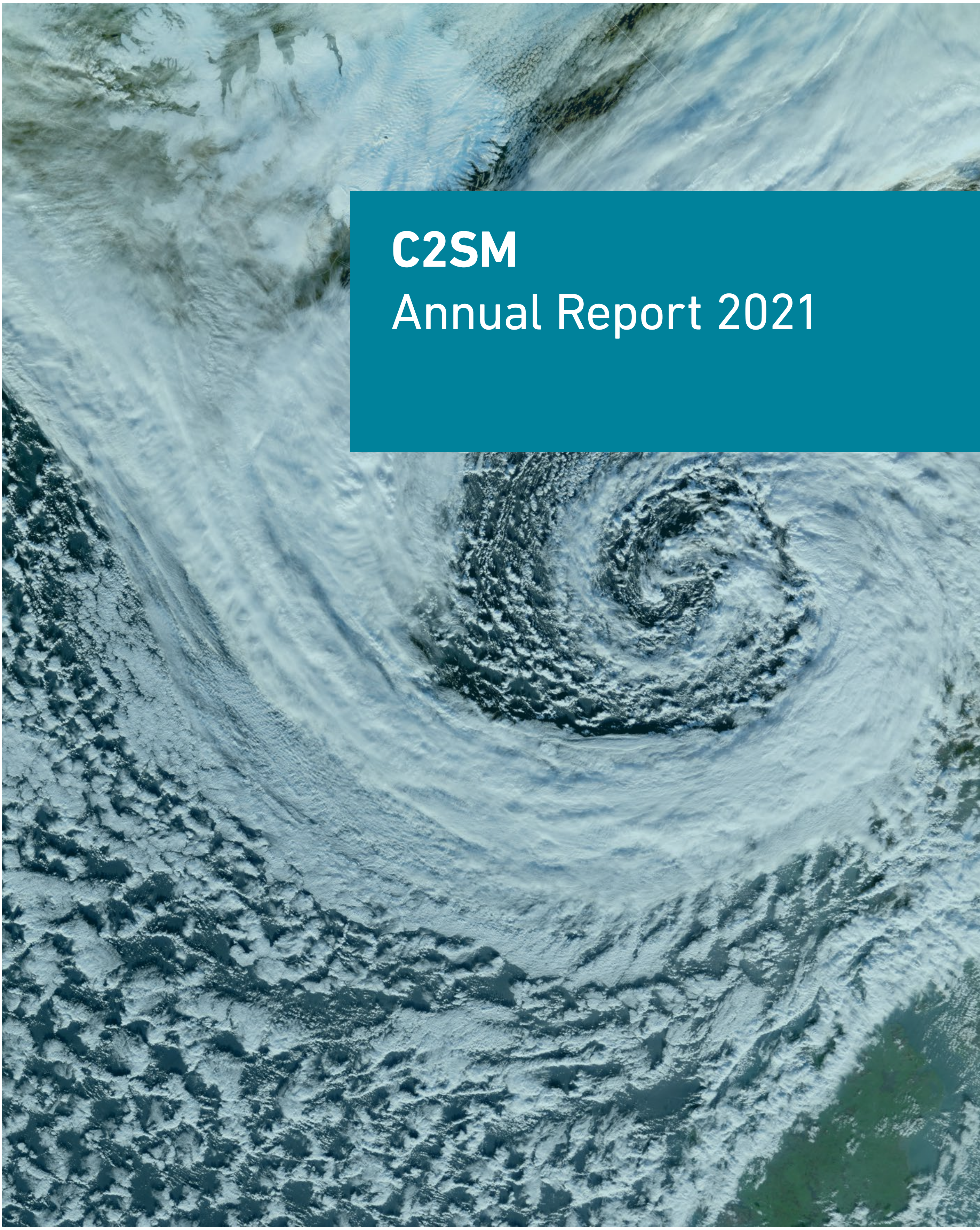
ETH zürich

Center for Climate Systems Modeling



C2SM
Annual Report 2021

C2SM Center for Climate Systems Modeling

The Center for Climate Systems Modeling (C2SM) is an extradepartmental science and technology center of ETH Zurich and a joint initiative between ETH Zurich, MeteoSwiss, Empa, and WSL with the main objective to improve the understanding of the climate system and to strengthen the predictive skill of atmospheric models on time scales from days to millennia. The center was established as a competence center of ETH in 2008. It was accredited as a center of the school board in December 2020 hereby gaining a long-term perspective to pursue its goals. This document highlights the main achievements in 2021.

The C2SM Steering Committee, June 2022

Table of contents

About C2SM

Rationale

There is probably no other societal challenge than climate change that is more deeply intertwined with the technological, economical, and human aspects of society and the natural environment around us. Addressing climate change requires a profound knowledge of these intertwined systems, all of which rests on the understanding of the Earth system and our ability to project its future. This knowledge is needed to address urgent societally relevant questions, such as how can we determine with greater certainty the carbon budget associated with the 1.5 or 2°C warming targets of the Paris agreement, how can we better project the changes in extreme precipitation events, or how can we improve our ability to assess the impact of climate change on ecosystems? Without such an understanding, the Paris target remains a loose goal. Thus, while the climate change problem cannot be solved by climate and weather sciences alone, it remains a key task of this community to provide the best scientific basis for climate change mitigation and adaptation across a wide spectrum of impacted fields.

To provide this scientific basis, numerical simulation has become one of the most important pillars in weather and climate science. Atmospheric models running on modern high performance computing (HPC) systems are large simulation infrastructures with millions of lines of code. Developing and maintaining such a simulation infrastructure goes significantly beyond the capability of individual research groups and institutions. Providing such a simulation infrastructure to its member institutions was the key rationale for the foundation of C2SM in 2008 and has been the cornerstone of its existence ever since. C2SM has substantially contributed to the rise and growing together of the atmospheric modelling community in the Zurich area, enabling it to become one of the leading research communities worldwide. The rationale for a coordinated science and technology platform extends further as individual groups are similarly challenged with the development and application of models, the handling and analysis of large data sets, with the training of researchers in coding and code & data management, and in the areas of education and outreach. In addition, the intertwined nature of the climate change problem requires a concerted and multidisciplinary approach extending from the fundamental aspects of atmospheric and climate science to the study of impacts across a wide range of areas. All this can be achieved by building and supporting a community brought together and supported by a central hub.

Vision

We solve tomorrow's challenges in the analysis and modelling of weather and climate.

Mission

Our overarching objective is to bring the weather, climate, climate impact, computational, and related communities in the Zurich area together in order to improve their ability to analyse, model, and predict multi-scale and multi-component interactions within the Earth System. To this end, our mission is to empower this community by acting

- as a collaborative platform for innovation,
- as a provider of scientific and technical support,
- as an organiser of technical training, and
- as a vehicle for public outreach.

We focus on the development and application of complex models of weather, climate, and the Earth system, including its atmospheric composition. We provide a simulation and data analysis infrastructure for these models and the science that emanates from them. We connect to related disciplines at ETH and beyond to exponentiate research outcomes and to bridge disciplines in the area of climate change impacts, adaptation, and mitigation.

Strategic foci

For the 2021 through 2025 period, C2SM focuses its work on four strategic areas:

(i) Working closely together with the Swiss National Supercomputer Centre (CSCS) and computer scientists at ETH and C2SM's member institutions, as well as international partners, C2SM develops and applies the next generation modelling paradigms in weather and climate. Through this endeavour, not only will the weather and climate models be readied for the next generation of supercomputers, but also will their resolutions be enabled to increase to unprecedented levels.

(ii) C2SM applies and further develops the developed ultrahigh-resolution models considering the interactions between atmospheric dynamics and the other components of the Earth system, such as land surface, ocean, and atmospheric composition.

(iii) In collaboration with MeteoSwiss, C2SM takes the lead in the development of the next generation modelling and data system required to provide the highest quality climate change information for Switzerland to the Swiss people and authorities.

(iv) C2SM works together with experts in the areas of impact and risk modelling to foster the seamless integration of climate impact sciences into weather and climate models.

Activities

Networking

C2SM acts as a network by bringing the scientific community together and creating cross-disciplinary and -institutional synergies through a number of initiatives and processes:

- the initialisation of joint projects through workshops
- creating networking opportunities by organising community-wide scientific seminars and technical workshops
- improved flow of information by publishing a four-monthly C2SM newsletter.

Research coordination

High priority for joint projects during the 2021-2025 period are given to the development of the next generation ICON model within the open ETH project EXCLAIM, which aims at refactoring the model to make it ready for emerging hardware achitectures and to permit high-resolution modelling on the global scale (page 10). Another strategic focus, in collaboration with MeteoSwiss, is the planning for and production of the next generation climate change scenarios to be published in the middle of the 2020s (page 9).

Support for research activities

C2SM maintains, improves, and provides to the center's community a hierarchy of state-of-the-art weather, climate, and climate-related models. In particular, the center is responsible for maintaining the regional climate model COSMO, and maintaining and refining the Earth System Model ICON. This includes providing the associated modules, e.g., for aerosols, atmospheric composition, (biogeo)chemistry, oceans, land surfaces, and clouds.
C2SM also prepares, quality-controls, and disseminates key national and international data sets such as CORDEX and CMIP data to its users who work in the areas of climate scenarios and impacts. It is envisaged to extend the services in the area of climate impacts to also directly and seamlessly integrate impact models in the evaluation chain of our climate models.
C2SM supports its ETH members in organising funding for data storage and computing nodes.

Education and training

C2SM contributes towards an improved training of PhD students through the establishment of projects across research groups, institutions, and disciplines. It trains scientists (PhD students, post docs, etc.) in the areas of data visualisation, data analysis, use and interpretation of climate data, programming, and code and data management. C2SM organises the international Swiss Climate Summer Schools jointly with the Oeschger Center for Climate Research at the University of Bern.

Outreach and events

C2SM raises 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 are the well-established "Klimarunde" and public outreach events such as Scientifica.

Governance

Structure, organisation, and personnel of C2SM

C2SM was established in 2008 as an ETH competence center by the funding partners ETH, MeteoSwiss, Empa, and Agroscope, and it 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 impacts. After 12 years, C2SM was transferred to become an extradepartmental center of ETH in the end of 2019. As such, it is directly associated with the school board and reports to the Vice President of Research of ETH and the directorates of its continued partner institutions MeteoSwiss, Empa, and WSL.
As of 31 December 2021, the center includes 43 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, scientific, and technical staff from the research groups of each member and thus represents a group of over 400 people. Seven members 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 recognised 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 data analyst, a project manager, a PR and communication specialist, and an administrative assistant. The scientific programmers and the data analyst are active in the four main focus areas of C2SM: High performance computing (HPC), general weather and climate modelling, climate scenarios, and climate impacts.Four working groups, composed of 6 to 10 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 six software developers and postdocs through specific research projects acquired by C2SM and its members (see page 23 for more details on the current projects). The structure and organisation of C2SM is described in greater detail in the Terms of Reference, which can be downloaded from the C2SM website.

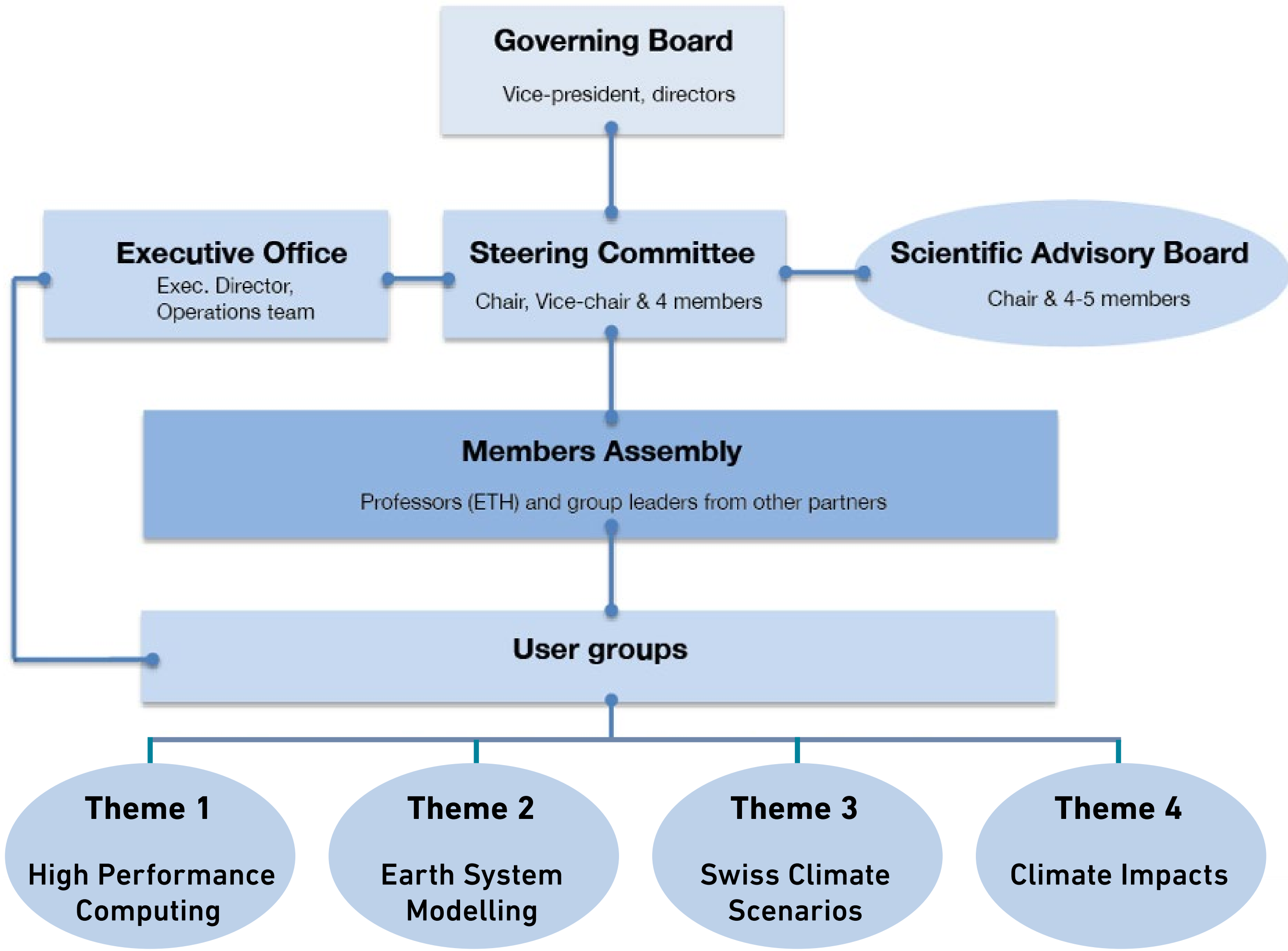
www.c2sm.ethz.ch/the-center/documents.html

Core staff

Role	Name
Executive Director	Christina Schnadt Poberaj
Scientific programmer	Urs Beyerle
Administrative assistant	Rahel Buri
Scientific programmer	Jonas Jucker
Scientific programmer	Matthieu Leclair
PR and communication	Tanja Meier
Project manager	Tamara Bandikova
Scientific programmer	Michael Jähn
Scientific Programmer	Jonas Jucker
Scientific programmer	Ruth Lorenz
Scientific programmer	Annika Lauber
Scientific Programmer	Katherine Osterried

As of 31 December 2021, the core staff corresponds to a total of **4.95 FTE**. The administrative assistant is directly supported by the Institute for Atmospheric and Climate Science, and is 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



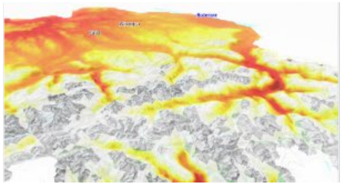
C2SM organisational structure as a science and technology platform (as of January 2021)

Main achievements

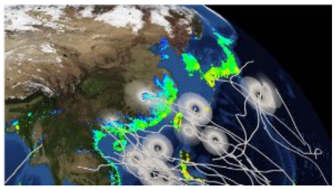
High Performance Computing

Earth System Modelling

Swiss Climate Scenarios



Climate Impacts



Support for research activities

C2SM provides services and support for research activities organised around its four major themes "High performance computing", "Earth system modelling", "Swiss climate scenarios", and "Climate impacts". This concept is built on the premise that the optimal way to support activities of research groups in the Zurich area is to work jointly on common objectives and to share resources.

C2SM provides the expertise, know-how, and infrastructure to enable and enhance the members' research portfolios and to foster synergies between the members, building upon the respective strengths of the four member institutions.

https://c2sm.ethz.ch/research.html

Establishing the center's working groups

Much of the programming support C2SM provides to the community is organised by means of working groups, which agree on programming tasks assigned to the C2SM scientific programmers. With the transition to the extra-departmental center, C2SM has restructured its previous working groups and created four new that are aligned with C2SM's four strategic themes High-performance computing (Working group 1), Earth system modelling and Climate (Working Group 2), Swiss climate scenarios (Working Group 3), and Climate impacts (Working Group 4). As a consequence of both the scientific programmers' and community members' involvement in several of these working groups, the Executive Office adapted the annual working group meetings and introduced a “C2SM Working Group Day”, at which all working groups will meet in successive meetings. As there is relevant overlap in terms of content between Working Groups 1 and 2, as well as between Working Groups 3 and 4, respectively, joint meetings of Working Groups 1&2 and 3&4 were set up. C2SM core staff also used the opportunity to update the work procedures to be transparent and consistent across all working groups. At the first such C2SM Working Group Day, which took place on 30 March 2021, the adapted mode of operation of the C2SM core staff was introduced to the community. C2SM community members find all relevant information on the new work procedures at the C2SM website and wiki.

The first regular Working Group Day was then carried out on 28 June 2021. With 26 participants at the WG1&2 meeting and 19 at the WG 3&4 meeting a large part of the community was reached. Besides activity reports by the core team programmers, who presented tasks achieved since the first Working Group Day, the meetings also provided space for an overview of short reports on actual research and projects by the C2SM groups. In addition, the C2SM programmers presented the planned work collected from the groups and community projects for the next half year. At the WG1&2 meeting, a lively discussion developed around the topic of containers. This was particularly relevant, as on the upcoming Alps research infrastructure at CSCS, which will be installed in 2023, container technology will play an important role. An equally vivid discussion characterised the WG 3&4 meeting. It much revolved around which data are available that should be used in the upcoming CH202X scenarios. In addition, an important exchange on data needs by the C2SM impact researchers was started. To concretise ideas, identify synergies and joint interests in data requirements, C2SM organised another specific Working Group 4 meeting in September 2021. More information on this meeting is available on page 8 under Theme 4.

https://c2sm.ethz.ch/services.html
https://wiki.c2sm.ethz.ch/ORGANIZATION/WebHome#Working_Groups
https://c2sm.ethz.ch/intranet/working-group-meetings.html

Highlights from the working groups

Theme 1: Development of next-generation modelling systems for weather and climate

C2SM activities concerning High-performance computing included implementing the prefetching of boundary data in the COSMO model for NetCDF formatted input files. This new feature allows to load the boundary data ahead of time and circumvent a major part of the performance penalty because of slow input/output (I/O). By this feature, in an ideal setup the total model runtime could be reduced up to 30% in comparison to a run without prefetching.
Further work focused on optimising the turbulence and surface schemes for the application of graphics processing units (GPU) in the weather and climate model ICON. In close collaboration with MeteoSwiss major bottlenecks were identified and rewritten in a way to run the schemes more efficiently. Increasing complexity of software used within the C2SM community required a complete revision of how software is built at CSCS. Based on initial work from MeteoSwiss, C2SM now officially uses Spack, a versatile package manager for supercomputers, to build all supported software.

Theme 2: Earth system modelling

Scaling analysis for high-resolution climate runs

In order to find optimal model setups on high-performance computing (HPC) architectures, it is desired to analyse the scaling capabilities, i.e., to calculate the runtime efficiency with an increasing number of processors / nodes. Such a scaling analysis has been performed for a set of models (ECHAM, ICON, and ICON-HAM) with different climate run setups. It could be shown that there is a very good scalability for all those models. In particular the GPU version of ICON is capable of high-resolution global climate runs (horizontal resolution of 5 km) on the Piz Daint machine at CSCS (Swiss Supercomputing Centre).

Processing chain for COSMO and ICON: extension for ICON-ART simulations

Besides model simulations themselves, it is very time-consuming to prepare necessary input data (preprocessing) and to analyse the output data (post-processing). C2SM provides a script that simplifies and automates these processing steps. It could already be used for COSMO and ICON and has now been extended to be compatible with the ART ("Aerosols and Reactive Trace Gases") extension of ICON.

Theme 3: Developing user tailored future climate scenarios

The current Swiss future climate scenarios, provided by the CH2018 project, were prepared in close collaboration between MeteoSwiss, C2SM, and ETH. The next generation of Swiss climate scenarios will again be prepared by these partners and are due approximately 2025 according to the Federal Council strategy for adaptation to climate change in Switzerland. In 2021 discussions began on which data these new climate scenarios will be based. Since CH2018, many new regional climate model (RCM) simulations based on World Climate Research Programme (WCRP) Coordinated Regional Climate Downscaling Experiment (CORDEX) data have become available, which did not exist yet for CH2018. However, these data still belong to the same generation of regional climate model CORDEX simulations, which are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) global climate model simulations. While the new global climate simulations, CMIP6, are available now, corresponding RCM simulations do not exist yet. Therefore, it was decided to update the database from CH2018 using the new RCM simulations based on CMIP5. In addition, it was decided to compare CMIP5 and CMIP6 data to obtain a better picture of what has changed from CMIP5 to CMIP6.

During 2021, C2SM core staff worked on updating the CH2018 database with these additional regional climate model simulation data. This effort increased the number of available model runs by up to 9 fold, depending on resolution and scenario. In particular, for the higher resolution case (11km) and the business-as-usual scenario many new model simulations have become available, which can be used for the next generation of Swiss climate scenarios. The new data have also been evaluated and key variables have been compared between the updated database and results from CH2018.This did not lead to major differences in key findings. Therefore, CH2018 results will remain valid and can still be used for the future scenarios.

Processing chain for ICON-CLM simulations

As part of the preparation of EURO-CORDEX simulations with ICON-CLM, C2SM has adapted a processing chain tool developed by the CLM community. It is known as the

"Starter Package for ICON-CLM Experiments" (SPICE). It has been modified to run on Piz Daint, as it was previously only available on the German HPC clusters. Necessary input data (ERAinterim and ERA5) to drive the climate runs can be downloaded directly from DKRZ. SPICE is now available for all members of C2SM via GitHub.

Theme 4: Climate impacts

Climate impacts science is a new topic at C2SM. The primary goal of C2SM's activities around impact sciences is to provide services for climate data to the C2SM impact community and integrate impact modules into C2SM's main Earth System Model ICON. In a first step, we established a plan to build services around data and determined user needs. For this purpose we organised a workshop in September 2021 to identify what kind of support is most urgently needed and can be provided by C2SM. The outcomes of this workshop were four main points C2SM will work on:

- Standardised datasets: easy access and documentation
- Support: contact ruth.lorenz@c2sm.ethz.ch
- Tool and/or advice for model selection
- Keep community in contact

As first standardised datasets C2SM provides access to the so-called CMIP6-Next-Generation (CMIP6-ng) archive. This is work that was started in the climate physics group of Prof. Reto Knutti to make working with CMIP data easier (a CMIP5-ng archive also exists) and is now taken over by C2SM. CMIP6-ng is a quality-controlled as-consistent-as-possible CMIP6 archive. Quality-controlling covers technical inconsistencies, file content issues, and some variable issues. Data is provided as monthly means, annual means, and re-gridded to a common grid. In addition, a small selected number of daily variables is provided. The data is provided as one file per variable, model run, and scenario. Common fixes are different time units, inconsistent time periods (too long or too short), wrong dimension names or inconsistent units. C2SM performs basic checks for physical plausibility, for instance warning and error ranges for each variable. More information can be found in the documentation of the CMIP6-Next-Generation archive:

https://zenodo.org/record/3734128#.Ynzqo5NBzAM

Direct access is available within ETH and a copy can be obtained on request outside ETH.

Research coordination

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

PASC ENIAC

The aim of the Platform for Advanced Scientific Computing (PASC) ENIAC project (July 2017 – June 2021) was 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 was a collaboration between ETH Zurich, C2SM at ETH Zurich, CSCS, and MPI of Meteorology in Hamburg, Germany (MPI-M). The port to GPUs was based on OpenACC compiler directives for most components, except for the soil model JSBACH which was automatically ported using the CLAW compiler developed as part of a previous 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 parameterisations 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. In the last months of the project, the focus was on the maintenance of the production of the GPU configuration for the QUBICC experiment and the support of the CLAW compiler used by JSBACH.

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

PASC HAMAM

The PASC project HAMAM (Nov 2021 – Jun 2024) aims to port the atmospheric chemistry and aerosol module ICON-ART to GPUs and to enhance the performance portability of ICON-HAM previously ported to GPUs in the PASC project ENIAC. The project is led by Dominik Brunner at Empa with partners at ETHZ, C2SM at ETHZ, and MeteoSwiss and is executed in close collaboration with experts at CSCS and the developers of ART at the Karlsruhe Institute of Technology. ART and HAM have been used previously within C2SM for studying aerosol–climate interactions, atmospheric chemistry processes, and air pollution in various model configurations coupled to the global model ECHAM and the regional model COSMO. The recent coupling of the two modules to ICON offers new possibilities for consistent and efficient modelling of atmospheric composition from the global to the regional scale.
In the first months of the project, a few remaining issues of the porting of ICON-HAM have been resolved and first steps for the porting of ICON-ART following the OpenACC paradigm have been taken. In particular, on the ICON-HAM side, the two-moment cloud microphysics and the wet deposition scheme have been ported to OpenACC and validated, which closed the list of HAM code parts to be addressed. In addition, a thorough benchmarking has been started in order to find out where attention is needed to enhance the performance. On the ICON-ART side, the usage of the "serialbox" serialisation tool within ICON has been extended for the usage of ART. The tool allows comparing the state of variables between CPU and GPU implementations before and after the call of a routine, which is an essential preparatory step for the porting. A next important goal in the project is to develop a fully GPU accelerated version of ICON-ART for the simulation of passive tracers. This will enable the simulation of long-lived greenhouse gases like CO_2 and CH_4 and to estimate their emissions from atmospheric measurements by inverse modelling.

WEW-ICON

WEW-ICON ("Weiterentwicklungen ICON") is a collaborative research and development project hosted at C2SM and funded by MeteoSwiss and partly by the consortium COSMO, which focuses on improving the ICON weather forecast and climate model for applications in the Alpine region. One focus is on improving the simulation of specific high-impact phenomena or processes such as fog, hail, and heavy precipitation, as well as improving the entire modelling system for the nowcasting timeframe (i.e., the first 6 forecasting hours), including the assimilation of additional high-frequency and high-density observational data. A second focus of the project is on adapting and testing the ICON model 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 2021 and succeeded the earlier project WEW-COSMO.
As part of the COSMO priority project IMPACT, the work developed by WEW-COSMO / WEW-ICON delivered a full port of all the target numerical weather prediction (NWP) configuration components to OpenACC. This extended the previously existing support for OpenACC of the climate configuration used by QUBICC (see the PASC-ENIAC report). While the dynamical core is shared among various configurations, large new components and parameterisations were ported to OpenACC like the radiation scheme ecrad (developed at ECMWF), and microphysics. Others like the soil model were adapted from the operational GPU port of COSMO. For the first time we have a full GPU capable configuration of ICON that can run NWP experiments entirely on the GPU (i.e. without having to run unsupported components on the CPU, which triggers expensive data transfers from the accelerator to the CPU). A 1km resolution over the Swiss domain setup, equivalent of COSMO-1E, has been setup for ICON running on GPUs. The corresponding data assimilation system (KENDA/DACE) has been integrated into the NWP GPU configuration. Currently the focus is on the GPU benchmarking and optimisation of the compute intensive components. A long validation against observations is planned for summer 2022.

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

EXCLAIM

The interdisciplinary research initiative EXCLAIM (Extreme scale computing and data platform for cloud-resolving weather and climate modelling) was officially kicked-off on April 1, 2021. This six year open ETH project aims to develop an ICON model based infrastructure that is capable of running kilometre-scale climate simulations at both regional and global scales. These high-resolution simulations will include phenomena such as the formation of convective clouds, which will allow predicting much more reliably the frequency and severity of extreme weather events such as heat waves, heavy rainfall, thunderstorms, and droughts.

To develop the weather and climate modelling infrastructure of the future, EXCLAIM pushes beyond the limits of what was previously possible in terms of hardware, system software, model algorithms or data infrastructure. Therefore, EXCLAIM brings together ETH Zurich, the Swiss National Supercomputer Centre (CSCS), the Federal Office of Meteorology and Climatology (MeteoSwiss), the Swiss Data Science Center (SDSC), and the Swiss Federal Laboratories for Materials Science and Technology (Empa). The project runs under the umbrella of the Center for Climate Systems Modeling (C2SM).

In 2021, EXCLAIM reached its first milestones that include (i) refinement of the planning and alignment with the ongoing development at MeteoSwiss and CSCS, (ii) hiring of the core team, and (iii) establishment of the EXCLAIM network nationally and internationally.

(i) The development is driven by the EXCLAIM scientific roadmap, which defines in detail the scientific goals, model requirements, use cases (climate simulations), deliverables, and milestones. Over the course of the next six years, EXCLAIM will develop the corresponding performant model versions and run them to demonstrate the ability of the platform to reach the specified targets. These include: aqua planet, global and uncoupled simulations of clouds and convection currents, global simulations that fully couple the atmosphere, oceans, sea ice and land surface, and regional and local climate scenarios for Europe. The scientific roadmap is in alignment with the ongoing development of ICON-22 at MeteoSwiss and GT4Py at CSCS.

(ii) The EXCLAIM core team has been successfully established. It consists of the executive committee (Prof. Nicolas Gruber, Prof. Christoph Schär, Thomas Schulthess and Christof Appenzeller) that steers the strategic direction of the project, and the board of directors (Dr. Anurag Dipankar, Dr. Mauro Bianco, Dr. Xavier Lapillonne and Dr. Christina Schnadt Poberaj) that represent the operational body of the project, and the project coordinator (Dr. Tamara Bandikova). In 2022, five software engineers and two postdocs will be joining the team.

(iii) Another major achievement was the establishment of the project-internal, the national and the international networks. With EXCLAIM, many new connections between the project partners have been established and the already existing collaborations have been deepened substantially. A major outcome was the alignment of the model-development strategies of the different partners. We also established collaborations with our international partners (DWD, ECMWF, and MPI-M). Discussions and strategy meetings are ongoing to become a key development partner of the ICON consortium and to find an agreement with respect to the licensing of the ICON software. We expect to sign the respective contracts in 2022.

https://exclaim.ethz.ch/

Education and training

C2SM organised and carried out several workshops.

COSMO/ICON user workshop

The Swiss COSMO/ICON User workshop is an informal one day event whose goal is to bring together COSMO/ICON users from Switzerland, share experience and knowledge about the models, and get to insights into some projects involving these models. In 2021, it took place online on 19 January. 22 presentations provided an overview of activities revolving around COSMO/ICON, the description of a technical problem or the presentation of results from a specific project. 65 people registered for the workshop co-organised by C2SM, MeteoSwiss, and EMPA. The program and presentations can be found at the C2SM wiki at:

https://wiki.c2sm.ethz.ch/MODELS/COSMOCuW2021

Scientific visualization using python 2021

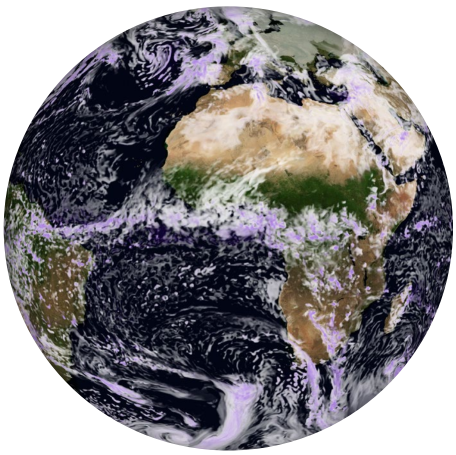
In November 2021, C2SM in collaboration with ETH Scientific IT Services (SIS) carried out its popular python workshops for their community. Due to the continued pandemic, both courses were conducted online again. The first course, carried out in the mornings of 2 and 3 November 2021, introduced the participants to the basic elements of python. The second course, a four mornings workshop on 15-18 November 2021, focused on the visualisation in the Python programming language. Both workshops were fully booked and again very well received by the C2SM community. Based on the popularity and the very positive feedback from the attendees, the workshops will be carried out again in autumn 2022.

Outreach and events

In 2021, C2SM organised the second online edition of ETH-Klimarunde.

Netto Null: Wie erreichen wir die Klimaneutralität?

Human-induced global climate change continues unabated and the Earth's temperature continues to rise. To prevent more severe, further warming, we must largely eliminate the use of fossil fuels worldwide by mid-century and bring effective CO_2 emissions to zero by 2050. What matters here is what "bottom line" remains in the atmosphere: The goal of "net zero emissions" is based on the principle that every ton of CO_2 in the atmosphere contributes roughly the same amount to warming in the long term, regardless of when and where it is emitted. This means that by 2050 at the latest, every additional ton of CO_2 emitted must be removed from the atmosphere, for example through technical CO_2 sequestration or CO_2 uptake in forests and soils. This applies to the entire world. But what does "net zero" mean for Switzerland, for our cities and for each individual? And how do we achieve this goal?



Klimarunde 2021 discussed the latest findings on possible solutions how to remove $C0_2$ from the atmosphere. We also looked specifically at whether net zero is a realistic goal for the city of Zurich and what political instruments are needed to realise the technological and societal transformation quickly enough.

This year ETH-Klimarunde was conducted online for the second time. We were very pleased with the large participation in this online event: More than 460 people joined the event for the live-webinar with an introduction by ETH Vice President for Research, Detlef Günther, and the keynote speakers Prof. Sonia Seneviratne, Jonas Fricker, and Dr. Robin Quartier.

In the second part we organised 8 parallel zoom sessions in which the participants could interact with the experts directly.

We received very positive feedback regarding the quality and the organisation of the event. We would like to thank all our volunteers and our co-organiser, the Energy Science Center, for their support in making this event a great success.

The video-recording of the webinar can be found on our website:

https://c2sm.ethz.ch/events/eth-klimarunde-2021.html

Prof. Detlef Günther
Vizepräsident für Forschung
ETH Zürich

Prof. Sonia Seneviratne
Land-Klima-Dynamik
ETH Zürich

«Aufgrund der neuesten Erkenntnisse der Klimaforschung ist es klar, dass kein Weg an einem raschen Übergang zu einer Netto-Null-CO_2-Welt vorbeiführt.»

Jonas Fricker
Projektleiter Klimaschutz
Stadt Zürich

«Der Stadtrat hat beschlossen, dass die Stadtverwaltung 2035 klimaneutral sein soll. Sie soll Vorbild sein und aufzeigen, dass Netto-Null 2040 in Zürich möglich ist.»

Dr. Robin Quartier
Geschäftsführer
VBSA und SwissZinc AG

«Eine Klimapolitik, die nur auf wirtschaftliche Anreize setzt, wird scheitern. Es braucht einen neuen Ansatz, bei dem die Carbon Capture Technologie eine zentrale Rolle

Parallele Zoom Sessions: Tischgespräche

18.30 - 19.30 Uhr

Während der Tischgespräche können Sie Ihre Fragen den Expertinnen und Experten direkt stellen. Dieses Jahr wieder per Zoom online. Hierzu ein paar Regeln:

- Sie können frei zwischen den Tischgesprächen wechseln, in dem Sie die Links auf unserer Webseite nutzen.
- Wenn Sie nicht reden, stellen Sie bitte Ihr Mikrofon auf stumm (mute).
- Möchten Sie eine Frage stellen oder einen Kommentar abgeben, verwenden Sie die «Raise hand» oder die Chat-Funktion . Die/der ModeratorIn wird Sie aufrufen.
- Seien Sie fair und lassen Sie andere auch zu Wort kommen.

Thema 1
Was sind die neuesten Erkenntnisse zum Klimawandel?

Tischgespräch 1
Wie verändert sich das Klima global? Neueste Erkenntnisse des Weltklimarats.
- Erich Fischer
- Gian-Kasper Plattner
- Martin Wild

Tischgespräch 2
Welche Auswirkungen hat der Klimawandel in der Schweiz und welche Risiken gehen damit einher?
- Sven Kotlarski
- Christoph Schär
- Cornelia Schwierz

Thema 2
Wie setzen wir Klimaschutz in der Schweiz um?

Tischgespräch 3
Wie erreichen wir die Klimaneutralität in der Schweiz bis 2050? Ist das schon früher möglich?
- Konstantinos Boulouchos
- Matthias Gysler
- Reto Knutti
- Sophie Wenger

Tischgespräch 4
Klimapolitik der Schweiz – wie weiter nach der Abstimmung zum CO_2-Gesetz?
- Julie Cantalou
- Anthony Patt
- Jonas Fricker

Thema 3
Was ist die Rolle von Negativemissionen* für die Klimaneutralität?

Tischgespräch 5
Negative Emissionen: Was ist die Rolle der Unternehmen?
- Patrik Bürgi
- Mischa Repmann
- Tobias Schmidt

Tischgespräch 6
Negative Emissionen: Wieviel können Wälder und Böden beitragen?
- Sebastian Dötterl
- Esther Thürig

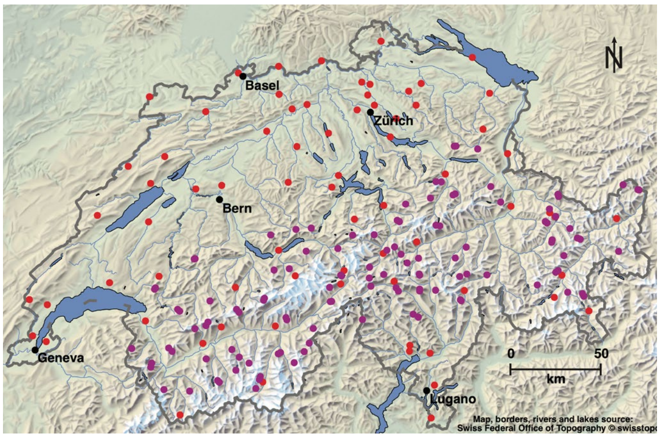
Tischgespräch 7
Negative Emissionen: Welches Potential hat CO_2-Abscheidung?
- Petrissa Eckle
- Peter Freudenstein
- Marco Mazzotti
- Robin Quartier

Tischgespräch 8
Mit gutem Beispiel voran: die Netto-Null-Universität! Wie ist das machbar?
- Niklas Beisert
- Anna Knörr
- Christian Schaffner

*Treibhausgase welche der Atmosphäre entzogen werden

Scientific highlights

Paper: A new set of hourly downscaled climate change scenarios over Switzerland



In fall 2018, a new set of climate change scenarios was released for Switzerland, the CH2018 dataset. The data are provided at daily resolution. From the CH2018 dataset we produced a new set of climate change scenarios temporally downscaled at hourly resolution. In addition, we extended this dataset integrating the meteorological stations from the Intercantonal Measurement and Information System (IMIS) network, an alpine network of automatic stations operated by the WSL Institute for Snow and Avalanche Research (SLF). The stations climate change scenarios are available at hourly resolution and are shown in the map above.

The extension to the IMIS network is obtained using a quantile mapping approach in order to perform a spatial transfer of the CH2018 scenarios from the location of the MeteoSwiss stations to the location of the IMIS stations. The temporal downscaling is performed using an enhanced delta-change approach. A careful reading of the paper accompanying the dataset is necessary to understand the limitations and scope of application of this new dataset.

Michel, A., Sharma, V., Lehning, M., and Huwald, H. (2021). Climate change scenarios at hourly time-step over Switzerland from an enhanced temporal downscaling approach, International Journal of Climatology, 2021,doi:10.1002/joc.7032

Paper: Global warming and population change both heighten future risk of human displacement due to river floods

Every year, millions of people around the world are being displaced from their homes due to climate-related disasters. River flooding is responsible for a large part of this displacement. Previous studies have shown that river flood risk is expected to change as a result of global warming and its effects on the hydrological cycle. At the same time, future scenarios of socio-economic development imply substantial population increases in many of the areas that presently experience disaster-induced displacement. Here we show that both global warming and population change are projected to lead to substantial increases in flood-induced displacement risk over the coming decades. We use a global climate-hydrology-inundation modelling chain, including multiple alternative climate and hydrological models, to quantify the effect of global warming on displacement risk assuming either current or projected future population distributions. Keeping population fixed at present levels, we find roughly a 50% increase in global displacement risk for every degree of global warming. Adding projected population changes further exacerbates these increases globally and in most world regions, with the relative global flood displacement risk is increasing by roughly 350% at the end of the 21st century, compared to an increase of 150% without the contribution of population change. While the resolution of the global models is limited, the effect of global warming is robust across greenhouse gas concentration scenarios, climate models and hydrological models. These findings indicate a need for rapid action on both climate mitigation and adaptation agendas in order to reduce future risks to vulnerable populations.

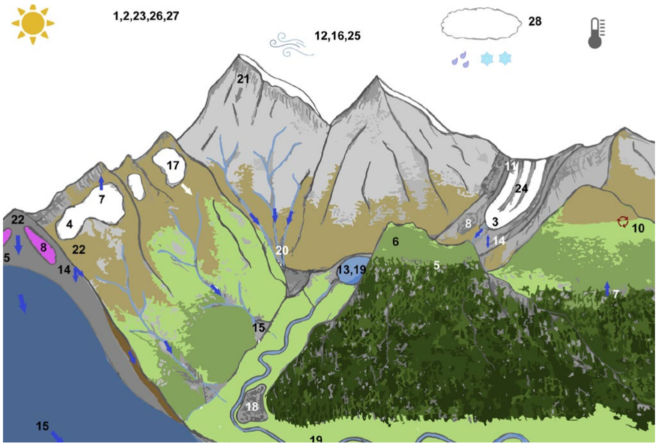
Kam, P. M., Aznar-Siguan, G., Schewe, J., Milano, L., Ginnetti, J., Willner, S., McCaughey, J., and Bresch, D., N., (2021). Global warming and population change both heighten future risk of human displacement due to river floods. Environ. Res. Lett. 16, 044026. https://doi.org/10.1088/1748-9326/abd26c

Paper: Genomic vulnerability to rapid climate warming in a tree species with a long generation time

The Swiss stone pine (Pinus cembra) has long been the 'queen' of the upper forest line, where it is a keystone species for this ecosystem. After a substantial loss of area mainly due to anthropogenic activities during the past few centuries, climate change could further displace the species by fast-growing competitors from lower elevation, with restricted habitat available for colonisation above the current tree line. As adaptation to rapidly increasing temperature and decreasing precipitation may require a fast response, persistence may be critical for a species with an excessively long generation time. The analysis of more than 3,000 genes from several hundred young and adult trees at high and low elevations throughout Switzerland revealed that juvenile trees at high elevations had the genetic make-up to cope with both the current and future climate. By contrast, young trees at low elevations mostly had gene variants that are likely disadvantageous in the future, warmer and drier climate. Such adaptational lag is particularly problematic for an old-growing species. The slow shift towards beneficial gene variants, confirmed through simulations, may hamper short-term adaptation to changing environments and, hence, lead to local extinctions of the enigmatic stone pines.

Dauphin, B., Rellstab, C., Schmid, M., Zoller, S., Karger, D.N., Brodbeck, S., Guillaume, F., Gugerli, F. (2021). Genomic vulnerability to rapid climate warming in a tree species with a long generation time. Global Change Biology, 27: 1181-1195. https://doi.org/10.1111/gcb.15469

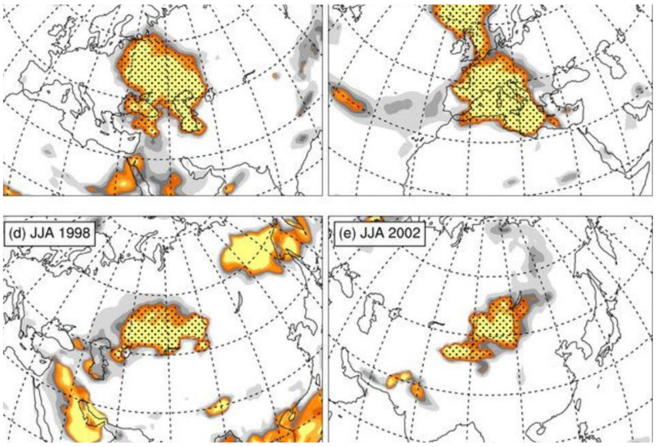
Paper: Towards a definition of essential mountain climate variables



A new article published in the journal One Earth proposes a set of potential Essential Mountain Climate Variables (EMCVs) to support the monitoring and understanding of key climate change-related mountain processes. The article builds upon a workshop organised by GEO Mountains and hosted by the Mountain Research Initiative (MRI). Following an interdisciplinary review of the main climate change processes in mountain environments and their interactions, 97 associated potential EMCVs are identified and ranked according to perceived importance. Many higher-ranked (more important) variables, such as albedo and land cover, correspond to multiple components of the Earth system (e.g., atmosphere, biosphere, cryosphere, hydrosphere). These 'sphere-linking' variables represent critical data requirements that strictly disciplinary approaches may overlook. In contrast, lower-ranking variables relate to specific components of individual spheres. Interestingly, several of the potential EMCVs are not among the globally relevant Essential Climate Variables (ECVs) curated by the Global Climate Observing System (GCOS), justifying the paper's mountain-specific approach.

Thornton, J.M., Palazzi, E., Pepin, N.C., Cristofanelli, P., Essery, R., Kotlarski, S., Giuliani, G., Guigoz, Y., Kulonen, A., Pritchard, D., Li, X., Fowler, H.J., Randin, C.F., Shahgedanova, M., Steinbacher, M., Zebisch, M., and Adler, C. (2021). Towards a definition of Essential Mountain Climate Variables. One Earth. doi: 10.1016/j.oneear.2021.05.005

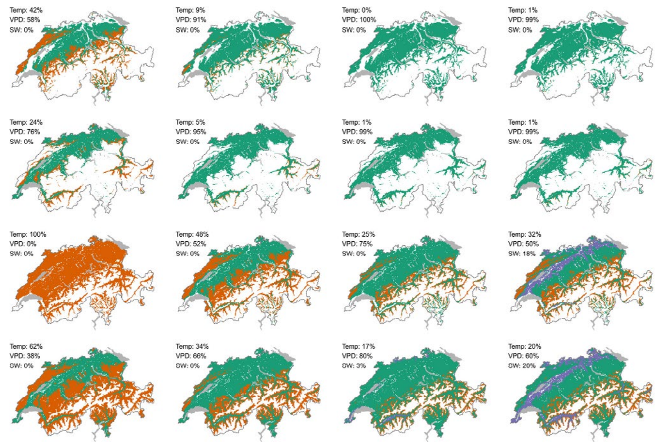
Paper: Identification of seasonal climate extremes in ERA-Interim and CESM-LENS



Climatic extremes on the seasonal time scale are societally relevant and understanding their underlying physical processes is challenging. In this conceptual study, a pragmatic approach to pool seasonal extremes across space is developed and applied to investigate hot summers and cold winters in ERA-Interim and the Community Earth System Model Large Ensemble (CESM-LENS). We identify spatial extreme season objects as contiguous regions of extreme seasonal mean temperatures based on statistical modelling. Regional pooling of extreme season objects in CESM-LENS then yields considerable samples of analogs to even the most extreme ERA-Interim events. This approach offers numerous opportunities for systematically analysing large samples of extreme seasons, and several such analyses are illustrated in the paper. For instance, we reveal a striking co-occurrence of El Niño to La Niña transitions and the largest ERA-Interim midlatitude extreme summer events.

Röthlisberger, M., M. Hermann, C. Frei, F. Lehner, E. M. Fischer, R. Knutti, and H. Wernli, (2021). A new framework for identifying and investigating seasonal climate extremes. J. Climate, 34, 7761–7782. DOI: https://doi.org/10.1175/JCLI-D-20-0953.1

Paper: Tree growth in Switzerland is increasingly constrained by rising evaporative demand



The response of trees to intra-annual environmental constraints varies temporally throughout a growing season and spatially across landscapes. A better understanding of these dynamics will help us anticipate the impacts of short-term climate variability and medium-term climate change on forests. Using the process-based 3-PG forest ecosystem model, we assessed the spatial manifestation and seasonal variation in environmental constraints [vapour pressure deficit (VPD), air temperature and soil water availability] on tree growth for the potential distribution range of seven widespread Central European tree species.

Our results highlight how the relative impact of environmental growth constraints has shifted in the last three decades, and show that the importance of VPD as a dominant environmental growth constraint has increased for tree species in Swiss and Central European forests. Understanding the spatial and temporal variability in environmental growth constraints will help to generate accurate species-specific risk maps for forest managers to identify areas with elevated drought and heat stress in the near future.

Trotsiuk, V., Babst, F., Grossiord, C., Gessler, A., Forrester, D.I., Buchmann, N., Schaub, M., Eugster, W. (2021). Tree growth in Switzerland is increasingly constrained by rising evaporative demand. J Ecology https://doi.org/10.1111/1365-2745.13712

Paper: Combined postprocessing of coarse and high resolution NWP models improves forecast skill

Even state-of-the-art high-resolution numerical weather prediction models (NWP) cannot fully resolve complex terrain as in the Alpine region and therefore suffer from systematic biases. Researchers from MeteoSwiss and the group of Prof. Heini Wernli demonstrate by way of example of temperature forecasts in Switzerland that statistical postprocessing using ensemble model output statistics (EMOS) effectively removes such systematic biases. In addition, postprocessing allows to combine short-term forecasts of the convection permitting COSMO ensemble and medium range forecasts of the global Integrated Forecasting System (IFS) model of ECMWF into one consolidated consensus forecast. EMOS allows not only to seamlessly combine the forecasts over short and medium term, the multi-model postprocessing (Mixed EMOS) of IFS and COSMO also yields lower errors in terms of the continuous ranked probability score (CRPS) than using postprocessing on either of the models individually.

Keller, R., Rajczak J., Bhend J., Spirig, C., Hemri, S., Liniger, M. A., and Wernli, H. (2021). Seamless multimodel postprocessing for air temperature forecasts in complex topography, Weather and Forecasting, 36, 3, https://doi.org/10.1175/WAF-D-20-0141.1

Paper: The Swiss alpine zero degree line: methods, past evolution, sensitivities

The near-surface zero degree line (ZDL) is a key isotherm in mountain regions, but a detailed analysis of methods for the ZDL determination, their properties and applicability in a changing climate is missing. Different approaches are used to determine the ZDL on a monthly scale in the Swiss Alps. A non-linear profile yields more robust and more realistic ZDLs than a linear profile, especially in the winter-half year when frequent inversions disqualify a linear assumption. In the period 1871-2019, the Swiss ZDL has risen by several hundred meters in every calendar month with the largest increases, but also very large uncertainties in December and January. The increases have accelerated in the last decades, especially in spring and summer. The ZDL is currently increasing by about 160 m/°C warming in the summer-half year and by up to 340 m/°C in winter months. The outlined methods lay a foundation for the analysis of further isotherms and to study the future ZDL evolution based on climate scenario data.

Scherrer, S.C., Gubler, S., Wehrli, K., Fischer, A.M., and Kotlarski, S. (2021). The Swiss Alpine Zero Degree Line: Methods, Past Evolution, Sensitivities. International Journal of Climatology, doi: 10.1002/joc.7228

Paper: Urban multi-model climate projections of intense heat in Switzerland

Originating from a master's thesis conducted at ETH Zurich, a paper on urban climate projections has now been published in the journal Climate Services. Projections are based on an ensemble of regional climate model simulations from EURO-CORDEX. The employed technique entails the empirical-statistical downscaling method quantile mapping, which is applied in two different settings, first for bias correction and downscaling of raw climate model data to rural stations with long-term measurements (accomplished in the frame of the CH2018 scenarios) and second for spatial transfer of bias-corrected and downscaled climate model data to the respective urban target site. The resulting products are projections for minimum and maximum temperature at five urban sites in Switzerland until the end of the 21st century under the RCPs 2.6, 4.5 and 8.5.

Comparing the generated urban climate projections with existing climate scenarios of adjacent rural sites allows to represent the urban heat island effect in future temperature-based heat indices. Urban areas will be more strongly affected by rising temperatures than rural sites in terms of fixed threshold exceedances, especially during nighttime.

Burgstall, A., Kotlarski, S., Casanueva, A., Hertig, E., Fischer, E.M., and Knutti, R. (2021). User-tailored climate projections of intense urban heat in Switzerland. Climate Services, 22, 100228. doi: 10.1016/j.cliser.2021.100228

Key publications of C2SM members 2021

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

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Annex

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Plenary members

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Prof. Benjamin Stocker	ETH D-USYS	Computational Ecosystems Science

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Prof. Sebastian Schemm	ETH D-USYS	Circulation of the Atmosphere
Prof. Tobias Schmidt	ETH D-GESS	Energy and Technology Policy

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Dr. Cornelia Schwierz	MeteoSwiss	Climate Monitoring
Dr. Reto Stöckli	MeteoSwiss	Climate Fundamentals
Prof. Heather Stoll	ETH D-ERDW	Climate Geology
Prof. Heini Wernli	ETH D-USYS	Atmospheric Dynamics
Prof. Martin Wild	ETH D-USYS	Climate and Radiation
Prof. Lenny Winkel	ETH D-USYS	Environmental Geochemistry
Dr. Massimiliano Zappa	WSL	Hydrological Impacts
Prof. Niklaus Zimmermann	WSL	Landscape Dynamics

As of 31 December 2021

Scientific Advisory Board (SAB) members

Dr. Karin Ammon	SCNAT, 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.

Project name	Lead PI	Funding mechanism	Duration
PASC ENIAC	U. Lohmann (ETH)	PASC	01/07/2017 - 30/06/2021
PASC HAMAM	D. Brunner (Empa)	PASC	01/07/2021 - 30/06/2023
WEW-COSMO	P. Steiner (MeteoSwiss)	MeteoSwiss	01/01/2017 - 31/09/2021
WEW-ICON	O. Fuhrer (MeteoSwiss)	MeteoSwiss	01/10/2021 - 31/12/2026
Klimasz. Anwendungen	S. Kotlarski (MeteoSwiss)	MeteoSwiss	01/10/2019 - 31/12/2021
Klimasz. Technisch	S. Kotlarski (MeteoSwiss)	MeteoSwiss	01/02/2021 - 30/06/2023
INCA	M. Liniger (MeteoSwiss)	MeteoSwiss	01/112020 - 31/12/2022
Machine Learning	M. Liniger (MeteoSwiss)	MeteoSwiss	13/12/2020 - 31/12/2023

Reporting period (1 January 2021 - 31 December 2021)

Budget

Saldo (CHF) 01/01/2021	**302'944**

Income (CHF) 01/01/2021-31/12/2021	
ETH School Board	300'000
USYS Department	150'000
Surcharges core staff	2'892
ETH members	53'000
MeteoSwiss	100'000
Empa	70'000
WSL	50'000
Total income	**745'892**

Expenses (CHF) 01/01/2021-31/12/2021	
Salaries core staff	580'854
Events	4'512
Running costs	8'380
Training	10'500
Hardware	8'264
Total expenses	**612'510**

Saldo (CHF) 31/12/2020	**436'326**

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

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