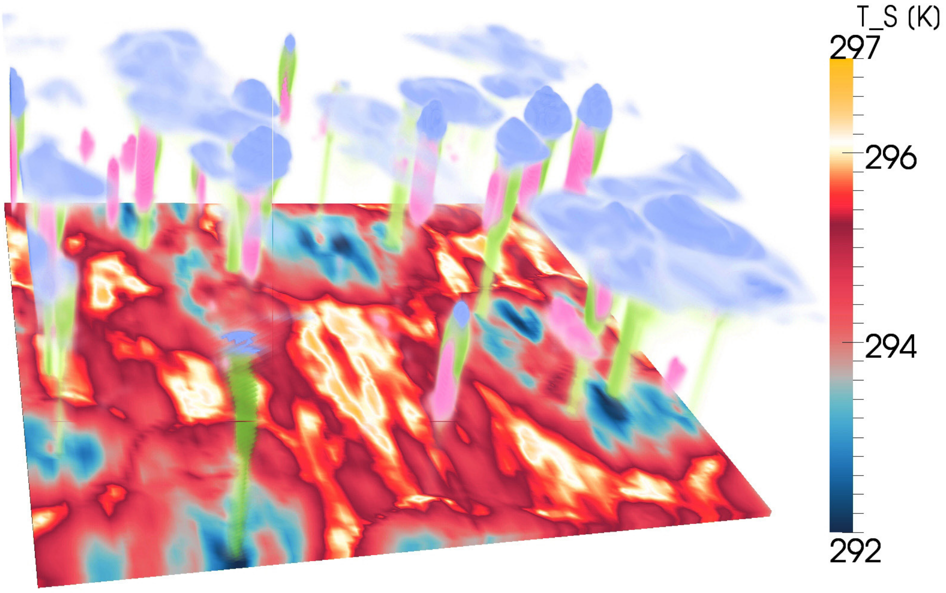

Figure 7. Instantaneous view of diurnal convection in an idealized cloud-resolving modeling framework at 1510 UTC. Pink volumes indicate cloud water, blue volumes cloud ice and green volumes hydrometeors (graupel, snow and rain). The skin temperature is displayed on the land surface with values in K given by the color-code. The domain size is 220x220 km2. Such simulations are used to assess the role of convection over land and its sensitivity to climate change. Courtesy L. Schlemmer, ETH Zurich, Schlemmer et al. 2011a).

further development is an improved interface to external data sets for accurate chemical boundary conditions and new emission inventories. This will enable not only new scientific investigation of aerosol formation processes but will also open new possibilities to support policy development.

In a second PhD project (Sarah Pousse-Nottelmann, supervised by Prof. Ulrike Lohmann), the regional climate model COSMO is applied in conjunction with a detailed aerosol scheme, which allows representing in details the complex cloud-aerosol interactions. The focus is currently put on refining the model by implementing an explicit and detailed treatment of cloud-borne aerosol particles. Application of the improved model focuses on orographic mixed-phase precipitations, which are of special interest for the Alpine regions. Preliminary two-dimensional simulations of idealized orographic clouds indicated that aerosol processing modifies significantly the interstitial aerosol distribution, with implications for the subsequent cloud formation. Next, it is planned to compare results obtained with the improved model to observations of total and interstitial aerosol concentrations and size distribution collected at the remote high alpine research station Jungfraujoch in Switzerland. This PhD work has contributed to a publication on the implementation of aerosol-cloud microphysics in the COSMO-CLM code (Zubler et al. 2011a).

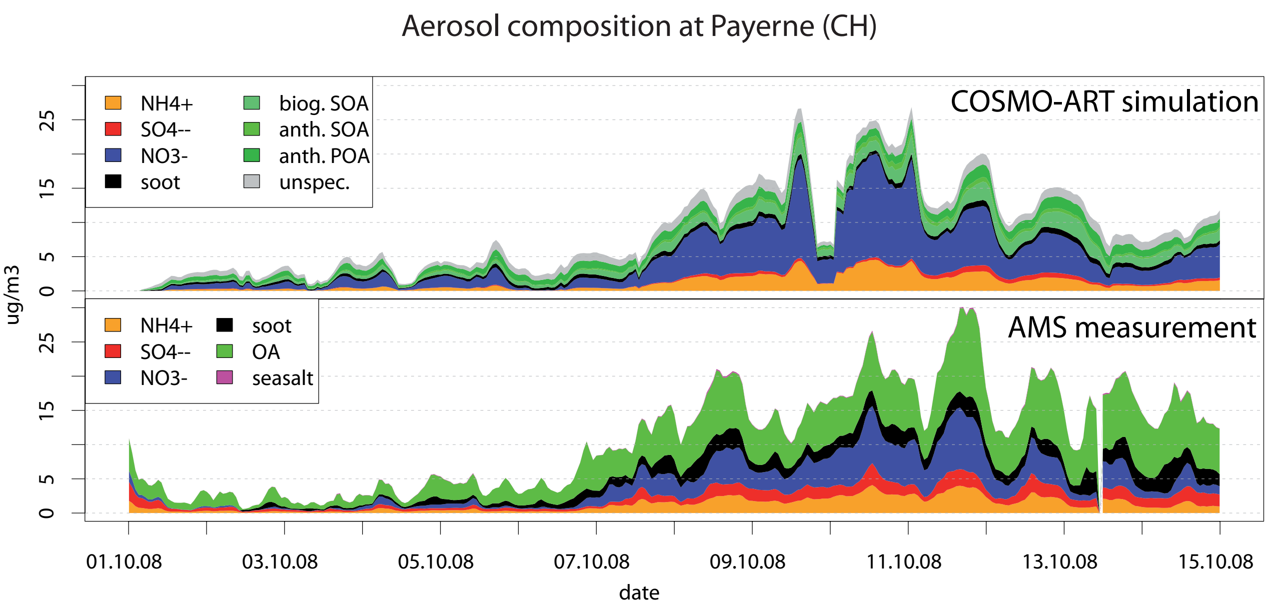

Figure 8. Time evolution of size-averaged chemical composition of sub-micron, non-refractive aerosol mass as simulated by COSMO-ART (top) and measured by an aerosol mass spectrometer (bottom) at NABEL measurement station Payerne (CH) for the period 10/01/08 to 10/15/08. Components represented are inorganic ions (NO3-, SO4--, NH4+), soot, total organic material (OA), and sea salt. In the simulation, organic matter is subdivided in secondary (biogenic SOA, anthropogenic SOA) and primary components (anthropogenic POA). Component 'unspec.' represents additional, unattributed particulate matter of anthropogenic origin. Courtesy C. Knote, Empa.

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.

C2SM has also contributed to communicate scientific results (for example, by publishing 4 editions of the C2SM Newsletter) and by writing articles for the ETH-Klimablog on a regular basis.

In addition, C2SM organized a number of outreach and scientific events, including:

Climate Change Scenario Workshop, ETH Zurich, 2 March 2010
C2SM organized a "Climate Scenario Workshop" with the goal to assess the scientific methods for developing climate scenarios and to provide information on the availability and usability of climate change scenarios for Switzerland.

International speakers shared their experiences with similar initiatives in other European countries and further discussions were engaged with end-users of climate data. About 200 individuals attended the workshop, illustrating the strong interest in, and need of, climate scenarios for Switzerland. Further information about the workshop can be found here: http://www.c2sm.ethz.ch/news/scen_workshop.

ECHAM-HAMMOZ user workshop, 25/26 March 2010, ETH Zurich
In March 2010, a HAMMOZ user workshop was held at ETH. The workshop welcomed about 30 users from various European countries and was a great opportunity to exchange about on-going and planned developments and applications within the community.

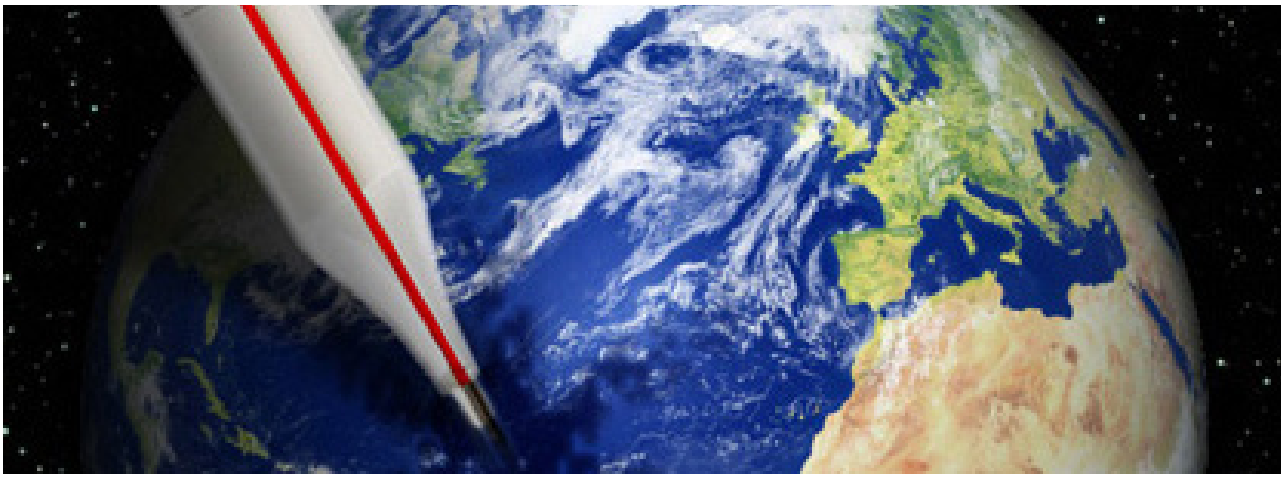

Figure 9. C2SM regularly contribute to the ETH-Klimablog.

NCL workshop, 30 August-2 September 2010, ETH Zurich.

A training workshop was organized for the NCL language and three developers of NCL were invited in Zurich to train interested users. The workshop was very well received as about 30 scientists from ETH Zurich, MeteoSwiss and University of Bern attended the workshop.

COSMO users workshop, 16 December 2010, ETH Zurich:

A COSMO user workshop was organized on 16 December 2010 at ETH. The goal of the workshop was to bring together the Swiss users of the COSMO model in various configurations so that they can learn about the latest development performed in different groups and to foster the establishment of collaborations. This event was particularly important in bringing together the different communities that work with the COSMO model, including for example, those interested in weather prediction, climate and land-atmosphere interactions, and air quality. About 30 people attended the workshop.

Figure 10. People gathering after the Climate Change Scenario Workshop, 2 March 2011, ETH Zurich. Courtesy G. Frontoso, C2SM

Concluding remarks and outlook

Overall achievements in 2010

Since its constitution in fall 2008, C2SM has established itself as a structure that fosters the development of joint research proposals, manages large research projects, and provides technical support in climate modeling and climate data analysis to a large community. During the last year (2010), the primary goal has been to consolidate the activities initiated during the first period (in 2008-2009, see first Annual Report).

In particular, climate modeling activities within the C2SM community have been facilitated by the development of (i) cross-institutional source code management systems to facilitate the management and traceability of different model versions and (ii) refined climate models through the implementation of new scientific features into one single framework and model version. The management and handling of climate data has been greatly improved through the collection and harmonization of datasets and the related processing tools needed for their analysis. The usage of common plotting and analyzing tools has been promoted through the Center. Third-party funding has been acquired to tackle the challenge of preparing for and exploiting the next generation of high-performance computers.

Overall, the activities developed in the frame of the Center have contributed to greatly strengthen the existing collaboration within the funding institutions and beyond (e.g., with CSCS, DWD, MPI-Met, NCCR-Climate, etc.) and to substantially improve the national and international visibility and coherence of the scientific climate community in the Zurich area.

Feedback from the Scientific Advisory Board

These first successful achievements were clearly recognized by the C2SM Scientific Advisory Board (SAB) who held its first meeting in November 2010 in Zurich. As part of its feedback, the SAB reported that "the Centre has during its first phase of development made significant progress on several fronts", through, for example, the establishment of inter-disciplinary research and co-operative activity between core partners and the development of a solid technological/logistical platform for facilitating modeling activities. In order to help the Center to "build upon, realize, and exploit its enormous potential", the SAB has encouraged the Steering Committee to "develop an ambitious long-term strategy that articulates clearly its vision and distinctiveness".

Outlook to 2011

In the coming months, C2SM will remain committed to provide the best possible technical support and scientific coordination. Particular emphasis will be given to:

- Finalizing and disseminating the CH2011 Swiss climate change scenario (report and data set) and organizing an event for their official release;
- Pursuing the development of the new, improved, version of the ECHAM6-HAMMOZ model and assessing its skills with respect to a suite of relevant observational datasets;
- Pursing the refinement of the COSMO-CCLM model and its adaptation for a most efficient use of current and future computing architectures;
- Coordinating the retrieval and maintenance of a number of dataset related to the up-coming IPCC assessment to be used by a large community within C2SM.

In addition, a large effort will be devoted to the preparation of the 2nd phase of C2SM as the contract between ETH, MeteoSwiss, and Empa runs until

31.06.2012. Initial discussions with the ETH Vice-Presidency for Research and Corporate Relations have started and have provided detailed guidelines with regard to the next steps towards the 2nd phase of C2SM. In June 2010 the C2SM Plenary Board meeting has approved the basic planning regarding these steps. In October 2010, the scientific strategy has been refined and approved in a C2SM open science workshop. There, the decision was taken to prepare the submissions of two scientific proposals including

- A collaborative project (Sinergia) proposal to quantify greenhouse gas fluxes (carbon dioxide and methane) and their sensitivity to climate variations, to be submitted on 15 January 2011 to the Swiss NSF.
- A Collaborative, Highly Interdisciplinary Research Projects - stage 2 (CHIRP2) proposal to examine the processes related to the water cycle across a wide range of spatial-temporal scales, to be submitted on 1 march 2011 to ETH.

Finally, a formal request for the 2nd phase of C2SM will be submitted to the ETH Vice-Presidency for Research and Corporate Relations in fall 2011.

Key publications of C2SM Members

Here we list key selected publications from C2SM members published in 2010, along with references mentioned in the text.

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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

Materials Science & Technology