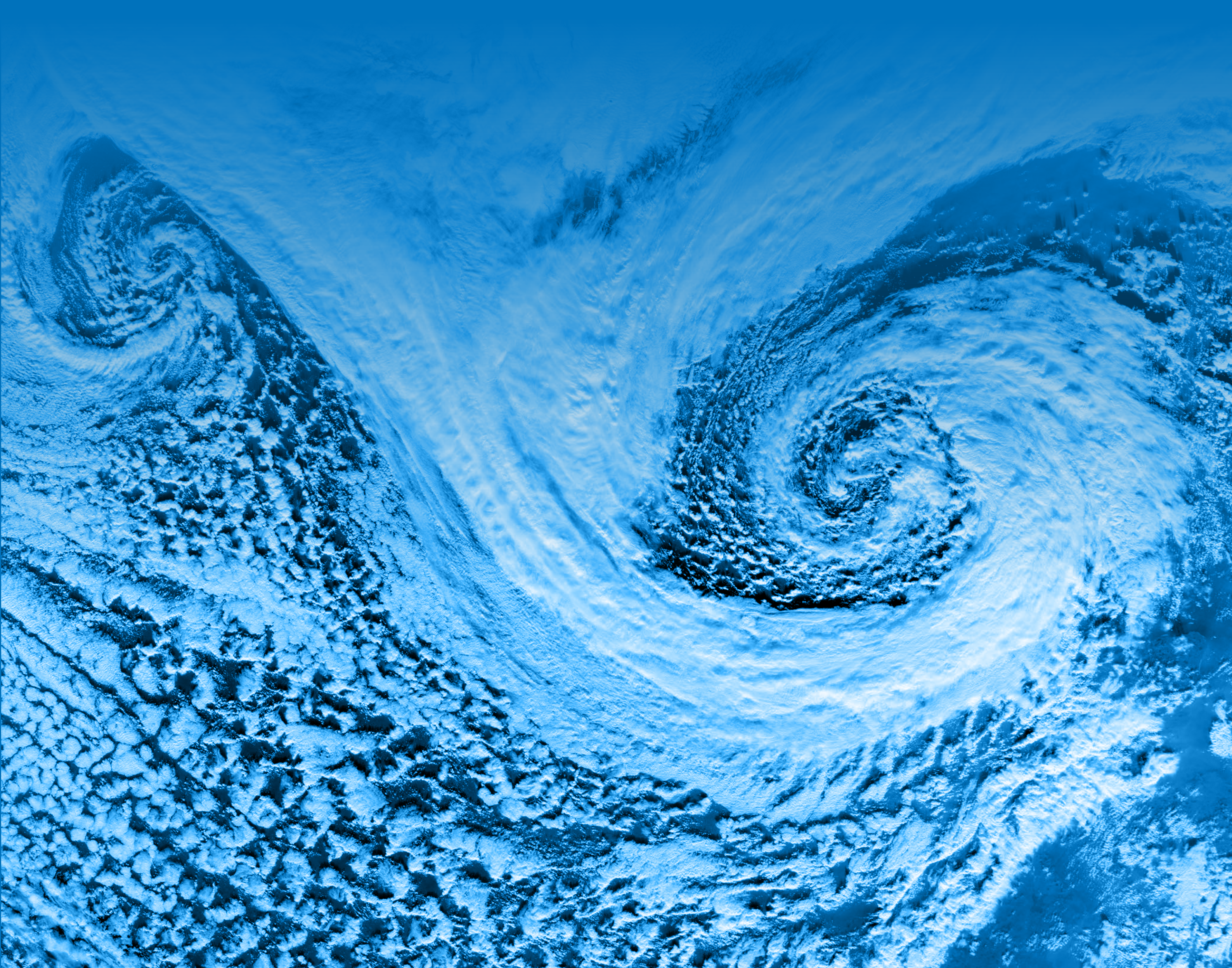
ETH zürich

C2SM

Annual Report 2019



C2SM
Center for Climate Systems Modeling

The Center for Climate Systems Modeling (C2SM) is a competence center based at ETH Zurich and a joint initiative between ETH Zurich, MeteoSwiss, Empa, WSL, and Agroscope 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. The center was established in 2008 and is now in its third phase (January 2017 – December 2020). This document highlights the main achievements in 2019.

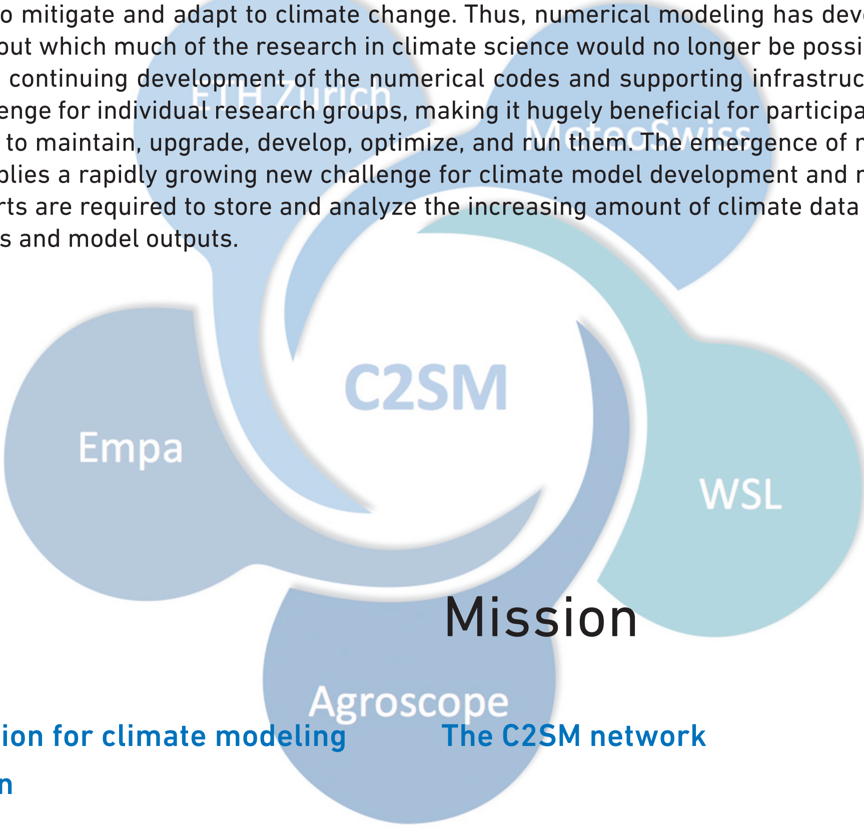
The C2SM Steering Committee, August 2020

Table of Contents

About C2SM

The Climate Modeling Challenge

Climate change is a challenging scientific issue that involves a multitude of complex, non-linear processes operating over a wide range of spatio-temporal scales in all sub-components of the Earth system. Over the last decades, numerical models have increasingly been used in research and service activities related to climate change. They now form the backbone for many applications including short-term weather forecast, climate data assimilation, seasonal climate prediction, climate predictions and projections (from decades to centuries), process and attribution studies, and the testing of strategies to mitigate and adapt to climate change. Thus, numerical modeling has developed into the third pillar of science, without which much of the research in climate science would no longer be possible.
At the same time, the continuing development of the numerical codes and supporting infrastructure is becoming an insurmountable challenge for individual research groups, making it hugely beneficial for participating groups to share models and the tasks to maintain, upgrade, develop, optimize, and run them. The emergence of new supercomputing architectures also implies a rapidly growing new challenge for climate model development and maintenance. In addition, coordinated efforts are required to store and analyze the increasing amount of climate data currently generated, including observations and model outputs.



Vision

A premier institution for climate modeling and data provision

The core aim of C2SM is to provide expertise, know-how, and infrastructure to enable and enhance the partners' research portfolios and to foster synergies between the partners in the areas of weather and climate sciences, atmospheric transport, chemistry, and aerosol research, climate risks and impact, as well as agricultural applications. In particular, we aim to exploit the favorable constellation with ETH Zurich, MeteoSwiss, and CSCS to push forward in high-performance computing in the area of weather and climate modeling, which has been identified as one of the grand challenges not only in high performance computing, but also in the area of environmental sciences. The plan is to build on the success stories of previous HPC projects and strengthen these links, building a world-leading center for climate modeling.

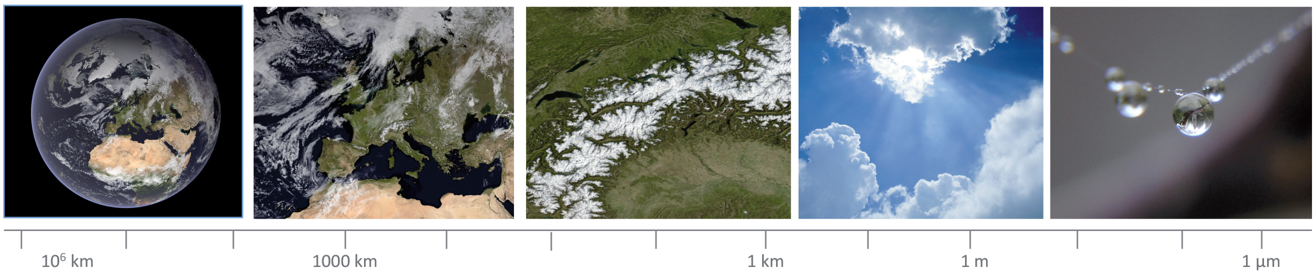
Mission

The C2SM network

The center's mission is to provide a technical and scientific platform and a network for its partners institutions

- to support the development and application of complex models of the weather and climate system and the analysis and visualization of climate data,
- to enable and facilitate collaborations within the C2SM's community and beyond,
- to exploit synergies among the partner institutions,
- to engage in a dialogue with the general public and other stakeholders about climate-relevant issues.

C2SM also acts as the primary entry and interaction point for ETH, for national and international institutions, and for society at large on issues related to climate and climate change.



Research Theme

Scientific strategy

In C2SM's third phase (2017 through 2020), we focus on building ICON as the common model platform for the C2SM community. We further work in the area of high performance computing taking advantage of the opportunities that arise from current developments in climate modeling and from the unique setting of partners that are brought together by C2SM. Specifically, we propose to strongly enhance the collaboration with CSCS and MeteoSwiss and to focus our technology/research efforts on (i) model consolidation around the ICON model, (ii) the development of the next generation of modeling platform for weather and climate, (iii) the development of methods and tools to analyze massive amounts of data, particularly in the context of the Swiss Climate Scenarios, and (iv) to integrate nearby science fields such as climate impact and atmospheric chemistry research into the core weather and climate activities exploiting the already existing close collaborations and the locational advantage of the ETH domain institutions. In addition, we continue providing specific services, training and outreach, building on the competences, products, and successes that were acquired and developed since 2008.

Activities

C2SM coordinates a world-leading network of research institutions and experts. It strongly relies on its affiliated research groups to provide the respective disciplinary expertise and capabilities to advance the frontiers of knowledge in their research fields. C2SM sees its primary role in bringing together the climate research community and integrating this knowledge base, as well as providing central technical, educational, and outreach services to the benefit of the whole community.

A key set of activities aims to foster interdisciplinary research and interactions across disciplinary boundaries. A second set of activities centers around establishing a common and coherent modeling framework that allows the community i) to bridge the gap between different spatio-temporal scales and between the different atmospheric, hydrological, oceanographic, and terrestrial components of the climate system and ii) expand on new research themes. These enable the partner groups and institutions to undertake the challenging model development and applications studies that would otherwise not be possible.

Research coordination

- To foster the collaboration between research groups by facilitating scientific discussions and exchanges.
- To coordinate the development of large, collaborative research projects and to further manage them.
- To develop a common modeling strategy that enables the development of new and original research avenues. Of particular importance is the planned consolidation of the supported model families through adopting the ICON weather and climate model.

Support for research activities

- To continue to maintain, improve, and provide to the center's community a hierarchy of state-of-the-art climate and climate-related models. In particular, the center is responsible for maintaining and refining both a global and a regional climate model, as well as the associated modules e.g., for aerosols, atmospheric composition, (biogeo)chemistry, oceans, land surfaces, and clouds.
- To pro-actively gain expertise in the ICON model and support the members to transition to this model.
- To exploit and disseminate key national and international data sets by providing a repository for them and by developing analysis and data management tools.
- To support the ETH members in organizing funding for data storage and computing nodes.
- To prepare for the exploitation of the next generation of high-performance computers.

Education and training

- To contribute towards an improved training of PhD students through the establishment of projects across research groups, institutions, and disciplines.
- To train scientists (PhD students, post docs, etc.) in the areas of data visualization, data analysis, use and interpretation of climate data, programming, and data management.
- To continue organizing the Swiss Climate Summer Schools jointly with the Oeschger Center for Climate Research at the University of Bern.

Outreach and events

- To continue raising public awareness related to climate and weather through various channels while focusing on linking with other relevant themes, for which climate change has implications. The primary avenues will be the well-established "Klimarunde" and public outreach events such as Scientifica.

Governance

Structure, Organization, and Personnel of C2SM

The center was established in 2008 by the funding partners ETH, MeteoSwiss, Empa, and Agroscope, and became operational in March 2009. WSL joined the center in 2013 to enhance the collaborations and respective expertise in the area of climate change and climate change impact. In January 2017, C2SM entered its third phase, which covers the four-year period 2017 through 2020.
As of 31 December 2019, the center includes 42 members, who are professors or senior scientists at the partner institutions (see Annex for a detailed list) and form the center's Plenary.
The C2SM community includes all students, postdoctoral fellows, and technical and scientific staff from the research groups of each member and thus represents a group of over 400 people. Six members out of 42 form the Steering Committee (SC), who defines the overall strategy and oversees its implementation. The SC elects a chair and co-chair from its members. The Scientific Advisory Board (SAB) consists of recognized individuals from different Swiss and European institutions and advises and supports the center in its strategic planning (see Annex).
Operationally, the center is run by an executive director, who oversees an administrative office composed of scientific programmers, a PR and communication specialist, and an administrative assistant. The scientific programmers are active in two main focus areas: Global Climate Modeling (GCM) and Regional Climate Modeling (RCM). Two 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 areas. The center also supports three software developers through specific research projects acquired by C2SM and its members (see page 26 for more details on the current projects). The structure and organization of C2SM is described in greater detail in the Terms of Reference, that can be downloaded from the C2SM website.

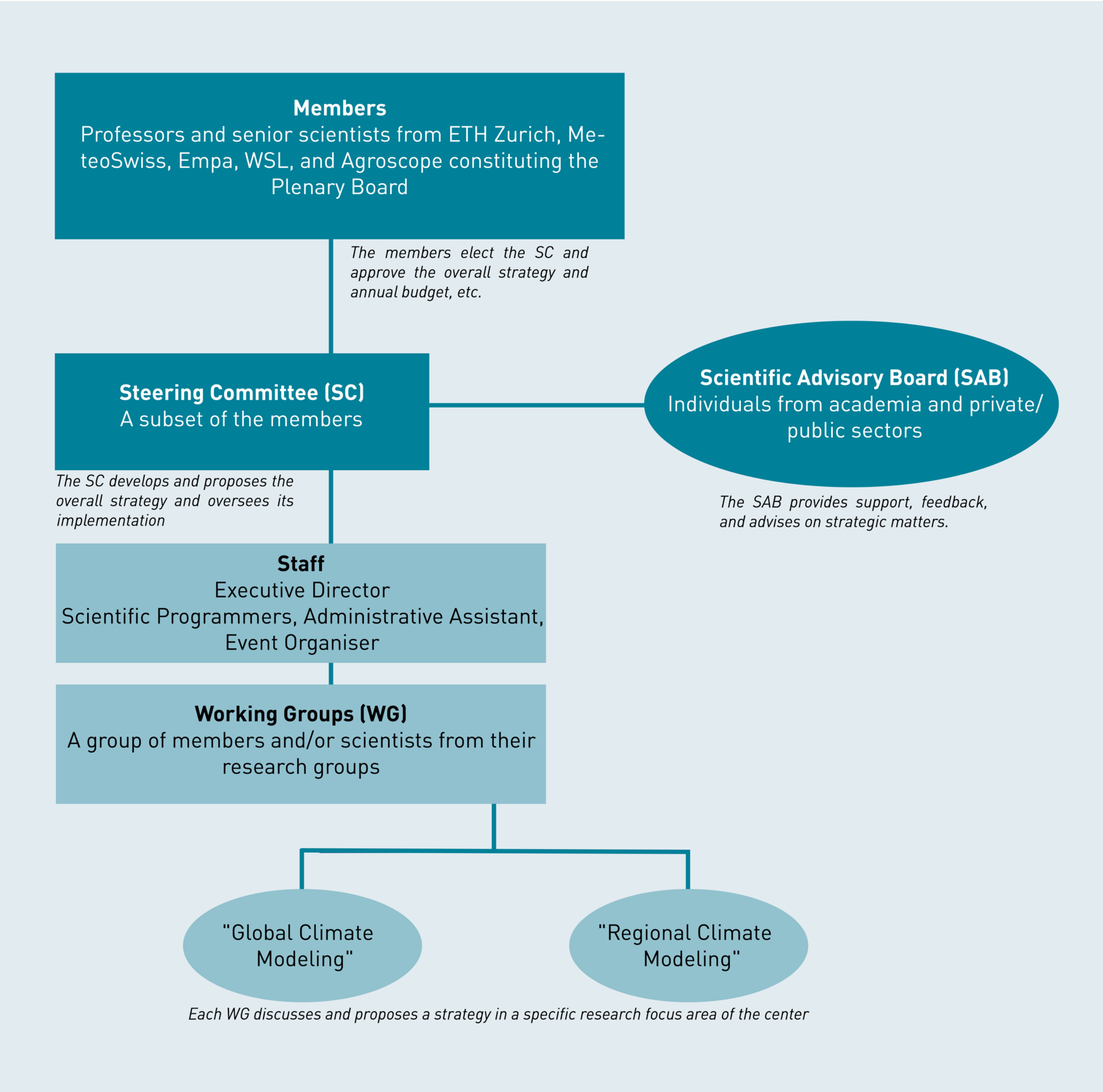
www.c2sm.ethz.ch/the-center/documents.html

Core staff

Role	Name
Executive director	Christina Schnadt Poberaj
Administrative assistant	Rahel Buri
Scientific programmer "Global climate modeling"	Colombe Siegenthaler-Le Drian, Urs Beyerle
Scientific programmer "Regional climate modeling"	Katherine Osterried
Scientific programmer "Scientific visualisation	Tarun Chadha
PR and Communication	Tanja Meier

* As of 31 December 2019, the core staff corresponds to a total of 3.75 FTE. The administrative assistant is directly supported by the Institute for Atmospheric and Climate Science, and only paid by C2SM to a small fraction. In addition to the core staff, project fellows and research assistants are supported through funding from different projects.

www.c2sm.ethz.ch/the-center/people.html


Members
Professors and senior scientists from ETH Zurich, MeteoSwiss, Empa, WSL, and Agroscope constituting the Plenary Board
The members elect the SC and approve the overall strategy and annual budget, etc.
Steering Committee (SC)
A subset of the members
Scientific Advisory Board (SAB)
Individuals from academia and private/ public sectors
The SC develops and proposes the overall strategy and oversees its implementation
The SAB provides support, feedback, and advises on strategic matters.
Staff
Executive Director
Scientific Programmers, Administrative Assistant, Event Organiser
Working Groups (WG)
A group of members and/or scientists from their research groups
"Global Climate Modeling"
"Regional Climate Modeling"
Each WG discusses and proposes a strategy in a specific research focus area of the center

Main Achievements

C2SM and its community have contributed to the successful acquisition and subsequent implementation of several large collaborative projects addressing a range of topics, particular in the area of high-performance computing.

Research Coordination

Highlight: Transition from competence to extradepartmental center

C2SM's current third phase will end in December 2020. According to ETH's regulations, it cannot be continued as a competence center anymore after that. Since 2016, C2SM has been preparing to be transferred to a long-term institution at ETH. As one preparational measure for ETH school board to decide on whether and how to continue C2SM after 2020, in December 2016 the school board requested an external evaluation of C2SM to take place in 2019. In addition, it requested the partner institutions to confirm their long-term commitment.

With the external evaluation and the end of the third phase nearing, the year 2019 was marked by a strong and joint effort towards the school board's decision on the fate of C2SM expected for the end of the year. An important milestone was the external evaluation in August 2019, for which the SC and the Executive Director in collaboration with the C2SM members prepared a self-evaluation and a business plan. The latter lays the fundament for C2SM's strategy and orientation with regards to contents and finances for the period 2021-25. Among others, C2SM conducted two member workshops in February 2019 to shape the documents, in particular the business plan.

For the external evaluation, a committee of four renowned national and international scientists from the field was set up. It was chaired by the director of Max-Planck Institute for Meteorology and chair of C2SM's scientific advisory board, Bjorn Stevens. The committee stressed the successes of C2SM of the past and strongly recommended a longer-term perspective for the Center: "The weather and climate research community in and around ETH is, in its quality and breadth, unsurpassed worldwide. [ ] C2SM gives a face to this expertise and in so doing greatly raises the profile of climate change science at ETH, in Switzerland, and internationally. [ ] After eleven years of existence, and a track record of important achievements, it makes sense to put the funding of C2SM on a more permanent footing, which would ensure planning security for all those involved, especially the partner institutions."

Finally, at an all directors' meeting in the middle of October 2019, the commitment of all partner institutions was settled.

In December 2019, C2SM was approved by ETH school board to be transitioned to an extradepartmental science center with a long-term perspective to be effective January 2021. As such, C2SM will directly report to the Vice-president for research. The decision implies a roughly doubled budget from ETH. In addition, the Department of Environmental Systems Science and MeteoSwiss also increased their contribution, and together with the continuing strong financial support by Empa and WSL, we are looking ahead on the basis of an excellent funding base. While C2SM no longer has a sunset clause, such an extradepartmental science center will undergo a review every five years.

High Perfomance Computing

Recent years have seen immense progress in our capacity to predict weather and climate evolution using numerical models. An important driver for this development has been the rapid progress in high-performance computing (HPC). It is expected that with the further increase of high-performance computing capacity, the computational resolution of such models will continue to be refined in the next decades. From a computer science perspective, this strategy poses major challenges. First, harvesting the computational capacity of emerging HPC architectures increasingly involves the use of heterogeneous many-core architectures consisting of both CPUs and accelerators (e.g., GPUs). The efficient exploitation of such architectures requires a paradigm shift and has only just started. Second, continuously adapting state-of-the art weather and climate models to emerging and new hardware and the associated programming models poses a formidable challenge, as these models typically entail huge code bases maintained by a large community of domain-scientists.

For almost a decade, C2SM has actively been contributing to this development preparing climate codes for the next generations of high-performance computers to exploit emerging computing capabilities. C2SM has been strongly collaborating with MeteoSwiss, ETH groups, and CSCS, and has been involved in several consecutive projects of the Swiss initiative for High Performance and High Productivity Computing (HP2C) (e.g., HP2C-COSMO, HP2C-OPCODE, and HP2C-POMPA) and since then has been contributing to the follow-up initiative, the Platform for Advanced Scientific Computing (PASC), where it was previously involved in the projects CLAW and GridTools. Currently, C2SM is involved in two PASC-related projects, ENIAC and PASCHA.

www.c2sm.ethz.ch/research/High_Performance_Computing

PASC ENIAC

The aim of the ENIAC project (July 2017 – June 2021) is to adapt the numerical weather prediction and climate model ICON to new hardware technologies such as GPUs and investigate the question of performance portability. ENIAC is a collaboration between ETH Zurich, C2SM at ETH Zurich, CSCS, and MPI of Meteorology in Hamburg, Germany (MPI-M). The port to GPU is based on OpenACC compiler directives for most components, except for the soil model JSBACH which is automatically ported using the CLAW compiler developed as part of the project. In the past year major progress has been made to port the code for global climate application to GPU and a first set of physical parameterizations has been completed. First test simulations for the “Quasi-Biennial Oscillation in a Changing Climate” (QUBICC) project lead by MPI-M have been carried out, running the code on up to 2000 GPU nodes at 2.8 km horizontal resolution. Single socket comparison shows a speed up factor of about 5 on GPU as compared to CPU. Thanks to the achievement reached, the project was granted an extension until June 2021. C2SM employed the software developers Valentin Clément and Philippe Marti on this project until summer 2019.

www.pasc-ch.org/projects/2017-2020/eniac-enabling-the-icon-model-on-heterogeneous-architectures

PASC PASCHA

The aim of the PASCHA project (July 2017 – Jun 2021) coordinated by Prof. Hoefler (D-INF, ETH), is to provide portability for the COSMO model (avoid- ing the GPU vendor lock), increase the productivity of programming models like domain specific languages (DSLs) adopted in production and enhance the performance on accelerators by integrating a new functional parallelism (in addition to data parallelism) into the COSMO model. In the last year an implementation using asynchronous directives of OpenACC and the use of OpenMP tasking for the parameterizations has been investigated..

The high-level DSL toolchain dawn is being developed as part of the project. The language provides a Matlab-like high level syntax that increases the productivity of model development. Further extensions have been developed, in particular to support non-structured grid, which could be applied to the ICON model.

The project was granted an extension until June 2021. C2SM core staff K. Osterried contributes to this project.

www.pasc-ch.org/projects/2017-2020/pascha/

WEW-COSMO

WEW-COSMO (Weiterentwicklungen COSMO) is a research and technical development collaborative project hosted at C2SM, funded by MeteoSwiss and partly by the consortium COSMO, which focuses on improving the COSMO and ICON weather forecast and climate models for the application in the Alpine region. One focus is on improving parameterisations such as fog, hail, and heavy precipitation. In addition, an ensemble dispersion system is developed and the numerical weather forecast is further developed in the nowcasting range. A second focus of the project is on adapting and testing the COSMO and ICON models to be used on hybrid high-performance architectures. The project is a collaboration between ETH Zurich, C2SM at ETH Zurich, and the Federal Office for Meteorology and Climatology MeteoSwiss. The project started in 2017 and will continue until the end of 2022.

As part of the high-performance component IMPACT (ICON on Massively Parallel ArchiteCTures) of WEW-COSMO, first steps were taken to run ICON-LAM on GPU. Since code executed on GPU cannot produce bit-identical output to the CPU, the testing infrastructure in ICON had to be extended. While simple bit-reproducibility tests already existed prior to this work package, more elaborate, probabilistic testing needed for GPU development did not. Therefore a new testing software was written that computes the spread of a perturbed model ensemble to estimate the expected growth of errors due to numerical differences arising from different hardware. This test is operational in ICON's continuous integration system since summer 2019 and has already detected several bugs in the GPU implementation. Based on this solid testing environment, GPU-capable code for the microphysics (graupel), turbulence (tiedke) and land (terra) parametrizations could be implemented and is now continuously tested and maintained. C2SM employs software developer R. Dietlicher on this part of the project.

Visualization of Ensemble Dispersion Simulations at MeteoSwiss

The emergency response to atmospheric release of radioactivity strongly relies on particle dispersion simulations. These are driven by numerical weather prediction models, which are increasingly run as ensembles to estimate meteorological uncertainty. In the framework of the project EMER-Met, MeteoSwiss is developing an ensemble dispersion simulation tool chain comprised of multiple FLEXPART dispersion simulations driven by one of the new COSMO ensembles. Visualizing this new ensemble information is the main task of C2SM postdoc Stefan Rüdisühli. Starting in May 2019, he has been developing a new software to visualize both deterministic and ensemble dispersion simulations, and created first prototype ensemble products. In addition, he has contributed to the single precision implementation of COSMO required to run the operational COSMO ensemble that will drive the new ensemble dispersion simulations.

www.c2sm.ethz.ch/research/wew-cosmo.html

Other projects

SDSC Carbosense4D

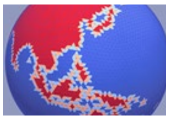
The project CarboSense4D, funded by the Swiss Data Science Center (SDSC), combines atmospheric CO_2 measurements from a dense network of more than 250 sensors across Switzerland with data science methods and atmospheric transport simulations to better understand the sources and distribution of CO_2 over Switzerland. The project was directed by Empa and included strong collaboration with the companies Swisscom and Decentlab, which supported the installation of the network and ensured an efficient data communication through the Internet-of-Things.
In CarboSense4D, Empa developed a high-resolution CO_2 model based on the atmospheric transport model COSMO-GHG, which simulates the natural components of atmospheric CO_2 from vegetation photosynthesis and respiration and the anthropogenic components from emissions from traffic, industry, etc., separately. SDSC developed algorithms for measurement outlier detection and for the spatial mapping of the sensor data using Gaussian Process modelling. C2SM visualization expert T. Chadha created several videos in support of project outreach, which show the evolution of the measurement network and visualize the individual components of CO_2 as simulated by COSMO-GHG.
Empa is currently securing new financial resources and collaborations to ensure the continuation of these worldwide unique CO_2 measurement and modelling activities.

www.carbosense.ch

Support for Research Activities

C2SM provides community support in the area of global and regional climate modeling and scientific visualization.
www.c2sm.ethz.ch/services.html

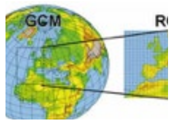
Global climate modeling



The global climate modeling activities at C2SM focused on the next generation weather and climate model ICON (ICOsahedral Nonhydrostatic Model). ICON is a joint project between the German Weather Service and MPI-M for developing a unified next-generation global numerical weather prediction and climate modeling system. The ICON model has been introduced into DWD's operational forecast system in January 2015 and will substitute the operational weather forecast model COSMO deployed at MeteoSwiss in 2022. C2SM aims at making ICON one of its main tools to enable atmospheric science at C2SM from the local to the global scale, covering numerical weather prediction, as well as weather and climate modeling. Activities in 2019 related to ICON included the construction and documentation of a repository on GitHub for C2SM users (ICON-C2SM), which contains ICON, as well as a first version of ICON-ART and related tools (ICON TOOLS). The ICON versions in C2SM-ICON have been installed and support was provided for new users. C2SM also organized ICON meetings for its community members at three-monthly intervals to exchange on technical issues around running ICON. During the transition time, the comprehensive aerosol (HAM) is still supported by C2SM, and input files for the World Climate Research Program (WCRP) Aerosol Chemistry Model Intercomparison Project (Aer- ChemMIP) were prepared. Moreover, C2SM developed a first version of an automatized sanity checker for global models and performed the scalings and benchmarkings of the model on Piz Daint (CSCS) for the technical part of a production proposal.

wiki.c2sm.ethz.ch/GCM/WebHome

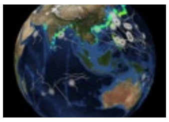
Regional climate modeling



The regional climate modeling activities at C2SM have traditionally focused on the COSMO model, a limited-area atmospheric model developed by the Consortium for Small-Scale Modeling (COSMO), including MeteoSwiss and other European meteorological services. Beginning in 2019, some activities in the RCM modeling group have also involved the ICON atmospheric model, because C2SM members are now beginning to use ICON for regional climate modeling. Activities in 2019 included porting of the M7 addition to the ART aerosol model, which was developed during the PhD work of Franziska Glassmeier in the group of Ulrike Lohmann,into the official ART code. The ART-M7 code is now regularly maintained and fully compatible with the latest version of the COSMO model. Additionally, a tolerance testsuite was adapted from the COSMO model for the ICON modeling framework to facilitate the porting of the ICON model to GPUs.

wiki.c2sm.ethz.ch/COSMO/WebHome

Scientific visualization

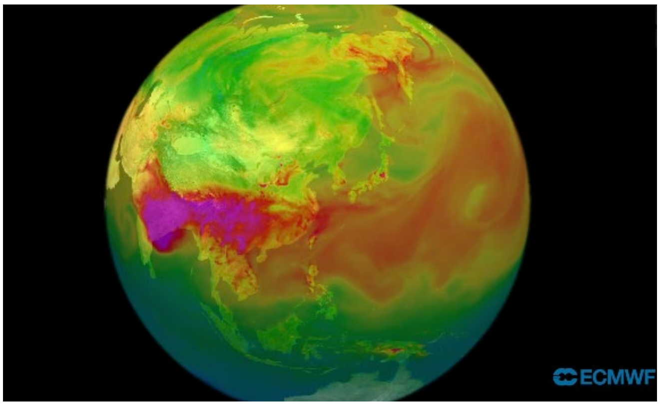


Scientific visualization and web programming service was being offered to the C2SM community since 2016 and suspended at the end of March 2020. This activity was carried out in collaboration with the ETH Scientific IT Services (SIS). While the service was running, any C2SM-affiliated research group (PI) could apply for the service following an established process (for details, see Annual Report 2017 and the C2SM visualization website). A large part of the visualizations created via this service can be viewed at C2SM's Vimeo channel "C2SM Weather and Climate Visuals" (https://vimeo.com/user92148307).

Some of the visualizations we worked on include

- a stand-alone animation of temperature anomalies for the CH2018 project, combining the past observations and future simulated data;
- an animation together with Prof. Nicolas Gruber showing the increase in surface ocean CO_2. This animation, along with another one we did for Prof. David Bresch, was shown at the "Call for Globes" exhibition in the ETH main building from October 4th-13th 2019;
- an animation highlighting the area of Switzerland under zero degrees during the winter months. We combined past observations and the future model predictions to visually demonstrate the shrinking of this "under zero-degrees region". This animation was shown at the C2SM booth at Klimarunde 2019".

The highlight of the year certainly is the animation done for the European Space Agency (ESY) SmartCarb project, together with Prof. Dominik Brunner (Empa). With the Paris Agreement in place aiming at reducing global greenhouse gas emissions to keep global warming well below 2°C, it is essential to monitor the further evolution of atmospheric CO_2 concentrations, the most important greenhouse gas contributing to climate change. This is why the European Commission (EC) and the European Space Agency (ESA) are planning a future constellation of CO_2 satellites called CO2M, which will be able to image the CO_2 plumes downwind of emission hot-spots such as cities and power plants. In the ESA funded project Smartcarb, the C2SM partner institution Empa conducted high-resolution CO2 simulations with the regional transport model COSMO-GHG nested into simulations of the Copernicus Atmospheric Monitoring Service run by the European Centre for Medium Range Weatherforecasts (ECMWF). The main goal was to study the potential of CO2M to quantify the CO_2 emissions of individual strong sources. To demonstrate how CO2M can successfully monitor CO_2 emissions, a scientific visualization video has been created in a collaboration between the scientific visualization service at C2SM, Empa and the company Visual Music and with financial support by ECMWF. The visualization explains the concept of the CO2M mission by illustrating its capabilities to observe CO_2 globally and to quantify emissions from hot-spots. Two versions of the visualization are now publicly accessible at the C2SM vimeo page, one narrated and the other using subtitles, that are available for inclusion in presentations by scientists and decision makers and for on-screen displays at conferences and meetings upon request.



Watch the video at C2SM Weather and Climate Visuals:

https://vimeo.com/353788629

Education and Training

C2SM organized and carried out several workshops.

Swiss COSMO User Workshop

The Swiss COSMO User Workshop is an informal one-day event whose goal is to bring together COSMO users and developers from Switzerland, share experience and knowledge about the COSMO model, and to get insights into some projects involving this model. Presentations could provide an overview of activities revolving around the COSMO model, the description of a technical problem, the presentation of results from a specific project, or the demonstration of a tool that can be useful for other COSMO users. 50 people registered for the COSMO User Workshop co-organized by C2SM and MeteoSwiss and held at ETH on 21 January 2019. Six new users of the COSMO model were briefly introduced, and 17 presentations were given highlighting the varied uses of COSMO within the Swiss user community. The program and presentations can be found at the C2SM wiki at:

https://wiki.c2sm.ethz.ch/COSMO/EventsCUW2019

Data Management Information Event and Workshop

Good data management is a key prerequisite for effective data sharing and publishing increasing the visibility of one's scholarly work and likely increasing citation rates. Funding organisations like the Swiss National Science Foundation or Horizon 2020 mandate data management plans (DMPs) for projects they fund. The plans are already required at the proposal stage and should be updated throughout the project. In the field of weather and climate modeling, the massive amounts of data produced constitute a particular challenge in terms of data storage, reproducibility, and open accessibility.

On 7 March 2019, C2SM's task force on Data Management carried out a workshop on the topic of best practices in data management. This workshop especially targeted Master and PhD students of C2SM's D-USYS members. Besides an introduction given by U. Beyerle, it covered the topics: 1) how to manage data during the PhD giving lots of examples how not to do it (M. Sprenger); 2) data workflow: from raw data to archiving including explanations of the FAIR principles, recommendations for formats and coding, and data repositories (S. Ferrachat), and 3) finally introductory overview on the version control system Git, which included a concrete application example (C. Siegenthaler).

With 41 registrations, the course was well-attended. A feedback survey showed that in general, the workshop was perceived well and expectations were met to a large extent

wiki.c2sm.ethz.ch/DataManagement/WebHome

Scientific Visualization using Python 2019

In 2019, C2SM carried out two python workshops for their interested community: The first was a one-day course in May 2019 introducing the participants to the basic elements of python. This course was done in collaboration with the Scientific IT Services of ETH (SIS) and carried out by Uwe Schmitt from SIS. In June 2019, a two-day workshop to introduce interested researchers of the C2SM community to visualization in the Python programming language followed. Both workshops were very well received by the C2SM community and fully booked. In particular, the combination of the introductory with the visualization information was appreciated. Based on the popularity and the very positive feedback from the attendees, the workshops are going to be continued on a regular basis. The next workshop is planned for September 2020.

Outreach and Events

C2SM organized two events in 2019 targeting scientists, lay audience, and various stakeholders.

ETH-Klimarunde 2019: Klimawandel in der Bergwelt – Was jetzt?

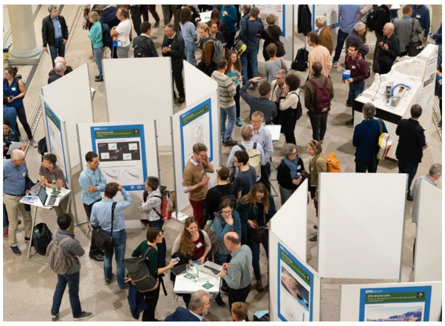
Climate is changing at great speed: temperature at ground level in Switzerland has risen by about 2 degrees Celsius over the last 150 years, twice the global average. Even if global warming can be limited to between 1.5°C and 2°C till the end of the century, regional warming in Switzerland could be significantly higher, at up to 3.4°C.

This has drastic consequences for the Swiss mountains and the Alps in general: We must prepare ourselves for the fact that most glaciers will have disappeared by the end of this century, that there will be less snow, that permafrost in the high mountain regions will thaw, that vegetation will change and that many animal species will be threatened with extinction. Natural hazards are also expected to increase sharply. For example, the rise in temperature will lead to more intensive precipitation, which may result in floods, landslides and debris flows. The melting of ice can also lead to the formation of new glacial lakes, which can be at risk of tidal waves if they are reached by ice or rock breakage.

What are the effects of climate change in our mountains? Which climate change related dangers will threaten the Alps? Will we lack water in the near or distant future when glaciers become smaller or disappear completely? What are neccessary actions to mitigate climate change?

These and other questions were discussed at "Klimarunde 2019". More than 400 people joined the event and engaged into lively discussions. As usual, the first part of the event was dedicated to direct interactions between experts and the public, while the second part featured keynote speakers such as Christoph Schär (ETH), Daniel Farinotti (ETH), and Andrea Burkhardt (BAFU), and featured a panel discussions with yet more experts. The event was jointly organised by C2SM and the Energy Science Center at ETH.

https://c2sm.ethz.ch/events/eth-klimarunde-2019.html



2019 Swiss Climate Summer School

C2SM contributes to the funding and organisation of the Swiss Climate Summer School on a yearly basis, together with the Oeschger Centre for Climate Change Research (OCCR). Every year, C2SM and OCCR alternate to lead the organisation of the school. The 18th International Swiss Climate Summer School was organised by C2SM and focused on 'Carbon and Climate in the Paris World – Getting out of the Fossil Fuel Carbon Budget Crunch'.

The school was motivated by the paradoxical situation wherein the internationally recognized warming targets of 2°C or even 1.5°C imply a tightly limited fossil fuel emission budget for the entire 21st century, while the trends in the fossil fuel emissions suggest that this budget is consumed within the next one to three decades. With conventional mitigation and adaptation options not sufficiently exploited, humankind may need to deploy unconventional methods to meet its climate target. The topics of this highly interdisciplinary summer school centred around

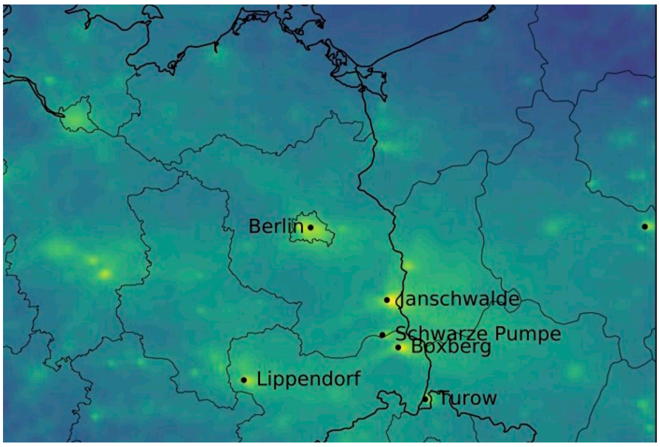
- the nature, size, and controlling processes of this carbon budget,
- the drivers behind past and future fossil fuel emissions,
- the climatic consequences of the Paris agreement,
- the options available to us to create negative emissions,
- and the socio-economic drivers that can either accelerate or decelerate these developments.

A special and particularly well-perceived element of the school were two mornings spent on case studies and the presentation of them on the last morning. In the case studies, smaller groups worked jointly on hypothetical negative emissions technology cases. The participants had to study and take on different stakeholder perspectives, such as company representatives, investor representatives, politicians, and UNFCCC expert. The case studies were supported by the lecturers and also practitioners, e.g. from Climeworks. Each topic was discussed in the form of a public hearing on the last day of the school, with the different participants taking on the roles of the different stakeholders and the other participants acting as the voting assembly.

The school took place on 8-13 September 2019 at Congressi Stefano Francini (CSF) on Monte Verità, Ascona, Switzerland. 57 participants, 11 lecturers, as well as two additional supervisors from C2SM and OCCR joined the summer school. The 2019 Swiss Climate Summer School was sponsored by C2SM and Congressi Stefano Franscini.

Scientific Highlights

Paper: Accounting for the vertical distribution of emissions in atmospheric CO_2 simulations



Inverse modeling of anthropogenic and biospheric CO_2 fluxes from ground-based and satellite observations critically depends on the accuracy of atmospheric transport simulations. Previous studies emphasized the impact of errors in simulated winds and vertical mixing in the planetary boundary layer, whereas the potential importance of releasing emissions not only at the surface but distributing them in the vertical was largely neglected. Accounting for elevated emissions may be critical, since more than 50 % of CO_2 in Europe is emitted by large point sources such as power plants and industrial facilities. In this study, we conduct high-resolution atmospheric simulations of CO_2 with the mesoscale Consortium for Small-scale Modeling model extended with a module for the simulation of greenhouse gases (COSMO-GHG) over a domain covering the city of Berlin and several coal-fired power plants in eastern Germany, Poland and Czech Republic. By including separate tracers for anthropogenic CO_2 emitted only at the surface or according to realistic, source-dependent profiles, we find that releasing CO_2 only at the surface overestimates near-surface CO_2 concentrations in the afternoon on average by 14 % in summer and 43 % in winter over the selected model domain. Differences in column-averaged dry air mole XCO_2 fractions are smaller, between 5 % in winter and 8 % in summer, suggesting smaller yet non-negligible sensitivities for inversion modeling studies assimilating satellite rather than surface observations. The results suggest that the traditional approach of emitting CO_2 only at the surface is problematic and that a proper allocation of emissions in the vertical deserves as much attention as an accurate simulation of atmospheric transport.

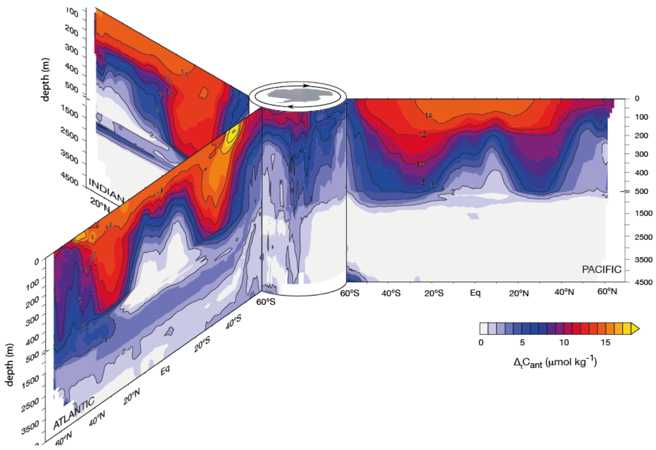
Brunner, D., Kuhlmann, G., Marshall, J., Clément, V., Fuhrer, O., Broquet, G., Löscher, A., and Meijer, Y., 2019: Accounting for the vertical distribution of emissions in atmospheric CO2 simulations, Atmos. Chem. Phys., 19, 4541-4559, doi.org/10.5194/acp-19-4541-2019.

Paper: The importance of mixed-phase and ice clouds for climate sensitivity in the global aerosol-climate model ECHAM6-HAM2

How clouds change in a warmer climate remains one of the largest uncertainties for the equilibrium climate sensitivity (ECS). While a large spread in the cloud feed- back arises from low-level clouds, it was recently shown that mixed-phase clouds are also important for ECS. If mixed-phase clouds in the current climate contain too few supercooled cloud droplets, too much ice will change to liquid water in a warmer climate. As shown by Tan et al. (2016), this overestimates the negative cloud-phase feedback and underestimates ECS in the CAM global climate model (GCM). Here we use the newest version of the ECHAM6-HAM2 GCM to investigate the importance of mixed-phase and ice clouds for ECS. Although we also considerably underestimate the fraction of supercooled liquid water globally in the reference version of the ECHAM6-HAM2 GCM, we do not obtain increases in ECS in simulations with more supercooled liquid water in the present-day climate, different from the findings by Tan et al. (2016). We hypothesize that it is not the global supercooled liquid water fraction that matters, but only how well low- and mid-level mixed-phase clouds with cloud-top temperatures in the mixed-phase temperature range between 0 and −35°C that are not shielded by higher-lying ice clouds are simulated. These occur most frequently in midlatitudes, in particular over the Southern Ocean where they determine the amount of absorbed shortwave radiation. In ECHAM6-HAM2 the amount of absorbed shortwave radiation over the Southern Ocean is only significantly overestimated if all clouds below 0°C consist exclusively of ice. Only in this simulation is ECS significantly smaller than in all other simulations and the cloud optical depth feedback is the dominant cloud feedback. In all other simulations, the cloud optical depth feedback is weak and changes in cloud feedbacks associated with cloud amount and cloud-top pressure dominate the overall cloud feedback. However, apart from the simulation with only ice below 0°C, differences in the overall cloud feedback are not translated into differences in ECS in our model. This insensitivity to the cloud feedback in our model is explained with compensating effects in the clear sky.

Lohmann, U. and Neubauer, D., 2018: The importance of mixed-phase and ice clouds for climate sensitivity in the global aerosol–climate model ECHAM6-HAM2, Atmos. Chem. Phys., 18, 8807-8828, doi.org/10.5194/acp-18-8807-2018.

Paper: The oceanic sink for anthropogenic CO_2 from 1994 to 2007



We quantify the oceanic sink for anthropogenic carbon dioxide (CO_2) over the period 1994 to 2007 by using observations from the global repeat hydrography program and contrasting them to observations from the 1990s. Using a linear regression–based method, we find a global increase in the anthropogenic CO_2 inventory of 34 ± 4 petagrams of carbon (Pg C) between 1994 and 2007. This is equivalent to an average uptake rate of 2.6 ± 0.3 Pg C year−1 and represents 31 ± 4% of the global anthropogenic CO_2 emissions over this period. Although this global ocean sink estimate is consistent with the expectation of the ocean uptake having increased in proportion to the rise in atmospheric CO_2, substantial regional differences in storage rate are found, likely owing to climate variability–driven changes in ocean circulation.

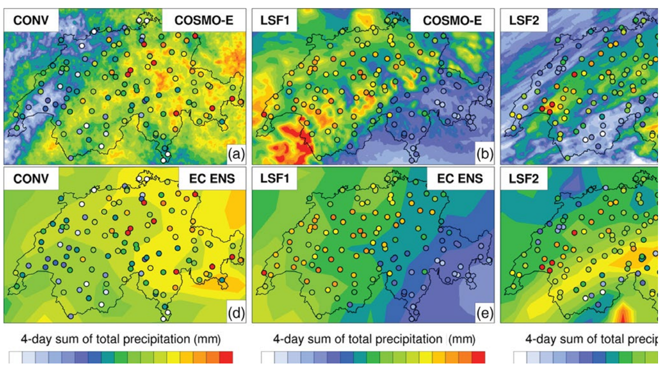
Gruber, N. et al, 2019: The oceanic sink for anthropogenic CO_2 from 1994 to 2007. Science, doi:10.1126/science.aau5153

Paper: Stratospheric ozone trends for 1985-2018: sensitivity to recent large variability

Ozone in the stratosphere acts as a protective shield against ultraviolet radiation that may harm the biosphere, and leads to cataracts, skin damage, and skin cancer in humans. The ozone layer was damaged last century due to anthropogenic emissions of ozone depleting substances. A global effort, through the Montreal Protocol, halted emissions and the ozone layer is no longer clearly thinning. However, there is still no evidence of a statistically significant increase in total column ozone since 1998. In previous work, we showed that lower stratospheric ozone had continued to decline over 1998–2016, counter to modelling expectations, and is likely responsible for the non-detection of a recovery. While surprising, many questions remained as to the robustness of this result, related to natural atmospheric variability, confidence in the observations, and the efficacy of trend analysis approaches. In this paper, we extend the data series, and address many of the aforementioned concerns. Ultimately, we demonstrate that the lower stratospheric ozone trends remain in place and ozone remains lower in 2018 than in 1998. Further, we show that tropical stratospheric ozone (30° S–30° N) shows highly probable decreases in both the lower stratosphere and in the integrated stratospheric ozone layer. The paper reinforces the need to understand both the drivers and why chemistry climate models may not be reproducing these changes.

Ball, W.T., Alsing, J., Staehelin, J., Davis, S.M., Froidevaux, L., Peter, T. (2019). Stratospheric ozone trends for 1985-2018: sensitivity to recent large variability, Atmos. Chem. Phys., 19, 12731-12748. https://doi.org/10.5194/acp-19-12731-2019

Papers: Intense precipitation case studies with the COSMO-E ensemble



Two publications present detailed results about the performance of the operational convection-resolving ensemble prediction system of MeteoSwiss (COSMO-E) for three contrasting precipitation events in Switzerland. The events include locally triggered air-mass convection on four consecutive days, a complex flood-producing rainfall episode, and a summertime cold-frontal precipitation event. In terms of the precipitation pattern, COSMO-E outperforms the driving ECMWF ensemble in all cases. The higher resolution of COSMO-E leads to increased spread and reduced underdispersion for near-surface variables. However, for both events with large-scale advection, underdispersion occurs for mid-tropospheric relative humidity near fronts also in COSMO-E. In the second study, a detailed investigation of the growth of ensemble variance of the horizontal wind reveals that ensemble variance increases in the presence of moist convective activity or strong synoptic-scale forcing, and stagnates or decreases otherwise, rendering forecasts of convection- permitting ensembles valuable beyond the very short forecast range.

Klasa, C., Arpagaus, M., Walser, A., and Wernli, H., 2018: An evaluation of the convection-permitting ensemble COSMO-E for three contrasting precipitation events in Switzerland, Quart. J. Roy. Meteorol. Soc., 144, 744–764. doi.org/10.1002/qj.3245

Klasa, C., Arpagaus, M., Walser, A., and Wernli, H., 2019: On the time evolution of limited-area ensemble variance: Case studies with the convection-permitting ensemble COSMO-E, J. Atmos. Sci., 76, 11–26. doi.org/10.1175/JAS-D-18-0013.1

Paper: Effects of land use and anthropogenic aerosol emissions in the Roman Empire

Did the Romans have an impact on climate already 2000 years ago? Using the global aerosol-climate model ECHAM-HAM-SALSA, we estimated the possible anthropogenic impact of land use, as well as aerosol emissions from burning activities (fuel consumption, crop residue burning, and pasture burning). For the simulations, two existing land use scenarios were used and three novel aerosol emission scenarios were created. The results suggest that both land use and aerosol emissions could have had an impact on climate. While land use induces a regional warming in one of the two scenarios, the anthropogenic aerosol emissions enhance the cooling effect of the clouds for all three scenarios. The magnitude of these changes in temperature is uncertain due to e.g. the prescribed sea surface temperatures.

Gilgen, A., Wilkenskjeld, S., Kaplan, J. O., Kühn, T., and Lohmann, U.: Effects of land use and anthropogenic aerosol emissions in the Roman Empire, Clim. Past, 15, 1885–1911, https://doi.org/10.5194/cp-15-1885-2019

Papers: Diabatic processes in extratropical cyclones simulated with COSMO and IFS

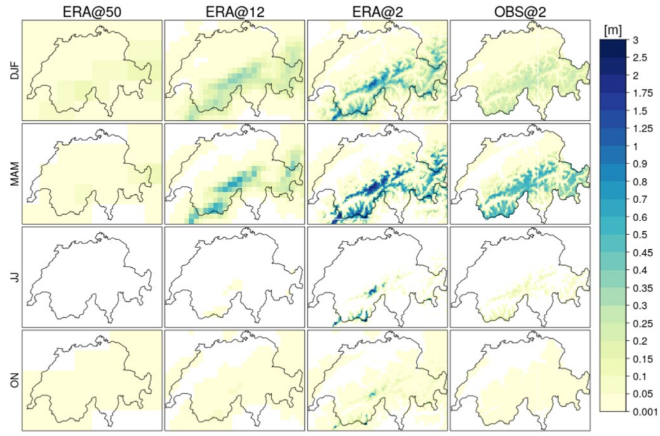
Three publications present detailed results about different aspects of moist dynamics in extratropical cyclones. The first study investigates the occurrence of embedded convection in warm conveyor belts, simulated with kilometre-scale COSMO simulations of a North Atlantic cyclone (Oertel et al. 2019). Episodes of fast ascent along warm conveyor belt trajectories calculated online during the COSMO integration reveal that convection occurs embedded within the larger-scale slantwise ascent, leading to prominent surface precipitation maxima and a heterogeneous cloud texture, in agreement with satellite observations. Two other studies focus on non-conservative processes that modify the potential vorticity (PV) in extratropical cyclones near the surface (Attinger et al. 2019) and near the tropopause (Spreitzer et al. 2019). IFS simulations are performed with detailed output of temperature and momentum tendencies for individual parameterisations, allowing for a detailed Lagrangian budget analysis of the formation of positive and negative PV anomalies. The results show that, in addition to latent heating by condensation, below-cloud processes (e.g., snow sublimation and rain evaporation) as well as turbulence contribute essentially to the formation of important PV features.

Attinger, R., E. Spreitzer, M. Boettcher, R. Forbes, H. Wernli, and H. Joos, 2019. Quantifying the role of individual diabatic processes for the formation of PV anomalies in a North Pacific cyclone. Quart. J. Roy. Meteorol. Soc., 145, 2454–2476. doi.org/10.1002/qj.3573

Oertel, A., M. Boettcher, H. Joos, M. Sprenger, H. Konow, M. Hagen, and H. Wernli, 2019. Convective activity in an extratropical cyclone and its warm conveyor belt – a case-study combining observations and a convection-permitting model simulation. Quart. J. Roy. Meteorol. Soc., 145, 1406–1426. doi.org/10.1002/qj.3500

Spreitzer, E., R. Attinger, M. Boettcher, R. Forbes, H. Wernli, and H. Joos, 2019. Modification of potential vorticity near the tropopause by nonconservative processes in the ECMWF model. J. Atmos. Sci., 76, 1709–1726. doi.org/10.1175/JAS-D-18-0295.1

Paper: Projections of Alpine Snow-Cover in a High-Resolution Climate Simulation



Besides allowing for an improved representation of precipitation and cloud cover, increased horizontal resolution in regional climate models also allows for a better representation of snow cover. The major cause for this improvement is the more accurate capture of topography, which influences quantities like snow depth and snow cover duration via the temperature lapse rate. In this study, we compare modelled snow cover for the Greater Alpine Region in a set of decadal-long COSMO simulations with different horizontal resolutions (50, 12 and 2.2 km). The performance of the simulations is evaluated with a gridded snow water equivalent (SWE) dataset for Switzerland. Only the 2.2 km simulation is able to capture elevations above 3000 m a.s.l., where substantial parts of the cryosphere (e.g. glaciers and permafrost) are located. The model evaluation indicates that the coarser-scale simulations (12 and 50 km) underestimate spatially averaged SWE throughout the winter, whereas the 2.2 km simulation reveals an excellent agreement with observations. Scenario simulations for the RCP8.5 and driven by the GCM MPI-ESM-LR reveal a distinctive decrease of SWE over the Alps. Highest relative changes in SWE are found at lower elevations (< 2000 m a.s.l.) but pronounced changes are also evident at high altitudes (> 3000 m a.s.l.), where SWE is projected to decrease between ~20-80% depending on the season and elevation.

Lüthi, S., Ban, N., Kotlarski, S., Steger, C. R., Jonas, T. and Schär, C., 2019: Projections of Alpine Snow-Cover in a High-Resolution Climate Simulation, Atmosphere, 10, 463, doi.org/10.3390/atmos10080463

Papers: The Mediterranean climate change hot spot and it's causes

The Mediterranean region is a hot spot for future climate change, mainly due to the expected strong summer warming as well as the year-round precipitation decline. In our papers, we aim to identify the responsible physical drivers behind the regional temperature and precipitation changes. We find that the strong summer warming is due to large-scale changes in the vertical structure of the atmosphere (increases and spatial variations in lapse-rate), while – contrary to expectations – the northward shift and expansion of the Hadley cell has a negligible influence. The causes for the precipitation decline depend on the season. In summer, changes in thermodynamics, lapse-rates, and land-ocean temperature contrast are important and circulation changes play a secondary role. In winter, changes in circulation are the primary cause for the projected Mediterranean precipitation decline.

Brogli, R., Kröner, N., Sørland, S. L., Lüthi, D., & Schär, C. (2019). The Role of Hadley Circulation and Lapse-Rate Changes for the Future European Summer Climate. J. Climate, 32, 385–404. 10.1175/JCLI-D-18-0431.1

Brogli, R., Sørland, S. L., Kröner, N., & Schär, C. (2019). Causes of future Mediterranean precipitation decline depend on the season. Environ. Res. Lett., 14, 114017. 10.1088/1748-9326/ab4438

Key Publications of C2SM Members

*For all publications with more than ten authors we cite the first author together with the author from the C2SM community

Arsenovic, P., A. Damiani, E. Rozanov, B. Funke, A. Stenke and T. Peter, 2019: Reactive nitrogen (NOy) and ozone responses to energetic electron precipitation during Southern Hemisphere winter, Atmos. Chem. Phys., 19, 9485–9494, doi.org/10.5194/acp-19-9485-2019

Attinger, R., J. H. Keller, M. Köhler, J. Riboldi, and C. M. Grams, 2019: Representation of atmospheric blocking in the new global non-hydrostatic weather prediction model ICON. Meteorol. Z., 28, 429–446, dx.doi.org/10.1127/metz/2019/0967

Aznar-Siguan, G., and D. N. Bresch, 2019: CLIMADA v1: a global weather and climate risk assessment platform, Geosci. Model Dev., 12, 3085–3097. doi.org/10.5194/gmd-12-3085-2019

Ball, W.T., J. Alsing, J. Staehelin, S.M. Davis, L. Froidevaux, T. Peter, 2019: Stratospheric ozone trends for 1985-2018: sensitivity to recent large variability, Atmos. Chem. Phys., 19, 12731-12748. doi.org/10.5194/acp-19-12731-2019

Bart, S., S. Pfenninger, S. Yang, D. Folini, B. Van der Zwaan, M. Wild, 2019: Estimation of losses in solar energy production from air pollution in China since 1960 using surface radiation data. Nature Energy, doi:10.1038/s41560-019-0412-4

Bayr, T., D. I. V. Domeisen, and C. Wengel, 2019: The effect of the equatorial Pacific cold SST bias on simulated ENSO teleconnections to the North Pacific and California Bayr, C.Climate Dynamics, doi.org/10.1007/s00382-019-04746-9

*Besnard, S., N. Buchmann, et al., 2019: Memory effects of climate and vegetation affecting net ecosystem CO2 fluxes in global forests. PLoS One 14: e0211510, doi.org/10.1371/journal.pone.0213467

Brogli, R., N. Kröner, S.L. Sørland, D. Lüthi and C. Schär, 2019: The Role of Hadley Circulation and Lapse-Rate Changes for the Future European Summer Climate. J. Climate, 32, 385-404, doi.org/10.1175/JCLI-D-18-0431.1

Brogli, R., N. Kröner, S.L. Sørland, and C. Schär, 2019: Causes of Future Mediterranean Precipitation Decline Depend on the Season. Env. Res. Letters, 14, Art. 114017, doi.org/10.1088/1748-9326/ab4438

Brunner, D., G. Kuhlmann, J. Marshall, V. Clément, O. Fuhrer, G. Broquet, A. Löscher, and Y. Meijer, 2019: Accounting for the vertical distribution of emissions in atmospheric CO2 simulations, Atmos. Chem. Phys., 19, 4541-4559, doi.org/10.5194/acp-19-4541-2019

Brunner, L., R. Lorenz, M. Zumwald, and R. Knutti, 2019: Quantifying uncertainty in European climate projections using combined performance- independence weighting, Environmental Research Letters, 14(12), 124010, doi:10.1088/1748-9326/ab492f

Büeler, D., and S. Pfahl, 2019: Potential vorticity diagnostics to quantify effects of latent heating in extratropical cyclones. Part II: application to idealized climate change simulations. J. Atmos. Sci., 76, 1885–1902, dx.doi.org/10.1175/JAS-D-18-0342.1

Burki, C., B. Sikoparija, M. Thibaudon, G. Oliver, D. Magyar, O. Udvardy, A. Leelössy, C. Charpilloz, A. Pauling, 2019: Artificial Neural Networks can be used for Ambrosia pollen emission parameterization in COSMO-ART. Atmospheric Environment, 218, doi.org/10.1016/j.atmosenv.2019.116969

*Cailleret, M., H. Bugmann, et al., 2019: Early-Warning Signals of Individual Tree Mortality Based on Annual Radial Growth. Frontiers in Plant Science 9: 1964, doi.org/10.3389/fpls.2018.01964

Casanueva, A., S. Kotlarski, S. Herrera, A. M. Fischer, T. Kjellstrom, C. Schwierz, 2019: Climate projections of a multi-variate heat stress index: the role of downscaling and bias correction. Geoscientific Model Development, 12 (8), 3419-3438, doi.org/10.5194/gmd-12-3419-2019

Chow, F.K., C. Schär, N. Ban, K.A. Lundquist, L. Schlemmer, and X. Shi, 2019: Crossing multiple gray zones in the transition from mesoscale to microscale simulation over complex terrain. Atmosphere, doi.org/10.3390/atmos10050274

*Chrysanthou, A., A. Stenke, et al., 2019: The effect of atmospheric nudging on the stratospheric residual circulation in chemistry–climate models, Atmos. Chem. Phys., 19, 11559–11586, doi.org/10.5194/acp-19-11559-2019

CH-Impacts, 2019: Klimaszenarien CH2018 und daraus abgeleitete Folgen für die Schweiz – wie weiter? Grundlagenbericht des Vorprojekts. Publiziert von ProClim, BAFU, ETHZ, MeteoSchweiz, NCCS, Universität Bern, Universität Zürich und WSL. Bern, Schweiz, 50 S., doi.org/10.3929/ethz-b-000364227

Clement, V., P. Marti, X. Lapillonne, O. Fuhrer, W. Sawyer, 2019: Automatic Port to OpenACC/OpenMP for Physical Parameterization in Climate and Weather Code Using the CLAW Compiler. Supercomputing Frontiers and Innovations, 6(3), 51-63, dx.doi.org/10.14529/jsfi190303

Dietlicher, R., D. Neubauer, and U. Lohmann, 2019: Elucidating ice formation pathways in the aerosol–climate model ECHAM6-HAM2, Atmos. Chem. Phys., 19, 9061-9080, doi.org/10.5194/acp-19-9061-2019

*Eichinger, R., A. Stenke, et al., 2019: The influence of mixing on the stratospheric age of air changes in the 21st century, Atmos. Chem. Phys., 19, 921- 940, doi.org/10.5194/acp-19-921-2019

Eirund, G. K., U. Lohmann, and A. Possner, 2019: Cloud ice processes enhance spatial scales of organization in Arctic stratocumulus. Geophys. Res. Lett., 46, 14,109–14,117, doi.org/10.1029/2019GL084959

Eirund, G. K., Possner, A., and U. Lohmann, 2019: Response of Arctic mixed-phase clouds to aerosol perturbations under different surface forcings, Atmos. Chem. Phys., 19, 9847–9864, doi.org/10.5194/acp-19-9847-2019

Feinberg, A., T. Sukhodolov, B.-P. Luo, E. Rozanov, L.H.E. Winkel, T. Peter, and A. Stenke, 2019: Improved tropospheric and stratospheric sulfur cycle in the aerosol–chemistry–climate model SOCOL- AERv2, Geosci. Model Dev., 12, 3863–3887, doi.org/10.5194/gmd-12-3863-2019

Friedlingstein P., M. Allen, J.G. Canadell, G.P. Peters, S.I. Seneviratne, 2019: Comment on “The global tree restoration potential”. Science, 10.1126/science.aay8060, https://science.sciencemag.org/content/366/6463/eaay8060

*Fronzek, S., H. Bugmann, et al., 2019: Determining sectoral and regional sensitivity to climate and socio-economic change in Europe using impact response surfaces. Regional Environmental Change 19.3: 679-693, doi.org/10.1007/s10113-018-1421-8

Gilgen, A., Wilkenskjeld, S., Kaplan, J. O., Kühn, T., and Lohmann, U.: Effects of land use and anthropogenic aerosol emissions in the Roman Empire, Clim. Past, 15, 1885–1911, doi.org/10.5194/cp-15-1885-2019

Goger B., M. W. Rotach, A. Gohm, I. Stiperski, O. Fuhrer, and G. de Morsier, 2019: A New Horizontal Length Scale for a Three-dimensional Turbulence Parameterization in Meso-scale Atmospheric Modelling over Highly Complex Terrain, Journal of Applied Meteorology and Climatology, journals.ametsoc.org/doi/full/10.1175/JAMC-D-18-0328.1

Graf, M., S.C. Scherrer, C. Schwierz, M. Begert, O. Martius, C.C. Raible, S. Brönnimann, 2019: Near-surface mean wind in Switzerland: Climatology, climate model evaluation and future Scenarios. International Journal of Climatology. 39(12), 4798-4810. doi.org/10.1002/joc.6108

Green, J.K., S.I. Seneviratne, A.M. Berg, K.L. Findell, S. Hagemann, D.M. Lawrence, P. Gentine, 2019: Large influence of soil moisture on long-term terrestrial carbon uptake. Nature, 565, 476–47, www.nature.com/articles/s41586-018-0848-x

Gruber, N. et al, 2019: The oceanic sink for anthropogenic CO2 (from 1994 to 2007). Science, doi:10.1126/science.aau5153

Hentgen, L., N. Ban, N. Kröner, D. Leutwyler, and Schär, C., 2019: Clouds in convection-resolving climate simulations over Europe. J. Geophys. Res. – Atmos., 124, 3849–3870, doi.org/10.1029/2018JD030150

Hodnebrog, Ø., L. Marelle, K. Alterskjær, R.R. Wood, R. Ludwig, E.M. Fischer, T.B. Richardson, P.M. Forster, J. Sillmann, G. Myhre, 2019: Intensication of summer precipitation with shorter time-scales in Europe, Environmental Research Letters, 14 (12), 124050, doi.org/10.1088/1748-9326/ab549c

*Hoegh-Guldberg O., S.I. Seneviratne, et al., 2019: The human imperative of stabilizing global climate change at 1.5°C. Science, 365, https://science.sciencemag.org/content/365/6459/eaaw6974.full

Imamovic, A., L. Schlemmer and C. Schär, 2019: Mountain Volume Control On Deep-Convective Rain Amount. J. Atmos. Sci., 76, 605-626, doi.org/10.1175/JAS-D-18-0217.1

Jiménez-Esteve, B. and D.I.V. Domeisen, 2019: Nonlinearity in the North Pacific atmospheric response to a linear ENSO forcing, Geophys. Res. Lett., doi.org/10.1029/2018GL081226

Karagodin, A., E. Rozanov, E. Mareev, I. Mironova, E. Volodin, and K. Golubenko, 2019: The representation of ionospheric potential in the global chemistry- climate model SOCOL, Science of the Total Environment, 697, doi.org/10.1016/j.scitotenv.2019.134172

Klasa, C., M. Arpagaus, A. Walser, and H. Wernli, 2019: On the time evolution of limited-area ensemble variance: Case studies with the convection-permitting ensemble COSMO-E, J. Atmos. Sci., 76, 11–26, doi.org/10.1175/JAS-D-18-0013.1

Kuhlmann, G., G. Broquet, J. Marshall, V. Clément, A. Löscher, Y. Meijer, and D. Brunner, 2019: Detectability of CO2 emission plumes of cities and power plants with the Copernicus Anthropogenic CO2 Monitoring (CO2M) mission, Atmos. Meas. Tech., 12, 6695–6719, doi.org/10.5194/amt-12-6695-2019

Leifeld, J., C. Wüst-Galley, S. Page, 2019: Intact and managed peatland soils as a source and sink of GHGs from 1850 to 2100. Nature Climate Change 9: 945–947, doi.org/10.1038/s41558-019-0615-5

Leutwyler, D. and C. Schär, 2019: Barotropic Instability of a Cyclone Core at Kilometer-Scale Resolution. J. Adv. Modeling Earth Syst., 11, 3390-3402, doi.org/10.1029/2019MS001847

Lévesque, M., L. Andreu-Hayles, W. K. Smith, W. A. Park, M. L. Hobi, B. W. Allred, and N. Pederson, 2019: Tree-ring isotopes capture interannual vegetation productivity dynamics at the biome scale. Nature Communications 10.1: 742, doi.org/10.3929/ethz-b-000325370

Lorenz, R., Z. Stalhandske, E.M. Fischer, 2019: Detection of a Climate Change Signal in Extreme Heat, Heat Stress, and Cold in Europe From Observations, Geophysical Research Letters, 46 (14), 83638374, doi.org/10.1029/2019GL082062

Lüthi, S., N. Ban, S. Kotlarski, C. Steger and C. Schär, 2019: Projections of Alpine snow-cover in a high-resolution climate simulation. Atmosphere, 10, 463; doi.org/10.3390/atmos10080463

Maurice Skelton, Andreas M. Fischer, Mark A. Liniger, David N. Bresch, 2019: Who is the user of climate services? Unpacking the use of national climate scenarios in Switzerland beyond sectors, numeracy and the research-practice binary. Climate Services, in press, doi.org/10.1016/j.cliser.2019.100113

Madakumbura, G. D., H. Kim, N. Utsumi, H. Shiogama, E.M. Fischer, Ø. Seland, J. F. Scinocca, D.M. Mitchell, Y. Hirabayashiand, and T. Oki, 2019: Event-to-event intensication of the hydrologic cycle from 1.5C to a 2C warmer world. Scientic reports, 9, (1), 34833483, doi.org/10.1038/s41598-019-39936-2

Merker, C., G. Geppert, M. Clemens, F. Ament, 2019: Estimating the Uncertainty of Areal Precipitation using Data Assimilation, Tellus A: Dynamic Meteorology and Oceanography, 71:1, doi.org/10.1080/16000870.2019.1606666

Monhart, S., M. Zappa, C. Spirig, C. Schär, and K. Bogner, 2019: Sub-seasonal hydrometeorological ensemble predictions in small- and medium-size mountainous catchments: Benefits of the NWP approach. Hydrol. Earth Syst. Sci., 23, 493–513, doi.org/10.5194/hess-2018-458

*Müller, A., P., Osuna, C., Fuhrer, et al., 2019: The ESCAPE project: Energy-efficient Scalable Algorithms for Weather Prediction at Exascale, Geosci. Model Dev., 12, 4425–4441, doi.org/10.5194/gmd-12-4425-2019

Müller, J., D. Folini, M. Wild, S. Pfenninger, 2019: CMIP-5 models project photovoltaics are a no-regrets investment in Europe irrespective of climate change. Energy. doi: 10.1016/j.energy.2018.12.139

Myhre, G., K. Alterskjær, C.W. Stjern, Ø. Hodnebrog, L. Marelle, B.H. Samset, J. Sillmann, N. Schaller, E.M. Fischer, M. Schulz, A. Stohl, 2019: Frequency of extreme precipitation increases extensively with event rareness under global warming, Scientic Reports, 9 (1), 110, doi.org/10.1038/s41598-019-52277-4

Nerini, D., L. Foresti, D. Leuenberger, S. Robert, and U. Germann, 2019: A reduced-space ensemble Kalman filter approach for flow-dependent integration of radar extrapolation nowcasts and NWP precipitation ensembles. MWR, 147, pp 987-1006, doi.org/10.1175/MWR-D-18-0258.1

Neubauer, D., S. Ferrachat, C. Siegenthaler-Le Drian, P. Stier, D.G. Partridge, I. Tegen, I. Bey, T. Stanelle, H. Kokkola, and U. Lohmann, 2019: The global aerosol–climate model ECHAM6.3–HAM2.3 – Part 2: Cloud evaluation, aerosol radiative forcing, and climate sensitivity, Geosci. Model Dev., 12, 3609–3639, doi.org/10.5194/gmd-12-3609-2019

Oertel, A., M. Boettcher, H. Joos, M. Sprenger, H. Konow, M. Hagen, and H. Wernli, 2019: Convective activity in an extratropical cyclone and its warm conveyor belt – a case-study combining observations and a convection-permitting model simulation. Quart. J. Roy. Meteorol. Soc., 145, 1406–1426, doi.org/10.1002/qj.3500

Padrón, R. S., L. Gudmundsson, S.I. Seneviratne, 2019: Observational constraints reduce likelihood of extreme changes in multidecadal land water availability. Geophysical Research Letters, 46, doi.org/10.1029/2018GL080521

Panosetti, D., L. Schlemmer, and C. Schär, 2019: Bulk and structural convergence at convection-resolving scales in real-case simulations of summertime moist convection over land. Quart. J. Roy. Meteorol. Soc., Q. J. R. Meteorol. Soc., doi.org/10.1002/qj.3502

Pauling, A., B. Clot, A. Menzel, S. Jung, 2019: Pollen forecasts in complex topography: two case studies from the Alps using the numerical pollen forecast model COSMO-ART, Aerobiologia, published online 15 May 2019. doi.org/10.1007/s10453-019-09590-2

*Peaucelle, M., N. Buchmann, et al., 2019: Co-variations between plant functional traits emerge from constraining parameterization of a terrestrial biosphere model with in situ GPP estimates. Global Ecology and Biogeography 28: 1351–1365, doi:10.1111/geb.12937

Roessler, S., S. Kotlarski, A. Fischer, M. Liniger, D. Keller, R. Weingartner, 2019: Evaluating the added value of the new Swiss climate scenarios for hydrology: an example from the Thur catchment, Climate Services, doi.org/10.1016/j.cliser.2019.01.001

Revill, A., C. Emmel, P. D'Odorico, N. Buchmann, L. Hörtnagl, W. Eugster, 2019: Estimating cropland carbon fluxes: a process-based model evaluation at a Swiss crop-rotation site. Field Crops Research 234: 95-106, doi:10.1016/j.fcr.2019.02.006

*Rugenstein, M., R. Knutti, et al., 2019: LongRunMIP–motivation and design for a large collection of millennial- length AO- GCM simulations, Bulletin of the American Meteorological Society, online first, doi:10.1175/BAMS- D-19-0068.1

Schuler, L.J., H. Bugmann, G. Petter and R.S. Snell. 2019: How multiple and interacting disturbances shape tree diversity in European mountain landscapes. Landscape Ecology 34.6: 1279-1294, doi.org/10.3929/ethz-b-000339837

Schulthess, T.P., P. Bauer, O. Fuhrer, T. Hoefler, C. Schär, N. Wedi, 2019: Reflecting on the goal and baseline for exascale computing: a roadmap based on weather and climate simulations. IEEE Computing in Science and Engineering, 21 (1), 30-41, doi.org/10.1109/MCSE.2018.2888788

Schulze E.D., E. Beck, N. Buchmann, S. Clemens, K. Müller-Hohenstein, M. Scherer-Lorenzen, 2019: Plant Ecology. 2nd edition. Springer. Pp 928

Schwingshackl, C., E. L. Davin, M. Hirschi, S. L. Sørland, R. Wartenburger, S.I. Seneviratne, 2019: Regional climate model projections underestimate future warming due to missing plant physiological CO2 response. Environ. Res. Lett., 14, 114019, https://iopscience.iop.org/article/10.1088/1748-9326/ab4949

*Shiogama, H., T., E.M. Fischer, et al., 2019: Limiting global warming to 1.5C will lower increases in inequalities of four hazard indicators of climate change Environmental Research Letters 14, (12), 124022

Sippel, S., N. Meinshausen, A. Merrifield, F. Lehner, A.G. Pendergrass, E. Fischer and R. Knutti, 2019: Uncovering the forced climate response from a single ensemble member using statistical learning, Journal of Climate, doi.org/10.1175/JCLI-D-18-0882.1

Skelton, M., A. M. Fischer, M. A. Liniger, D. N. Bresch, 2019: Who is 'the user' of climate services? Unpacking the use of national climate scenarios in Switzerland beyond sectors, numeracy and the research–practice binary. Climate Services, doi.org/10.1016/j.cliser.2019.100113

Škerlak, B., S. Pfahl, M. Sprenger, and H. Wernli, 2019: A numerical process study on the rapid transport of stratospheric air down to the surface over western North America and the Tibetan Plateau. Atmos. Chem. Phys., 19, 6535–6549, doi.org/10.5194/acp-19-6535-2019

Spreitzer, E., R. Attinger, M. Boettcher, R. Forbes, H. Wernli, and H. Joos, 2019: Modification of potential vorticity near the tropopause by nonconservative processes in the ECMWF model. J. Atmos. Sci., 76, 1709–1726, doi.org/10.1175/JAS- D-18-0295.1

Stieger, J., I. Bamberger, R.T.W. Siegwolf, N. Buchmann, W. Eugster, 2019: Source partitioning of atmospheric methane using stable carbon isotope measurements in the Reuss Valley, Switzerland. Isotopes in Environmental & Health Studies 55: 1-24, doi:10.1080/10256016.2018.1561448

Stolpe, M. B., I. Medhaug, U. Beyerle and R. Knutti, 2019: Weak dependence of future global mean warming on the background climate state, Climate Dynamics, doi:10.1007/s00382- 019-04849-3

Trotsiuk V, Hartig F, Cailleret M, Babst F, Forrester DI, Baltensweiler A, Buchmann N, Bugmann H, et al., 2020: Assessing the response of forest productivity to climate extremes in Switzerland using model-data fusion. Global Change Biology 26: 2463–2476

Vattioni, S., D. Weisenstein, D. Keith, A. Feinberg, T. Peter, and A. Stenke, 2019: Exploring accumulation- mode H2SO4 versus SO2 stratospheric sulfate geoengineering in a sectional aerosol–chemistry–climate model, Atmos. Chem. Phys., 19, 4877- 4897, doi.org/10.5194/acp-19-4877-2019

*Vitasse, Y., M. Lévesque, et al., 2019. Contrasting resistance and resilience to extreme drought and late spring frost in five major European tree species. Global Change Biology 25.11: 3781-3792, doi.org/10.1111/gcb.14803

Vogel, M. M., J. Zscheischler, R. Wartenburger, D. Dee, S.I. Seneviratne, 2019: Concurrent 2018 hot extremes across

Northern Hemisphere due to human-induced climate change. Earth's Future, 7, 692-703, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019EF001189

Wehrli K., B. P. Guillod, M. Hauser, M. Leclair, S.I. Seneviratne, 2019: Identifying key driving processes of major recent heatwaves. JGR Atmospheres, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2019JD030635

Wulff, C.O. and D.I.V. Domeisen, 2019: Higher subseasonal predictability of extreme hot European summer temperatures as compared to average summers Geophysical Research Letters, 46, 11520 - 11529, doi.org/10.1029/2019GL084314

*Xiao, J., X. Li, B. He, M. Altaf Arain, J. Beringer, A.R. Desai, C. Emmel, D.Y. Hollinger, A. Krasnova, I. Mammarella, S.M. Noe, P. Serrano Ortiz, C. Rey-Sanchez, A.V. Rocha, A. Varlagin, 2019: Solar-induced chlorophyll fluorescence exhibits a universal relationship with gross primary productivity across a wide variety of biomes. Global Change Biology 25: e4– e6., doi.org/10.1111/gcb.14565

Zscheischler, J., E.M. Fischer, and S. Lange, 2019: The eect of univariate bias adjustment on multivariate hazard estimates. Earth Sys. Dyn. 10 3143, doi.org/10.5194/esd-10-31-2019

Annex

As of 31 December 2019

Plenary Members

Steering Committee members

Prof. Nicolas Gruber, Chairman	ETH D-USYS	Environmental Physics
Dr. Dominik Brunner	Empa	Atmospheric Modeling
Dr. Mischa Croci-Maspoli	MeteoSwiss	Climate Change, Climate Services
Prof. Daniela Domeisen	ETH D-USYS	Atmospheric Predictability
Prof. Reto Knutti	ETH D-USYS	Climate Physics
Prof. Heini Wernli	ETH D-USYS	Atmospheric Dynamics
Prof. Niklaus Zimmermann	WSL	Landscape Dynamics

Regular members

Prof. Christof Appenzeller	MeteoSwiss	Analysis and Forecasting
Dr. Marco Arpagaus	MeteoSwiss	Numerical Predictions
Prof. David Bresch	ETH D-USYS, MeteoSwiss	Environmental Decisions
Dr. Brigitte Buchmann	Empa	Mobility, Energy and Environment
Prof. Nina Buchmann	ETH D-USYS	Grassland Sciences
Prof. Harald Bugmann	ETH D-USYS	Forest Ecology
Prof. Paolo Burlando	ETH D-BAUG	Hydrology and Water Resources
Prof. Jan Carmeliet	Empa, ETH D-MAVT	Building Science and Technology
Prof. Tom Crowther	ETH D-USYS	Integrative Biology
Dr. Lukas Emmenegger	Empa	Air Pollution/Environmental Technology
Prof. Daniel Farinotti	ETH D-BAUG, WSL	Glaciology
Prof. Andreas Fischlin	ETH D-USYS	Terrestrial Systems Ecology
Dr. Sven Kotlarski	MeteoSwiss	Climate Evolution
Dr. Xavier Lapillonne	MeteoSwiss	Computing
Prof. Michael Lehning	WSL	Snow and Permafrost
Dr. Jens Leifeld	Agroscope	Air Quality and Climate
Dr. Mark Liniger	MeteoSwiss	Climate Prediction
Prof. Ulrike Lohmann	ETH D-USYS	Atmospheric Physics
Prof. Nicolai Meinshausen	ETH D-MATH	Statistics
Dr. Carlos Osuna	MeteoSwiss	Computing
Prof. Anthony Patt	ETH D-USYS	Human-Environment Systems
Prof. Thomas Peter	ETH D-USYS	Atmospheric Chemistry
Dr. Gian-Kasper Plattner	WSL	Directorate Staff
Prof. Christoph Schär	ETH D-USYS	Climate and Water Cycle
Prof. Sebastian Schemm	ETH D-USYS	Circulation of the Atmosphere
Prof. Thomas Schulthess	ETH D-PHYS	Theoretical Physics
Dr. Cornelia Schwierz	MeteoSwiss	Climate Monitoring

Prof. Sonia Seneviratne	ETH D-USYS	Land-Climate Dynamics
Prof. Konrad Steffen	WSL	Climate and Cryosphere
Dr. Philippe Steiner	MeteoSwiss	Numerical Prediction
Dr. Reto Stöckli	MeteoSwiss	Climate Fundamentals
Prof. Benjamin Stocker	ETH D-USYS	Computational ecosystems science
Prof. Heather Stoll	ETH D-ERDW	Climate Geology
Prof. Martin Wild	ETH D-USYS	Climate and Radiation
Prof. Lenny Winkel	ETH D-USYS	Environmental Geochemistry

As of 31 December 2019

Scientific Advisory Board (SAB) Members

Scientific Advisory Board (SAB) members	
Dr. Karin Ammon	ProClim, Bern, CH
Dr. Albert Klein Tank	Met Office, Exeter, UK
Prof. John Mitchell	University of Reading, Reading, UK
Dr. Jürg Füssler	INFRAS, CH
Prof. Bjorn Stevens	MPI-Meteorology, Hamburg, DE

The SAB has the mandate to advise the Center on strategic matters and to provide feedback regarding the achievements, as well as the planned developments.

Within the C2SM community

Research Projects Related to C2SM

A number of projects were initiated within the C2SM community, with some of the projects contributing to the core budget (see below).

Project name*	Lead PI	Funding mechanism	Duration
ESA SmartCarb	D. Brunner (Empa)	ESA	01/02/2017 - 30/04/2018
PASC ENIAC	U. Lohmann (ETH)	PASC	01/07/2017 - 30/06/2020
PASC PASCHA	T. Hoefler (ETH)	PASC	01/07/2017 - 30/06/2020
WEW-COSMO	P. Steiner (MeteoSwiss)	MeteoSwiss	01/01/2017 - 31/12/2020
PostCH2018	R. Knutti (ETH)	MeteoSwiss	01/09/2018 - 31/01/2019
Vorhersage COSMO	H. Wernli (ETH)	MeteoSwiss	01/07/2018 - 31/05/2019
Carbosense4D	D.Brunner (Empa)	SDSC	01/12/2017 - 31/12/2019

Reporting period (1 January 2019 - 31 December 2019)

Budget

Saldo (CHF) 01/01/2019	**354'102**

Income (CHF) 01/01/2019-31/12/2019	
ETH School Board	160'000
USYS Department	100'000
ETH members	50'000
MeteoSwiss	50'000
Empa	70'000
WSL	50'000
Agroscope	10'000
Education and events	35'206
Third-party and project contributions *	27'199
SciViz Fees	9'269
C2SM reserve fonds	899
Total income	**562'572**

Expenses (CHF) 01/01/2019-31/12/2019	
Salaries core staff	522'198
Events	24'642
Running costs	14'121
Travel	3'062
Data storage	17'118
Swiss Climate Summer school	22'388
TEAMx project contribution	10'000
C2SM reserve fonds	1'479
Total expenses	**615'008**

Saldo (CHF) 31/12/2019	**301'666**

* The PASC PASCHA, WEW-COSMO, and SDSC Carbosense4D projects have contributed to the core C2SM budget.

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

MeteoSchweiz

Empa
Materials Science and Technology

WSL

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Wirtschaft, Bildung und Forschung WBF
Agroscope

Contact
Dr. Christina Schnadt Poberaj - Executive Director
Center for Climate Systems Modeling (C2SM)
ETH Zürich
Universitätstrasse 16
8092 Zürich, Switzerland

info@c2sm.ethz.ch
www.c2sm.ethz.ch
@C2SM_ETH

+41 44 633 8458