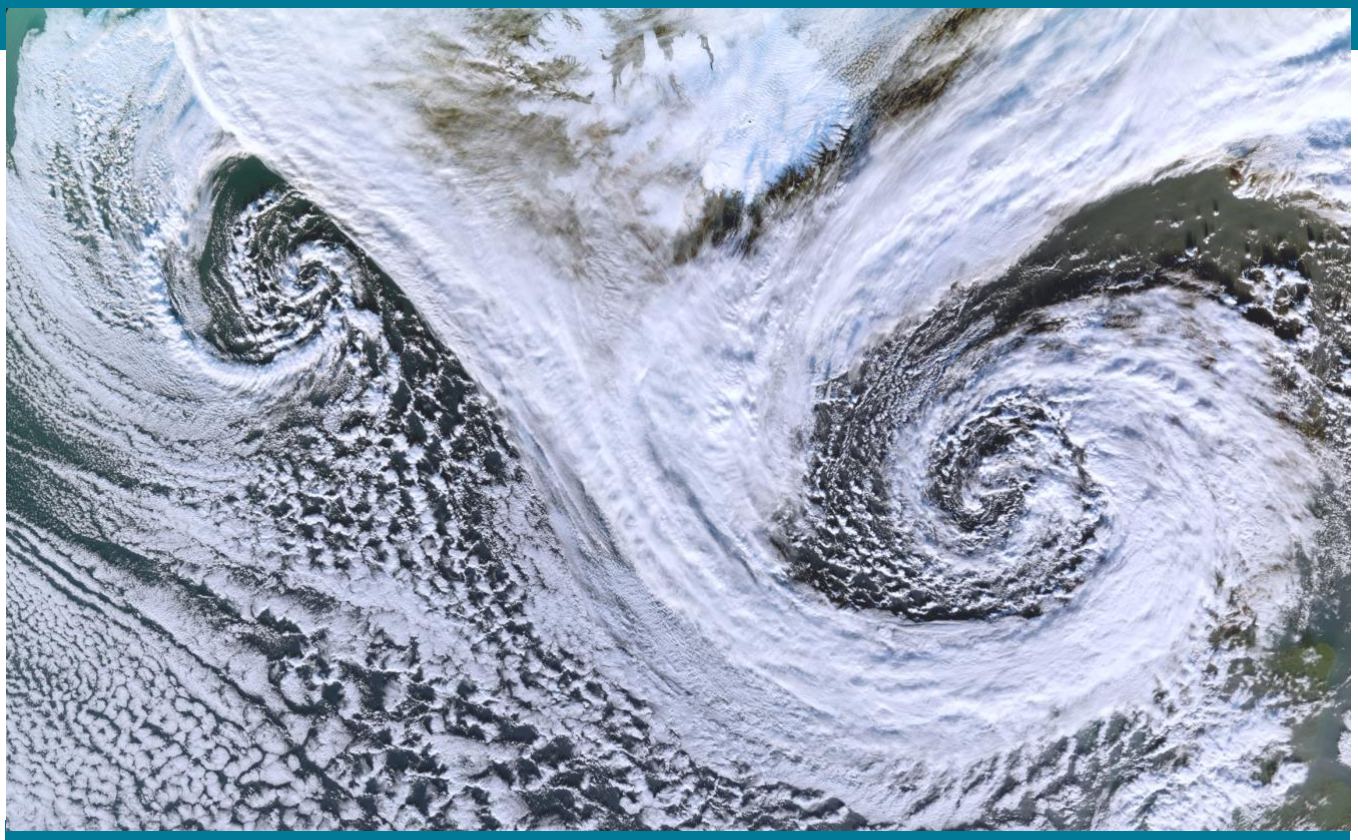
ETH zürich



Self-evaluation 2008-2018

Competence Center for Climate Systems Modeling (C2SM)

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July 2, 2019

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Content

1 Background and rationale

The Center for Climate Systems Modeling (C2SM) was established in 2008 as a multi-institutional Competence Center of ETH together with the Swiss Federal Office for Meteorology and Climatology (Meteo–Swiss), the Swiss Federal Laboratories for Materials Science and Technology (Empa), and the Swiss centre of excellence for agricultural research (Agroscope) as founding partners. In 2011, C2SM submitted a request to the executive board of ETHZ to support its 2nd phase. This request was granted in early 2012 and after successful negotiations with all other partners including WSL as a new partner, the second phase officially started in July 2012 with the funding secured through December 2016. In November 2016, C2SM filed a request for a third phase, covering the period January 2017 through December 2020. This request was granted in December 2016, although as a Competence Center (with a sunset clause) rather than as the research platform (without a sunset) that was favored by the applicants.

The primary rationale for the establishment of C2SM was the growing recognition that the soft- and hardware requirements to undertake world-leading research in the areas of weather and climate is growing at a pace that makes it impossible for the individual research groups to establish and maintain the needed infrastructure. This requires the pooling of resources, primarily with regard to the development and support of the complex and large (order of 10^6 number of lines) numerical codes that are at the heart of the weather and climate models. This primary need was reflected in the organizational structure of C2SM from the very beginning, where most funding was allocated to fund programmers/model experts that supported the members in the development and application of models.

The second rationale was the opportunity to unlock the great potential for synergies that existed in the different partner institutions, especially between MeteoSwiss and ETH Zurich with regard to regional climate/weather simulations. While sharing many common interests and tools, the two institutions had drifted apart in the 1990s, making collaborations difficult. This was overcome first through the National Competence Center for Research for Climate (NCCR Climate) (2000-2012) and then through the funding of C2SM, resulting in one of the internationally most productive collaborations between a national weather service and an academic institution. Similar synergies were unlocked through C2SM between the other partners, Empa, WSL, Agroscope, ETH, and MeteoSwiss, as well as the CSCS, the Swiss National Supercomputing Centre, creating a network of tight collaborations.

The third rationale for the establishment for C2SM was the commitment of the partner institutions in the NCCR Climate for ensuring a more permanent structure that exists beyond the lifetime of this program. With the establishment of the Oeschger Centre for Climate Research in 2007, the University of Bern fulfilled its requirement. The establishment of C2SM in 2008 permitted ETH and the other C2SM partners to ensure the fulfilling of their commitments.

2 Mission statement (2008-2018)

The Center for Climate Systems Modeling's mission is to provide a technical and scientific platform and a network for its partner institutions.

C2SM's mission is

- to support the development and application of complex models of weather, climate, and atmospheric composition 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.

3 Organizational structure

As an official ETH-wide competence center, C2SM's organizational structure was modeled after the template for ETH competence centers, i.e., with a plenary board of all members at its core, an executive team with a director in charge of everyday's activities, and a scientific steering committee focusing on the strategic development of the center (Figure 1). A scientific advisory board of external, independent experts advises the steering board and C2SM on strategic matters. C2SM organized its main activities in the areas of regional and global climate modeling into two working groups, providing a forum for the interactions between the members and the core staff members. These working groups, together with the executive director, provide guidance with regard to the definition of the tasks for the core staff members.

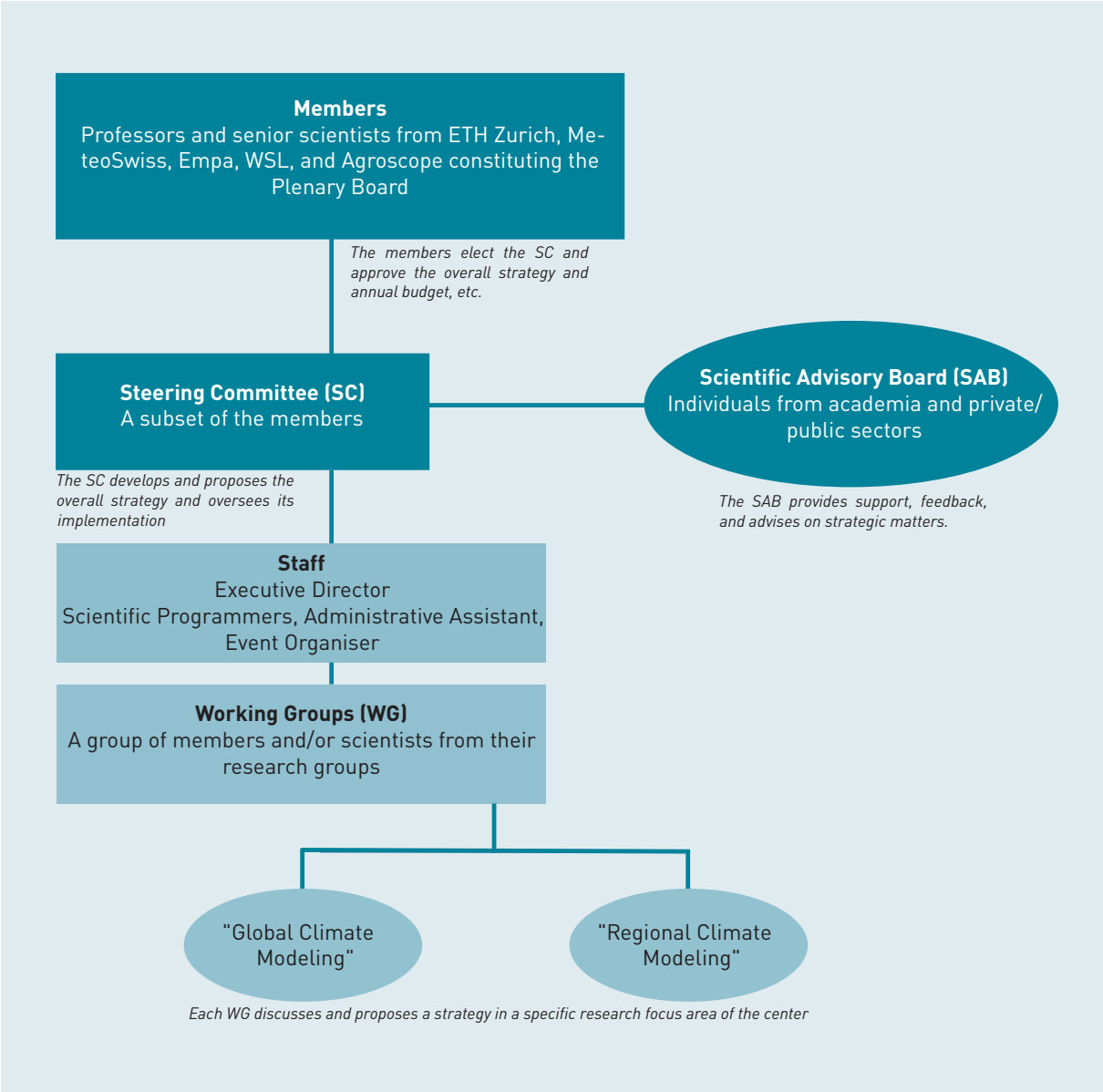


Figure 1: Organizational structure of C2SM since 2008.

4 Accomplishments

The establishment of C2SM has not only substantially strengthened the collaborations between the partner institutions, but also created many new ones. In particular, the following achievements can be clearly attributed to C2SM:

4.1 Research coordination

- Acquisition of several joint projects and initiatives (ETH-funded CHIRP1[1] and CHIRP2[2] projects, SNF-funded Sinergia projects (CarboCount CH and CarboSense led by Empa, crCLIM led by ETH), ETH domain funded projects (Maiolica and Maiolica II) and several projects within the High Performance Computing initiatives (HP2C[3] and PASC[4]). These projects were initiated and/or executed under the umbrella of C2SM and aimed to bring together a substantial fraction of the community in order to address novel research avenues.
- Support of the development and dissemination of the climate scenarios for Switzerland. C2SM already played a central role for the CH2011 scenarios, i.e., the first set of regional scenarios generated for Switzerland and released in 2011. This engagement became even stronger with the updated and expanded CH2018 scenarios released in November 2018. C2SM gave an institutional home to the project, employed one of the project coordinators, and acted as an integrator across the different institutions. It also took leadership with regard to the organization of the launch event and the subsequent dissemination of the results.
- Establishment of an extensive research program to take advantage of newly emerging computer architectures (High Performance Computing, HPC) in the framework of a strong collaboration between ETH, MeteoSwiss, and CSCS under the umbrella of C2SM. A key achievement in this respect is the complete porting of the COSMO model to heterogeneous multi-core platforms (i.e., those including accelerators together with the conventional processors units). This joint work was the foundation for MeteoSwiss and CSCS winning the Swiss Informatics and Telecommunication technology sector ICT award in 2016. This award was given explicitly for the development of the high-resolution weather forecast model COSMO-1 and the ensemble system COSMO-E of MeteoSwiss running on the hybrid machine Piz Kesch at CSCS.
- Establishment of a Joint Professorship for Weather and Climate Risks between ETH Zurich and MeteoSwiss. The new research group of Prof. David Bresch at the Department of Environmental Systems Science combines numerical probabilistic modeling of weather and climate risks with the engagement of decision makers and end-users. The research aims to explore ways to strengthen their resilience and create a shared understanding of weather and climate susceptibility.

4.2 Technology development & support

- Development of a coherent modeling strategy to foster opportunities for research collaboration within the community. In particular, the originally very diverse set of models were bundled into two sets of global models (namely MPI-ESM/ECHAM-HAMMOZ and NCAR CESM) and one set of regional models centered around COSMO for the atmosphere and ROMS for the ocean, with C2SM having supported their coupling. In fact, the resulting regional Earth System Model (R-ESM) is a globally unique tool that enables ground breaking research across complex regional issues (Figure 2). Currently, C2SM actively supports ECHAM-HAMMOZ, NCAR CESM, and COSMO. These tools served as the backbone for the joint research initiatives in the past.
- Support for the transitioning of the C2SM research community to the upcoming new backbone modeling system, ICON. C2SM has ported ICON onto the supercomputer Piz Daint at CSCS, and established a working configuration for the community. In addition, C2SM supports the growing community through organizing regular exchange meetings of the ICON@C2SM community, by attending international training events, and by actively supporting the deployment of this modeling system.

[1] Collaborative, Highly Interdisciplinary Research Project, stage 1

[2] Collaborative, Highly Interdisciplinary Research Project, stage 2

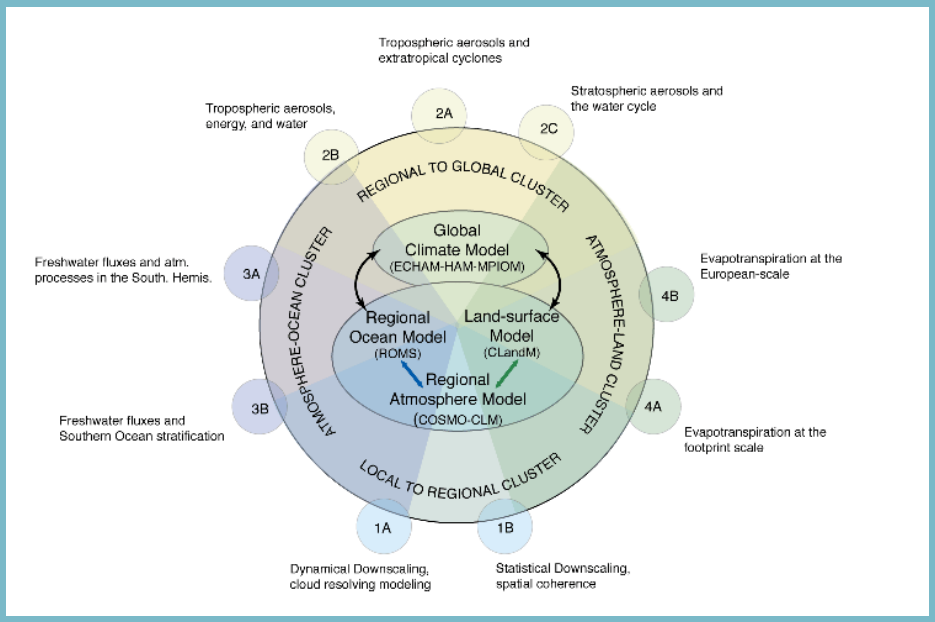
[3] High-Performance and High-Productivity Computing

[4] Platform for Advanced Scientific Computing

CHIRP2: collaborative project on the changing water cycle

C2SM played a crucial role in inspiring, supporting, and managing the project "The water cycle in a changing climate – a multi-scale interaction challenge" that supported a total of nine PhD students and two postdocs. Starting in 2015 and lasting for three years, it was the first "collaborative, highly interdisciplinary research project, stage 2" (CHIRP2) ever supported by the ETH Research Commission. CHIRP2 aimed to advance our understanding of key processes of the Earth's water cycle, with the ultimate goal to improve our ability to project its changes and its impacts in a warming climate. The project was initiated by C2SM through a call for collaborative ideas followed by a workshop where the most promising ideas were discussed and selected. The proposal was then jointly developed by an interdisciplinary team of 17 professors and senior scientists from 4 research institutions (4 departments at ETH, MeteoSwiss, PMOD, and ART) under the leadership of N. Gruber. The project was organized in four research clusters: 1. Local to regional dynamics, 2. Regional to global dynamics, 3. Atmosphere-ocean interaction, and 4. Atmosphere-land surface interactions (see Figure). The four clusters were arranged around two common modeling infrastructures: A regional Earth System Model consisting of the regional atmosphere model COSMO, the land surface model CL(and)M, and the regional ocean model ROMS, and a global Earth System Model consisting of the main elements of the Max Planck Institute for Meteorology (MPI-M) models. Part of this common modeling infrastructure was built in the first phase of the project with strong support by C2SM, and then served as a hub and point of interaction for the PhD students involved in the project throughout the project. In fact, this common infrastructure, in particular the availability of a fully coupled regional ESM is one of the most impactful legacies of the project.

The project was very successful: It led to 8 Ph.Ds. and more than 20 publications, several of which appeared in high impact journals. For example, Greve et al. (2014) showed that the classical tenet that "Dry regions dry out further, whereas wet regions become wetter" actually does not hold well over land. Haumann et al. (2015) demonstrated that the changes in sea-ice drift in the Southern Ocean over the last decades led to substantial increase in the lateral transport of freshwater by ice from the region around Antarctica to the Antarctic Polar Front freshening and cooling the Southern Ocean.



CHIRP2 project structure

High Performance Computing

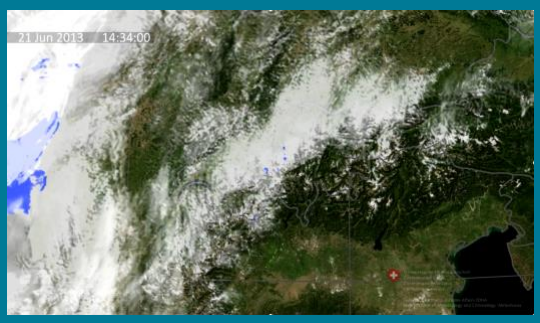
An important focus of C2SM and its community has been high-performance computing at CSCS and on ETH scientific computing platforms such as EULER. For over 10 years, C2SM has been deeply involved in a wealth of technical and collaboration projects that cover the further development and improvement of the regional model COSMO and since 2017, of the global model ICON. The funding volume of these projects, mostly provided by MeteoSwiss and HP2C/PASC, amounts to more than 4 million Swiss Francs, and ~15 scientific programmers were and have been employed at C2SM over the years on these projects.

Particularly valuable characteristics of this endeavor are (i) the refactoring of the COSMO model for energy-efficient simulations on GPUs (e.g., Fuhrer et al. 2014), (ii) similar efforts to port the ICON physics to GPUs (PASC ENIAC project, ongoing), (iii) substantial progress in projections of heavy precipitation in Europe based on convection-resolving simulations, and (iv) a highly fruitful and mutually beneficial cooperation between MeteoSwiss, CSCS, and C2SM.

Porting COSMO to heterogeneous hardware architectures with GPUs required rewriting the dynamics in C++ using the Stencil Loop Language (STELLA), an embedded domain-specific language developed in the C2SM community (Gysi et al., 2015). For the handling of physical parameterizations and lateral boundary conditions, OpenACC compiler directives were used in the existing FORTRAN code. For this innovative model development, MeteoSwiss and CSCS were awarded the 2016 Swiss ICT Award, and since 2016, MeteoSwiss has been running their 1 km resolution and ensemble operational weather forecasts with COSMO on GPUs. In 2018, the modified code was integrated into the official COSMO version making it available to other research institutions and weather services. The efficiency of this code also permitted simulating CO_2 plumes from cities and power plants at kilometer-scale resolution (Brunner et al. 2018).

A particular challenge for improving European climate change projections in summer is the model representation of atmospheric convection. The advent of the GPU-based high-resolution regional model allowed the researchers to carry out continental-scale climate simulations in convection-resolving mode (e.g., Ban et al., 2015; Leutwyler et al. 2016), i.e., representing convective processes explicitly based on the governing dynamical equations. This approach substantially improves the simulation of the diurnal cycle of summer precipitation, intense hourly rainfall events, and the representation of the scaling of precipitation with temperature.

The fruitful collaboration within C2SM and with CSCS has also helped defining an ambitious vision for extreme-scale computing in weather and climate for the coming decade (Fuhrer et al. 2018, Schulthess et al. 2018): It is envisioned to invest in computing capabilities allowing convection-resolving global simulations at 1 km grid spacing with a throughput of one simulated year per day. Key to this development will be an appropriate domain specific software framework, i.e., a generalization of STELLA to grids suitable for global models. To this end, CSCS, MeteoSwiss, and C2SM, along with their partners at ECMWF and MPI-M, already started developing the GridTools framework in 2014. GridTools is now made available to the broader weather and climate community. It is the goal of CSCS to support such simulations without significantly higher power consumption on its next generation hardware systems.



C2SM will continue to play an important role in this ambitious co-design effort, by supporting the scientific community in using the complex future HPC platforms, in adapting specific diagnostics and modules to the needs of the new technology, in developing novel and efficient approaches to handle the ever-increasing data volume, and in further employing project staff contributing to the HPC

- Establishment of a strategy for data storage facilities. This service, currently limited to the ETH based members only, has been achieved through the acquisition of two ETH equipment proposals and the development of a funding model that ensures a participation of all the relevant research groups at a level proportional to their needs in data storage.
- Development of a tracer module for the COSMO model to standardize the treatment of transport of meteorological tracers and gaseous and particulate constituents throughout the different extensions of COSMO including COSMO-ART and COSMO-M7. This module has been fully integrated into the latest COSMO version 5.x.
- Establishment of a state-of-the-art support for the visualization of weather, climate, and environmental data (SciViz service). The C2SM SciViz expert, who is employed at C2SM by a collaboration contract with ETH Scientific IT Services (SIS), develops and creates elaborate two- and three-dimensional animations or applications for individual members, which would be too cumbersome and time consuming for an individual group to realize. Some of the recent visualizations are available from C2SM's vimeo channel.
- Support for the licensing of the different modeling systems by the different partners. C2SM acted on behalf of the ETH members of the C2SM community for negotiating the licenses for COSMO and ICON.

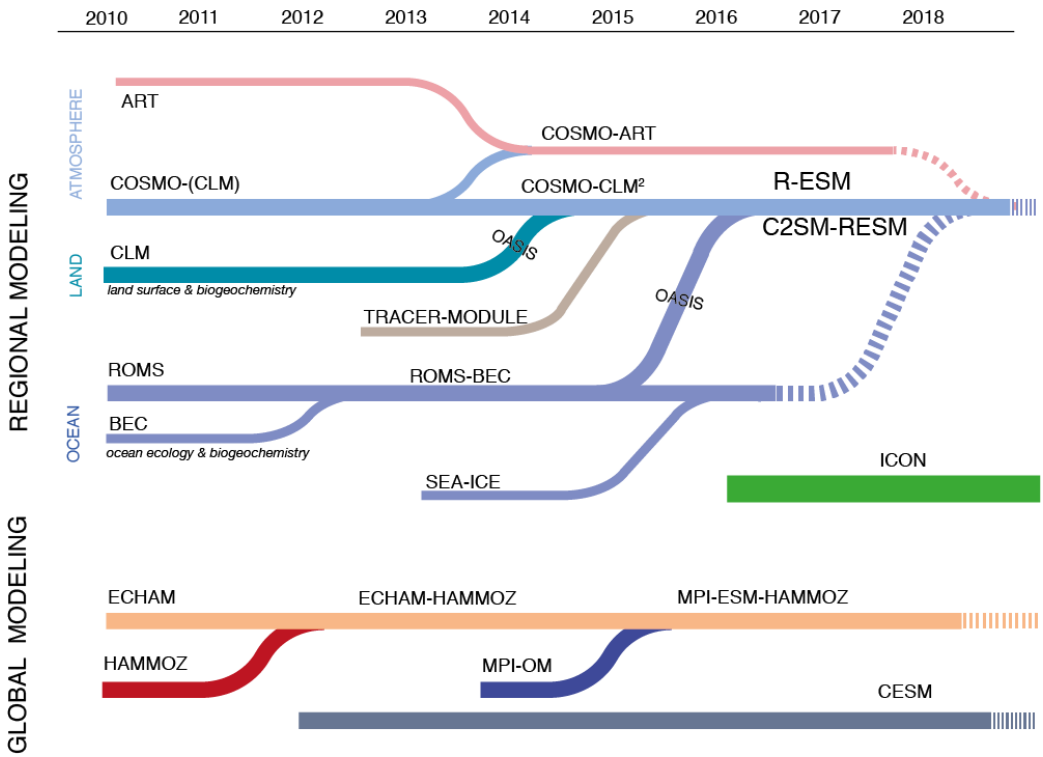


Figure 2: C2SM supported the development of fully coupled Earth System Models at both the regional and global scales. These models will provide the basis for the ongoing work, but will be slowly superseded by the new ICON based family of models, which will cover both regional and global applications.

Swiss Climate Scenarios CH2018

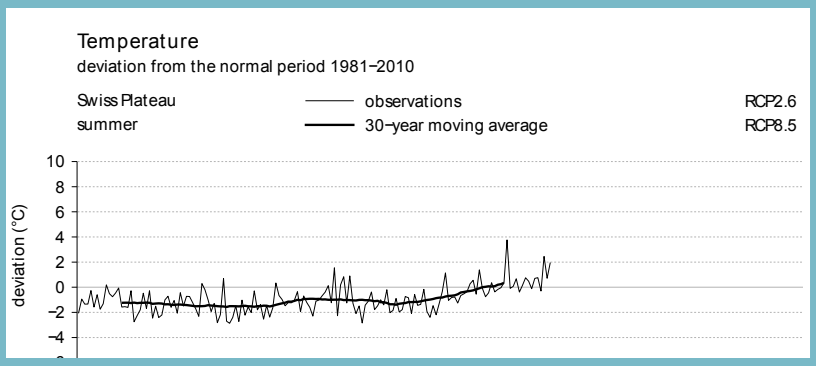
The Swiss Climate Scenarios CH2018 have their origin in the Action Plan for Adaptation to Climate Change, which is part of the Swiss Federal Council's Adaptation Strategy (FOEN, 2014). Thus, the need to provide up-to-date and actionable climate scenarios on the local to regional scale has been recognized as a prerequisite for tailored adaptation activities. In 2014, the Federal Council mandated MeteoSwiss to "coordinate and regularly provide national climate scenarios …in collaboration with the research community".

CH2018 has been a priority theme and central climate service of the National Centre for Climate Services (NCCS) – Switzerland's virtual centre and federal network in the field of climate services. NCCS was established as a response to the recommendation of the Global Framework for Climate Services (GFCS) to establish national coordination and innovation mechanisms to better manage the risks and opportunities arising from climate variability and change (WMO, 2017).

The Swiss Climate Scenarios CH2018 are the result of a joint effort by the main partners MeteoSwiss, ETH Zurich, C2SM at ETH Zurich, the University of Bern, and the Institute for Snow and Avalanche Research (SLF/WSL), under the umbrella of NCCS. They provide the most accurate, up-to-date, and coherent climate information available to support assessments of climate change impacts and decisions about adaptation and mitigation in Switzerland. They build on previous scenario efforts and assess past and future changes in the physical climate system of Switzerland.

They are based on the most recent set of global and regional climate models, combined with high-quality observations and process understanding of global and regional climate change. They consider the research and results of many international projects.

The conclusions of CH2018 reflect the consensus of the Swiss climate science community, supported by international reviewers. The data is provided free of charge for anyone to use and includes future changes at various spatial and temporal resolutions for research on climate impacts. The CH2018 scenarios encompass projections of a number of variables, addressing changes in mean climate and extreme events (along with uncertainty estimates where possible) for different regions, different future time periods, and different scenarios of socio-economic development. The past and current climate in Switzerland is documented using observational data, which serve as a reference for future climate change.
In response to the recommendations of users, the results of the new climate scenarios were structured in six service-oriented product groups that serve different user types. Next to the Technical Report and the data itself, these comprise a brochure along five storylines, a web atlas with more than 20'000 graphics, as well as a set of animated videos and expert statements. All these products and further easily accessible information can be found on the new quadrilingual website of the NCCS.



4.3 Education/Training

- Development of technical training and tutorials for the C2SM community. The objective of these training sessions is to provide PhD students and post-doctoral fellows with technical skills and best practices in the areas of e.g., scripting and coding, pre- and post-processing, data analysis and management, and visualization.
- Organization of, and contribution to, the yearly International Swiss Climate Summer Schools. The lead for the organization alternates between the Oeschger Centre for Climate Change Research at the University of Bern and C2SM with C2SM having led the 2015 edition on “Extreme Events and Climate” and the 2017 edition on "High-resolution climate: observations, models and projections". The 2019 edition on "Carbon and climate in a 2°C world: getting out of the fossil fuel carbon budget crunch" will take place in September 2019 on Monte Verita, Switzerland. From the 100 applications received, 59 participants have been chosen for the school according to their qualifications. More information on the summer schools can be found at www.climateresearch.ch.
- Development of a collaboration (MINT Lernzentrum) with the “ETH-Kompetenzzentrum für Lehren und Lernen” for supporting the development of teaching modules for high schools in the areas of mathematics, physics and chemistry, using climate and weather-related phenomena.

4.4 Outreach

- (Co-)Organization and sponsoring of several scientific conferences and seminars, such as the CHIRP2-related symposium on the “Water cycle in a changing climate” (2013), the Latsis symposium on “Atmosphere and Climate dynamics: from clouds to global circulation (2014), the AGU Chapman conference on Lagrangian Modeling of the Atmosphere (2012), the extraordinary Maiolica II seminar series, and others.
- Organization of regular public events (Klimarunde 2013, 2014, 2015, 2016, 2017) to foster the dialogue between scientists and the general public and other stakeholders. Klimarunde 2013 was selected as the best outreach event of the year by Hochschulkommunikation of ETH. The 2014, 2015, and 2017 editions of Klimarunde were jointly organized with ETH's Energy Science Center. We also collaborated with ETH’s Energy Science Center for the 2016 event, but this time also included MeteoSwiss. C2SM provided leadership within the framework of the National Center for Climate Services (NCCS) for the organization of the release event for the new CH2018 climate scenarios in November 2018. This event turned into one of the largest climate related outreach events in Switzerland in the last decade, with more than 600 people attending, and creating a very large media response with frontline news in the largest Swiss newspapers.
- Organization of booths at public science fairs (e.g., Nacht der Forschung 2009, Scientifica 2012, 2013 & 2015) to enhance the understanding of scientific issues and of their relevance for the general public.
- Organization of the ETH Institute for Atmospheric and Climate Science (IAC) girls’ experimental day. This one-day event is carried out annually for school girls aged between 10 and 13. The event has a long tradition at IAC, and since 2016, the organization alternates between IAC and C2SM. It is funded by ETH’s Office for Equal Opportunities ETH Equal!.

ETH-Klimarunde: A new form of outreach

ETH-Klimarunde is an annual outreach event organized by C2SM that provides non-expert academics and the general public a forum to discuss exciting topics around climate change. One element of the event are table discussions ("Tischgespräche") at which the attendees have the opportunity to directly interact with experts in the field to pose their questions and discuss their views. The second is short keynote presentations and a panel discussion on the chosen topic, in which experts discuss their personal or sector-related perspectives and also provide more insight information to the visitors.

ETH-Klimarunde was introduced in 2013 and since then has been carried out on an annual basis and has evolved into one of ETH's flagship outreach events in the environmental sciences. Visitor numbers typically amount to around 400, filling ETH's largest lecture hall, and themes such as "Which conclusions do we draw from the 4th assessment report of IPCC" (2013), "Innovations for climate: what are the conditions to be able to act?" (2014) or "Cities and climate change: how do we rise to the challenges?" (2017) have hitherto been covered. More details on the individual events are provided at the C2SM past events website.

ETH-Klimarunde is typically prepared and run by C2SM together with a co-sponsoring partner. So far, C2SM has partnered with the ETH competence center Energy Science Center (ESC) and MeteoSwiss. An interdisciplinary task force from the different C2SM partners designs the format and focus. C2SM's executive office organizes the logistics, prepares the poster exhibition of the table discussions, and takes care of public relations in the run-up to the event.

On the basis of the success of the first five events, C2SM was asked to organize the launch event of the new Swiss Climate Change Scenarios 2018 on 13 November 2018 in collaboration with NCCS. Overwhelming interest by the national media and a record number of 700 registered visitors made this event another unforgettable success story to C2SM, NCCS, and the CH2018 project and event preparation teams.

The fact that ETH-Klimarunde has become one of ETH's most established and effective outreach measures has been possible only due to C2SM's central role connecting its partners and beyond, and strengthening interdisciplinary collaborations between research groups and institutions. It is also a demonstration of its importance as a central service unit providing capacities that individual groups cannot provide. We envision ETH-Klimarunde to be continued throughout C2SM's third phase and to constitute the main pillar of its outreach activities after 2020.

Table discussions, ETH Klimarunde 2017

Panel discussion, CH2018 Launch event

5 Competitive position, impact, and added value

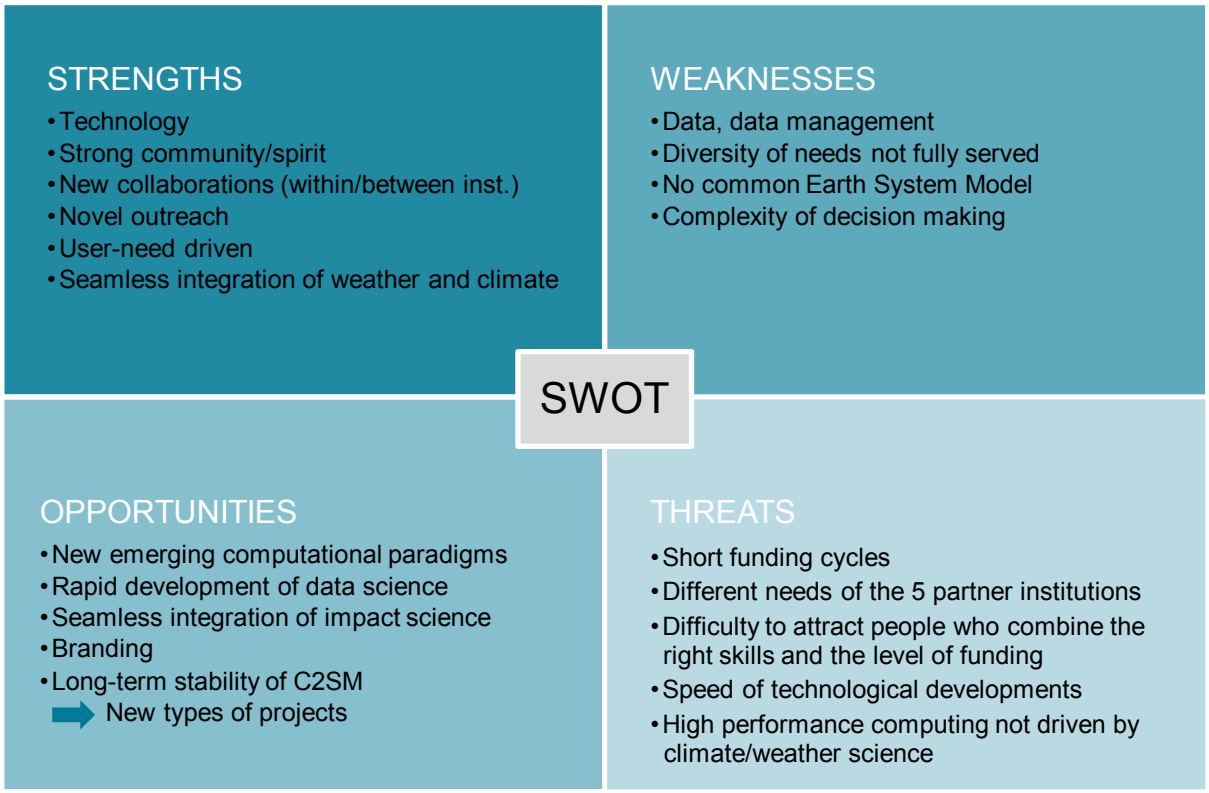


Figure 3: SWOT analysis. Strengths, weaknesses, opportunities, and threats C2SM faces in its third phase.

As outlined in detail in the preceding sections, C2SM has developed into a strong institution with many areas of strengths (Figure 3). These strengths center around the empowerment of the community by providing tools, creating synergies, unlocking hidden potential, and supporting the development of new projects and collaborations. Specifically,

- Technology: C2SM has been very successful in establishing itself as the most important science and technology platform for weather and climate modeling in Switzerland. It successfully acts as a forum that brings the community together and as a technical platform that develops and maintains common tools. This has enabled the members to embark on new and ground breaking research avenues, especially in the area of HPC, leading to the development of the first GPU-based weather model world-wide;
- Community spirit: By reason of its 11-year existence, scientific achievements and outreach activities, C2SM has developed a strong community and team spirit within and across its partner institutions. This has contributed to the enhanced visibility and influence of the climate research community at ETH in particular and in the Zurich area in general;
- Collaborations: Many new collaborations among the partners have been initiated and existing ones strengthened, as attested by the many past, on-going, and future collaborations. One prominent result of the successful long-term collaboration is the appointment of David Bresch as professor in Weather and Climate Risks, a joint professorship of ETH and MeteoSwiss. The creation of this new professorship was initiated through C2SM, with C2SM also leading many of the initial discussions;

- Outreach: Novel outreach avenues have been developed, which have led not only to more intense exchange among the partners, but also have become important events for ETH as a whole;
- User need driven: All activities are strongly user-need driven and reviewed by the working groups on a regular basis. This solidly connects the center to its members, and also makes the decision process transparent and robust;
- Seamless integration of weather and climate: The close collaboration between the weather and climate communities within C2SM is a strong asset that several other institutions are trying to emulate.

With C2SM being a complex cross-institutional network driven by bottom-up needs and initiatives, it naturally also has some weaknesses:

- Data services and management: The needs concerning data services vary greatly between groups and institutions. As the common denominator was too small, the data working group that had been established a few years ago was discontinued. Recently, a more general request for data management services has been emerging due to different research funding agencies' requirements for data management plans and the need for applying the FAIR principle, i.e., findability, accessibility, interoperability, and reusability, in scientific data management. This direction represents a promising joint requirement, providing the basis for new tasks taken on by C2SM;
- Diversity of needs: While all members profit from C2SM as a network and a provider of technical workshops, only those groups that are involved in modeling benefit from the programming support C2SM offers. This requires C2SM to seek a balance, which sometimes takes away resources from the strategically most important issues;
- Lack of a common Earth System Model (ESM): Until today, regional and global modelers within C2SM use and further develop different models to drive their research. In regional modeling, C2SM has been successful in establishing and supporting the COSMO model as the common tool. This has proven to be very beneficial to advance their core research and bringing the community closer together. However, due to differing requirements in the groups, e.g., model development vs. pure applications, no respective joint tool has been used within the global modeling community. With the advent of the unified modeling system ICON, which bridges scales from global over regional to local in a seamless way and offers both climate and numerical weather prediction applications, C2SM plans to make this model system a common research infrastructure (see business plan for further details);
- Complexity of decision-making: C2SM has a large and diverse community and is largely user-driven. Further successful initiatives need to be carried by members of the community. As a result, the decision-making process is complex. In addition, the most important decision body, i.e., the Plenary Assembly meets formally only once per year, so that the decision-making process takes time. This is often a strength, but can sometimes also be a weakness.

There are many opportunities for C2SM to grow and strengthen. These opportunities include

- New emerging high performance computing (HPC) paradigms: The development of new hardware systems, new software paradigms, and new workflows (i.e., domain-specific simulation platforms with services such as a high-level programming interface, transparent re-simulations to replace long-term storage, and workflow management for reproducible science) will permit a breakthrough scaling up of current domains and resolutions;
- Ultrahigh resolution modeling: The above changes in HPC paradigms together with new codes and parameterizations will make it possible to break the convection-resolution barrier over global-scale domains, i.e., to run cloud-resolving simulations across the entire Earth;
- Data science: Many new opportunities are arising in the modelling of weather and climate through the merging of numerical modelling approaches with machine-learning tools. C2SM partners are already working at this interface together with the recently established Swiss Data Science Center (SDSC) (see Appendix A for an example of such a project).

- Seamless integration of impact sciences: While the impact community is currently working "downstream" of the modeling community providing the climate scenarios, there are many synergies emerging from better connecting these two communities. In fact, a seamless integration of the impact sciences into the climate change scenarios would alleviate many of the current problems and issues.
- Branding: A more permanent setup for C2SM would permit it to enhance its branding. While C2SM has already become a well-known and important institution within the ETH domain and the Swiss climate community, C2SM brand name has strong potential for growth internationally.
- New types of projects: A long-term perspective will permit C2SM to engage more strongly in longer-term high-risk high reward types of projects, such as the coupling of weather and climate models with models in other sectors (e.g., energy sector) to assess how extremes can cascades through the coupled system.

These opportunities will be described in more detail in the business plan.

There are few yet potentially harmful factors threatening C2SM.

- Shortness of funding cycles: The four year funding cycles, with a maximum of three (now two) renewal periods are short relative to the time it takes to build up and maintain the excellence of atmospheric and climate science at ETH and at C2SM's member institutions. Engaging in the next wave of development in HPC-based modeling of weather and climate is not possible, unless a long-term perspective is available. This step will be needed in order to stay at the forefront of weather and climate research.
- Speed of technological developments vs speed of developments of codes: While hardware systems develop very fast, the massive codes of the weather and climate models tend to develop only slowly. Thus, while it would be desirable that HPC would be driven by weather and climate science serving its requirements, reality is that the modernisation of weather and climate model code typically lags behind developments in HPC. This discrepancy in development also goes along with difficulties to attract employees skilled both in HPC and the atmospheric sciences and/or with expertise in HPC and willing to work in the environmental sciences where salaries are significantly lower than in the informatics sector.
- Partner Institutions: The needs and/or missions of the five partner institutions may alter with time posing a potential threat to the support of C2SM.

Summarising, the most important impact of C2SM consists in the empowerment of its members and their groups. This enabling role together with the spirit of collaboration, sharing, and joint developments created by C2SM is an important pillar of the success of the world class community that C2SM has brought together. This quality is well reflected by the large number of high quality/high-impact papers being published by the community, the high success in obtaining additional grants, and the numerous awards received by the members. It is noteworthy, for example, that of the 22 ETH researchers recognized as "highly cited authors" by Clarivate Analytics in 2018, 7 are members of C2SM. This has also been noted by the departmental review committee of D-USYS who wrote in January 2019: "Among the world leading research groups are those in: climate physics, next generation climate modeling and future projections on climate, [..], and terrestrial and aquatic biogeochemical cycling."

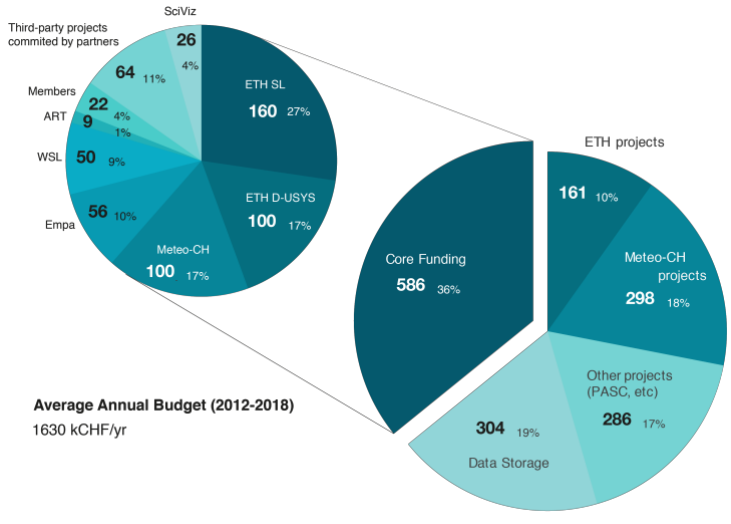
6 Finances

From the beginning, C2SM's total annual operating budget of about 1'600 kCHF/yr (average of the years 2012 through 2018) has been financed using funds from a very diverse set of sources. We thereby differentiate between the sources that fund the activities of C2SM's executive office and pay for the salaries of its staff (core budget) and the sources that support project specific activities, and thus pay the salaries of the project staff (Figure 4).

Between 2012 and 2018, the executive board of ETH (German: Schulleitung, SL) funded, on average, 27% of the total core income of 586 kCHF/yr (Figure 4, left pie). D-USYS contributed 100 kCHF or 17% per year to the core budget. These funds were obtained from the SNF overhead return that the department decided to retain and to allocate to overarching activities, such as competence centers and shared platforms. The other partners (MeteoSwiss, Empa, WSL, and ART) contributed, on average, 37% to the core budget, and 11% was received from third-party funding committed by the partners to support the executive office staff. Smaller contributions to the core budget came from ETH member fees (4%), i.e., by the individual ETH professorships, and since 2016 from the newly established Scientific Visualization (SciViz) service of C2SM (4%) (cf. Sect. 4.2).

The activities of the executive office represent only about a third of the total operations. In the last few years, C2SM received, on average, more than 1 MCHF/yr in addition in the form of project- or infrastructure-based funding (Figure 4, right pie). The sources associated with projects can roughly be grouped into ETH-funded projects (10%), projects financed by MeteoSwiss (18%), and other projects such as SNF or HP2C/PASC projects (project table in Appendix A). In addition, C2SM organized data storage for its ETH members by successfully applying for funds from ETH's scientific equipment program (ETH SEP), and receiving contributions from D-USYS, as well as from the individual groups involved in the activity. On average, this contributed another CHF 300'000 CHF per year to the total budget.

In total, C2SM has been very successful in leveraging the core funding with project-based funding and has thus created the size necessary to serve the needs of its partners and members. Although the core funding by ETH SL to the overall budget amounts to only 10% of the total operating budget, this contribution is crucial since it forms the foundation for the contribution by all other partners to the core budget. And without a solid core funding in place, C2SM would not have been able to raise the project funding.



Left pie: Core funding

Right pie: Total income consisting of core and project funding

Figure 4: Distribution of average annual income by source for the years 2012 to 2018. Left pie: Average contributions to the funding of the executive office of C2SM. Right panel: C2SM's total income consisting of the core and project-based funding and data storage resources. Project-based funding and data storage resources roughly tripled the total budget of C2SM. From 2012 until 2018, ETH SL contributed a little less than 30% to the core funding on average, and about 10% to the total annual operating budget of C2SM.

7 Conclusions

C2SM has been a game changing institution for the Zurich-based weather and climate community. It has brought together different communities, ranging from statisticians and computer scientists to biogeochemists and ecologists, and enabled them to develop and apply breakthrough technologies, and to envision new ways of communicating science. The success of C2SM is well reflected in the words of the Scientific Advisory Board (SAB): “The multi-faceted nature of the technological and communication challenges far exceed that which can be addressed by any single individual researcher, or research group. In this context, C2SM has proven itself to be exceptionally prescient and successful.” (SAB, 2018).

An important shortcoming hampering the long-term planning of C2SM and of its partners has been the relatively short funding cycles. These cycles have been substantially shorter than the planning cycles for the major hardware and software infrastructure investments that need to be made by the PIs of C2SM in general, and MeteoSwiss in particular. This has been brought up several times by the SAB: “In summary, C2SM is a vital organizational framework. [..] To ensure that this continues into the future, the C2SM should therefore work with its partners and stakeholders – and with some urgency as strategic decisions depend on it – to develop a sustainable organizational structure”. This has also been echoed by the departmental review committee who noted in November 2018: “The Department should maintain and further develop the human and technical infrastructure to remain at the forefront in research and teaching, both internally and in partnership with other ETH departments and external partners.”

Appendices

Appendix A: References

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Appendix B: Project-based funding 2012-2018

C2SM Second and Third Phases (2012-2018) gross income from projects.
*) Projects contribute to core funding.

Project	Funding Body	Period	Income (kCHF)
ETH funded			
CHIRP2 Grant	ETH Forschungskommission	2012-2015	850
PASC CLAW	ETH SL	2015-2017	138
Sum			988
MeteoSwiss funded			
POMPA UV6	MeteoSwiss	2013-2014	150
HP2Ccont UV7	MeteoSwiss	2013-2015	188
CH2011 UV8	MeteoSwiss	2013-2015	45
MeteoSwiss Cosmo 1x1	MeteoSwiss	2013-2015	250
COSMO-UV9	MeteoSwiss	2014-2017	126
COSMO-GAW*	MeteoSwiss	2014-2017	20
Wettergenerator	MeteoSwiss	2015-2016	100
CH2018	MeteoSwiss	2015-2018	600
PostCH2018	MeteoSwiss	2018-2019	25
COSMO Vorhersagequalität	MeteoSwiss	2018-2019	20
WEW-COSMO*	MeteoSwiss	2017-2020	956
Sum			2480
Other funding			
COSMO-CLM (HP2C)	Univ. Svizzera Italiana	2010-2013	310
Opcode (HP2C)	Univ. Svizzera Italiana	2011-2012	20
OPTIWARES*	ETH-CCES	2012-2016	60
MAIOLICA-II*	ETH-CCES	2013-2016	80
Coconet (HP2C)	Univ. Svizzera Italiana	2013	180
CarboCount	SNF Sinergia	2012-2014	84
Paleofires*	SNF Sinergia	2014-2016	30
crCLIM*	SNF Sinergia	2014-2018	30
PASC GridTools	PASC	2014-2017	676
COSMO POMPAC	DWD	2015-2017	40
SmartCarb	ESA	2017-2018	70
PASC ENIAC	PASC	2017-2019	455
PASC PASCHA*	PASC	2017-2019	26
CarboSense4D*	SDSC	2018-2019	23
Sum			2085
Total sum projects			5553

DWD: Deutscher Wetterdienst
ESA: European Space Agency
ETH-CCES: Competence Center Environment and Sustainability
ETH SL: ETH Schulleitung
PASC: Swiss Platform for Advanced Scientific Computing
SDSC: Swiss Data Science Center

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July 2019 Zurich