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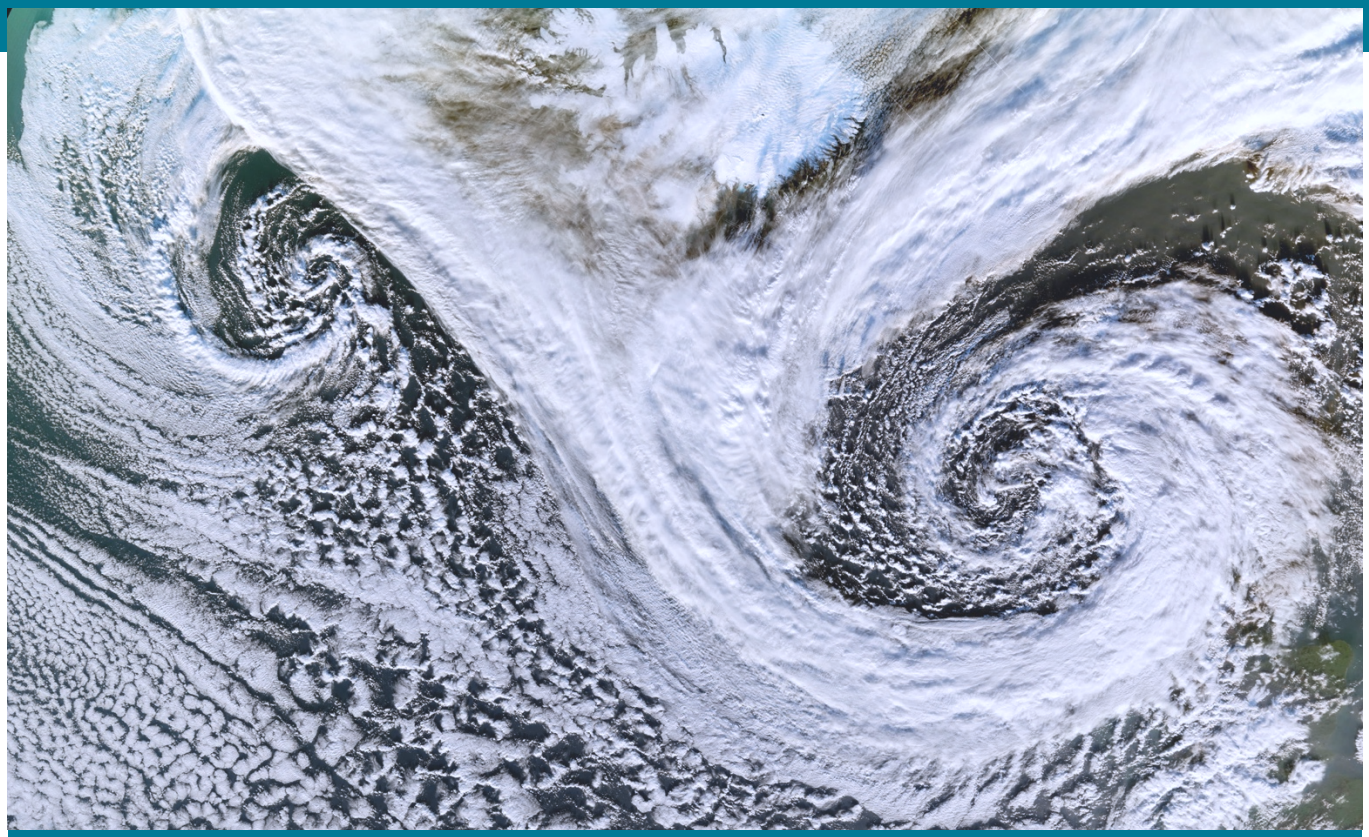

Strategy and Business Plan: 2021 to 2025

Center for Climate Systems Modeling (C2SM)

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C2SM Center for Climate Systems Modeling

ETH zürich

Empa Materials Science and Technology

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Content

Executive Summary

Research on weather and climate is at a crossroad. The scientific challenges associated with climate change require a multi-disciplinary approach that brings together diverse communities to work jointly on these challenges. This is especially, but not exclusively the case in the area of weather and climate modeling. Here, taking the next step requires among others, spatially ever more refined models, as well as models with an ever increasing number of components. But the model developments are not keeping pace with the advances in computer infrastructure and software paradigms. To overcome this stalemate requires fundamental changes in our modeling paradigms and workflows away from small groups working on individual problems. Similarly, the complexity and interdependencies of the impacts of climate change on natural and human systems push the modeling challenges outside the purview of single groups. With its more than 10 years of experience in bringing the atmospheric, climate, and advanced scientific computing community at the Zurich hub together and providing services to its members, C2SM provides the platform to solve these challenges. After its current third phase ends in 2020, we propose C2SM to continue as an ETH extradepartmental science platform that brings together the weather and climate community and empowers them to take the next step forward. C2SM will act as the focal point for the ETH-wide community and beyond by also tying in the research groups from the other member institutions that make up C2SM, the Federal Office for Meteorology and Climatology (MeteoSwiss), the Swiss Federal Laboratories for Materials Science and Technology (Empa), the Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL), and the Swiss centre of excellence for agricultural research (Agroscope). C2SM provides a collaboration platform to foster innovation, i.e., it will initiate and conduct joint research projects in strategically critical areas of common interest. Through its centrally managed operations team, it will provide scientific and technical support for its members, especially in the areas of weather and climate. It will also train researchers in modeling and data sciences and conduct targeted outreach efforts. For the 2021 through 2025 period, C2SM will focus on four areas: 1) 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 will develop and apply the next generation modeling paradigms in weather and climate. 2) C2SM will work together with the community to push the realms and resolutions of weather and climate models to unprecedented levels and to apply the 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. 3) Further, C2SM will take the lead in the development of the next generation modeling and data system required to provide the highest quality climate change information for Switzerland to the Swiss people and authorities. 4) C2SM will also work together with experts in the areas of impact and risk modeling to foster the seamless integration of climate impact sciences into the weather and climate models. To support this research and to provide these services, C2SM plans to operate with a core budget of about 870 kCHF yr^{-1}. This will support an executive director, ~4 full time programming/scientist positions, and a small communication and event staff that together forms the core operation team. The programmers' tasks will be to provide support for the members on the one hand and to provide a nucleus for the work in the four strategic areas on the other hand. We anticipate an additional project-based income of at least ~600 kCHF yr^{-1} that will finance project staff. Through their support by C2SM, the members and the member institutions have the opportunity to become a major player in the development and application of the next generation models, i.e., those tools that will shape climate and weather research and applications in the years 2021 and beyond.

1 Vision

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

2 Objective and 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 analyze, 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 organizer 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.

3 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. Thus, addressing climate change requires a profound knowledge of these intertwined systems, irrespective of whether the focus is on mitigation or adaptation. The foundation upon which this knowledge rests is the understanding of the Earth system itself, and our ability to project its future. This 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 causing widespread flooding, 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, and the adaptation and mitigation measures deduced from it can be severely misguided. 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.

Numerical simulation - along with theory, experimentation, and data analysis - has become one of the most important pillars for weather and climate science to provide this scientific basis. Similar to large experimental infrastructures such as mass spectrometers or particle accelerators, climate models running on modern high performance computing (HPC) systems are large simulation infrastructures with millions of lines of code. The development and maintenance of such a simulation infrastructure goes

significantly beyond the capability of individual research groups and even individual institutions. Providing such a simulation infrastructure to its member institutions was the key rationale for the foundation of C2SM more than 10 years ago and has been the cornerstone of its existence ever since. C2SM has substantially contributed to the rise and growing together of the weather and climate 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 handling and analysis of large data sets, and the training of researchers in coding and the development and application of models. Additionally, the intertwined nature of the climate change problem requires a concerted and multidisciplinary approach that extends from the fundamental aspects of atmospheric and climate science to the study of impacts across a wide range of areas. This can only be achieved by building and supporting a community that is being brought together and supported to address the major challenge of climate change.

The need for providing support to the C2SM community in a concerted and efficient manner will only grow further in the future, owing to i) the continuing rapid development and diversity of software and HPC infrastructure, ii) the increasing challenges associated with the rapid increase of the amount of generated data and the tools to analyse them, iii) the increasing complexity of the codes owing to the need to incorporate more processes and components, and iv) the continuous increase in the spatial resolution of the models to achieve better accuracy at small scales (e.g., in regional-scale weather forecasting or convection-resolving climate models) requiring new approaches to software engineering and data handling.

Finally, there is also a substantial demand for the center to act as an enabler in the areas of outreach, especially by realizing joint community activities that are beyond the capacities of individual groups. These activities include the organization of the internationally renowned Swiss Climate Summer School on a biannual basis and the highly successful annual one-day event Klimarunde that has helped create a public face of climate science at ETH. The continuation of these activities supports the transfer of cutting edge scientific knowledge to students and the interested public and completes C2SM's profile.

The strong rationale for a coordinated science and technology platform was expressed in the last evaluation and support letter by the scientific advisory board (SAB) dated January 2018: "To remain at the forefront of weather and climate science and to address emerging computational and technological challenges ETH and the partner institutions need C2SM — now more than ever." Similarly, the committee that reviewed D-USYS in November 2018 wrote as one of their identified opportunities for the further development of the department: "Enlarging the focus of C2SM to develop opportunities in high-resolution modelling, computational efforts, data science and management, could benefit several Institutes in D-USYS, as well as other Departments within ETH."

4 C2SM as a Nexus

C2SM constitutes a unique nexus for its members and its five member institutions. By working jointly on the modeling and analysis of weather, climate, and related environmental systems, C2SM creates the opportunities and synergies needed for tackling the grand challenge associated with the multi-scale and multi-component interactions within the Earth system. This is strongly aided by the close links between C2SM, its member institutions, and the Swiss National Supercomputer Center (CSCS), which is formally part of ETH. This collaboration has led not only to the world-wide first implementation of an operational weather forecast model on a supercomputer with GPU accelerators, but also permitted C2SM researchers to run models at resolutions that were hitherto unachievable. Thus, the C2SM constellation of partners is optimally poised to push forward in HPC in the area of weather and climate modeling, while at

the same time being able to make major advances at the interface between the scientific realm and the operational services. This unique setting nurtures new networks between the members and enhances the existing ones, fostering joint interdisciplinary and cross-institutional research projects.

Many institutions around the world have tried to bring weather services, computer centers, and university-based researchers in computational and climate sciences together, but the success has been very limited so far. As such, the constellation of the C2SM community is unique worldwide and a great asset for its member institutions.

C2SM also constitutes an important nexus for the members by supporting the integration of models from other disciplines of applied environmental and impact science, extending the application of weather and climate models to a wider range of environmental problems such as water resources, air quality, ecosystem services, food security, and environmental risk and impact assessment. This brings a wide community of scientists from within ETH, but also from C2SM's member institutions together.

Finally, C2SM also constitutes a nexus for the members to liaise nationally and internationally, most importantly with the University of Bern, the Max Planck Institute for Meteorology (MPI-M) and the Deutscher Wetterdienst (DWD).

5 Emerging Opportunities

The establishment of C2SM as an extra-departmental science platform will permit it to take advantage of at least four opportunities associated with its scientific mission.

***Toward ICON as joint modeling platform*:** First, the weather and climate model ICON (Icosahedral Nonhydrostatic), which has been developed over the last decade and has recently started to be used for research purposes, allows researchers to model processes from the global to the regional and even local scale in a seamless manner, providing large opportunities to make substantial progress on our core research question, i.e., modeling across scales. ICON is still rapidly developing and it will become one of the first (if not the first) true multi-scale model, enabling computational resolution from 100 m to 100 km, covering global to limited-area domains including regional grid refinement, and enabling atmospheric and coupled climate, atmospheric chemistry, and biogeochemical simulations. This model was developed jointly by MPI-M and DWD. MeteoSwiss together with the other Met-services of the Consortium for Small-Scale Modelling (COSMO) has committed to switch from its current modeling system COSMO to ICON in 2022. Already now, ICON serves as the global NWP model at DWD and is about to replace the ECHAM model at MPI-M. At ETH, there is a broad consensus among research groups to make this model system a common research infrastructure as well, with two groups already using it. By fostering this convergence of modeling systems, researchers within the C2SM community will be able to provide their unique and world-leading expertise in across-scale modeling. At the same time, this convergence is bound to create many new synergies especially owing to the ultra-high spatial resolution ICON can provide which are needed in many impact modelling communities. By providing high-level support for the further development and application of ICON, C2SM will accelerate this development and smooth the transition.

Toward new modeling paradigms: Second, the leadership class HPC capabilities at CSCS provide a unique opportunity for breakthrough science at the forefront of weather and climate modeling. C2SM is now working together with MeteoSwiss, CSCS, MPI-M, and DWD to adapt ICON to current and emerging HPC hardware architectures. The capability of efficiently running ICON on the planned upgrade of the Piz Daint system at CSCS in the early 2020s will provide C2SM members with world-leading Earth

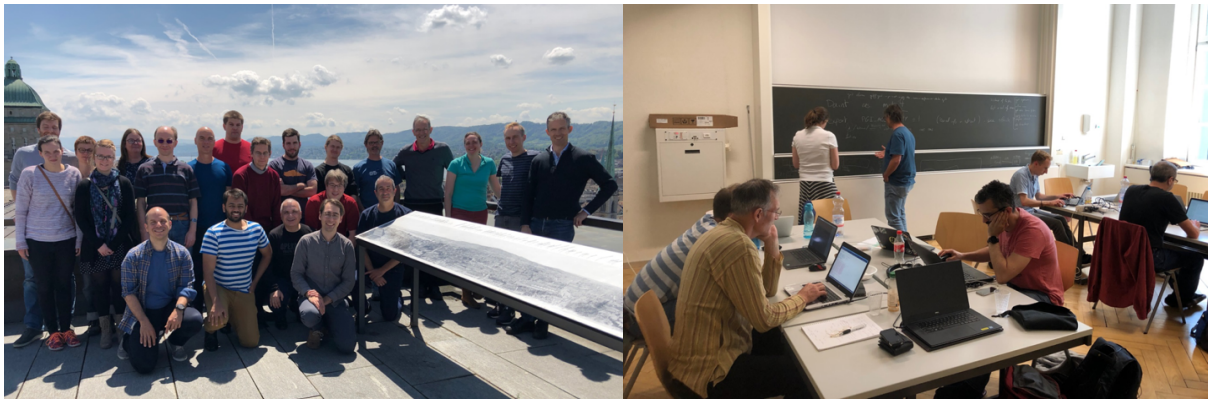

Fig. 1: ICON GPU hackathon in May 2019

system simulation capabilities and allow them to investigate pressing questions in weather and climate science. In a more general context, C2SM members and CSCS are addressing the urgent need to develop a domain-specific simulation platform, with services such as a high-level programming interface, transparent re-simulations to replace long-term storage, and workflow management for reproducible science. C2SM is playing a key role as a platform to bring together computer science, computational science, and climate and environmental science and to more deeply link CSCS and C2SM. For example, a large team of ETH Zurich, C2SM, CSCS, MeteoSwiss, DWD, and MPI-M programmers met in May 2019 to leap forward in the porting of ICON to GPUs in a one week hackathon, a venture that built on the work of the ENIAC project (Fig. 1).

***Toward ultra-high resolution modeling*:** Third, several initiatives are on the way worldwide to push the resolution of Earth System Models (ESMs) down to cloud and convection resolving scales (< 1km). These initiatives are motivated by the growing recognition that only the explicit representation of the key processes occurring on these scales can reduce the large uncertainties still associated with global climate projections. This requires a scientific breakthrough on many fronts, since the associated challenges not only require a speedup in compute performance by more than a factor of 100, but also new paradigms in output processing (big data) and analyses. C2SM with its members sees great potential in these initiatives and is committed to contribute its expertise and resources, as this aligns perfectly with its long-term mission. C2SM is optimally positioned to play a key role in these activities owing to its role at the nexus for the involved institutions, especially CSCS, ETHZ, and MeteoSwiss.

***Toward seamless climate scenarios*:** Fourth, the collaboration of the climate community with the climate-change impact community in the context of, e.g., the National Centre for Climate Services (NCCS) and the climate change scenarios for Switzerland constitutes an important opportunity to link basic research directly to the needs of the private and public sectors. MeteoSwiss has the official mandate from the Swiss Federal Council to provide Switzerland with climate change scenarios on a regular basis and ETH Zurich as a member of NCCS has made a commitment to contribute to achieving this task. C2SM is positioned exactly right to provide the computing platform for all members to transfer the science knowhow into operations and services. Situating this service at the interface between research and operations ensures that the public and private sectors receive highest quality information about the potential developments of weather and climate in the coming decades and century.

6 Strategy and Themes

Our strategy builds on C2SM being organized as an ETH extra-departmental science platform that will be active in networking, in the development and support of models, in data provisioning, in training, and in outreach.

For the next five years, these key activities will be organized around four major themes. This is built on the premise that the optimal way to bring together the members 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 five member institutions:

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

A fundamental challenge that limits our understanding of the Earth system and our predictive skills is the wide range of spatial and temporal scales over which the relevant processes in the climate system operate. Processes at small scales, such as convection, strongly influence the phenomena at large scales and vice versa. However, the relevant range of scales is not yet adequately accounted for in most models of the Earth system. This is partly due to major computational impediments to adopting rapid development and deployment cycles for Earth system models: adaptation of large legacy code bases to rapid and disruptive changes of HPC hardware architectures; I/O demand growing with computational capability, but only slow progress on I/O hardware for bandwidth, latency, and capacity; ensuring robustness and reproducibility for complex simulation workflows. In the next five years, the objective is to address these impediments with the establishment of a development environment for weather and climate science in a tight collaboration between C2SM members and CSCS. We thereby will focus on ICON as the common modeling infrastructure. Similar to a Platform as a Service (PaaS)-infrastructure, the development framework will provide services for more rapid code development, for transparently re-simulating climate data instead of accessing long-term storage, and for ensuring more robust and reproducible workflows using container technology and a workflow engine. The developments will result in the possibility to apply the models at ultrahigh resolution previously impossible, tackled under Theme 2.

Theme 2: High-resolution Earth System Modeling

Ultrahigh resolution modeling over large domains (continents/ocean basins to global), allowing the explicit consideration of across-scale interactions, is critical for the accurate modeling and prediction of e.g., extreme events, but also fundamental to some of the key challenges in climate change research, such as better constraining the Equilibrium Climate Sensitivity (ECS) and the projected global mean warming. However, as a result of recent advances in our process understanding and HPC, Earth system models and their component models can now be run at increasingly high resolution. We are planning to continue pushing these models in terms of increasing resolution and improving process representation in order to better bridge the relevant spectrum of scales (Fig. 2: example of an ultra-high-resolution near-global simulation with COSMO-GPU). We intend to do this while fully considering the interactions between atmospheric dynamics and the other components of the Earth system, such as land surface, ocean, and atmospheric composition. The large amount of data stemming from such models also require novel methods for the analysis and visualization, also tasks that will be increasingly taken on by C2SM. Themes 1 and 2 will closely collaborate to tackle the technological challenges arising from high-performance computing applications in the weather and climate field.

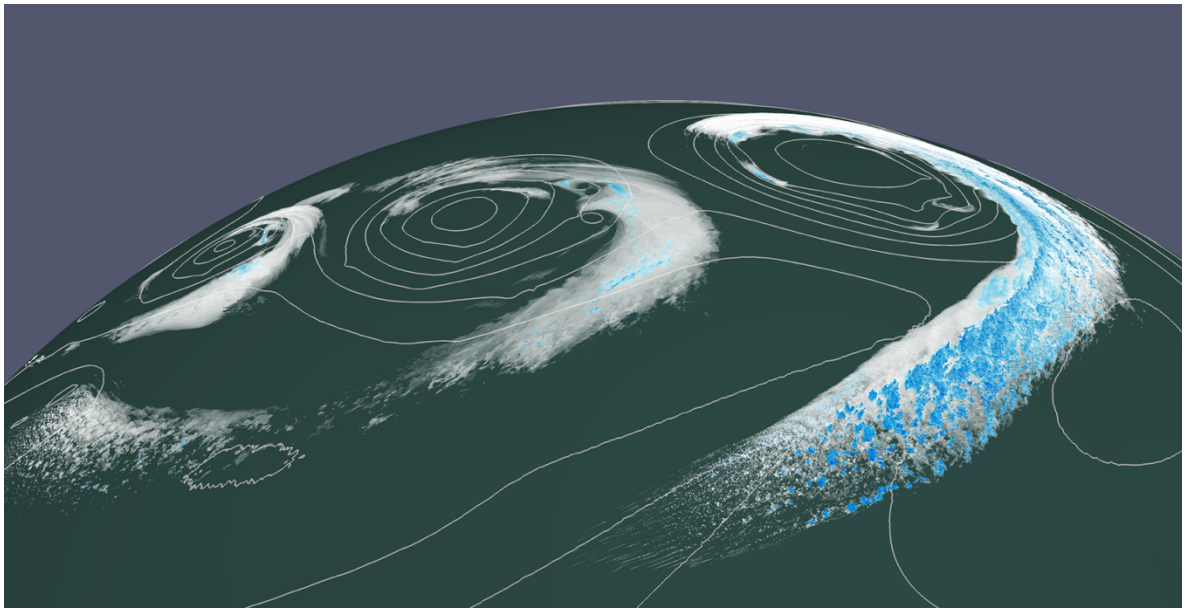

Fig. 2: Baroclinic wave from a near-global simulation with the non-hydrostatic climate model COSMO-GPU at ultrahigh spatial resolution of 1 km. The simulation was carried out on the full Piz Daint supercomputer on 4888 GPUs. At the time of the study, this constituted the first complete atmospheric model being run entirely on accelerators on this scale. White shading: cloud ice, cloud water, and graupel. Blue shading: rain and snow hydrometeors. The white contours denote surface pressure. More details in Fuhrer et al. (2018)[1].

Theme 3: Developing user-tailored future climate scenarios

The provision of local-to-regional scale climate scenarios for Switzerland has become an indispensable basis for decision making in the face of climate change and climate adaptation. For producing the next generation future scenarios, C2SM will act as the main climate modeling and data platform, bringing together the expertise of MeteoSwiss regarding operational service, user interactions and communication aspects with the scientific expertise of ETH. This joint setup enables C2SM to also bring in better the expertise of the communities working on impact-science. This will be even more facilitated in the future, as we seek to account more strongly for the needs of the data users and climate impact partners community. Benefitting from the developments in themes 1 and 2, C2SM will lead the development of the next-generation model used to support upcoming generations of climate scenarios for Switzerland. With dedicated simulations using global and regional climate models on the basis of ICON, C2SM contributes to large simulation ensembles within internationally coordinated multi-model efforts such as CMIP and CORDEX. C2SM will develop an optimized strategy to combine comprehensive international simulation archives with our own simulations. This includes supporting the development of the infrastructure to mine, transfer, store and standardize the large amount of available simulation data in order to fulfill the specific needs of the users, specifically those of the impact modeling community. C2SM will support its members in handling the large amounts of data. Overall, C2SM will provide a simulation and data analysis infrastructure for global and especially for regional climate models. This will result in an improved and more consistent quantification of climate change on key scientific and societal aspects, contribute to the generation of comprehensive climate services, and ultimately contribute to national and international adaptation initiatives.

Theme 4: Integrating applied environmental and impact sciences into Earth System modeling

Changes in weather and climate influence a large number of scientifically and societally relevant topics, such as ecosystem services, water resources, food production, air quality, energy provision, impact research, etc., as demonstrated in previous projects among C2SM members. These topics

[1] Fuhrer, O., T. Chadha, T. Hoefler, G. Kwasniewski, X. Lapillonne, D. Leutwyler, D. Luethi, C. Osuna, C. Schaer, T. C. Schulthess, H. Vogt, 2018: Near-global climate simulation at 1 km resolution: establishing a performance baseline on 4888 GPUs with COSMO 5.0. *Geosci. Model Dev.,* **11,** 1665–1681, DOI.

are addressed by diverse communities using specific modeling tools, which are typically either only available in highly specified branches of Earth System models or even applied offline (sequentially) using the output of such a model. C2SM will refine and couple the theme specific modules into the main ESM developed under Themes 1) and 2) in a modular fashion i.e. optionally allowing for increased complexity, e.g. in the areas of land-atmosphere coupling or atmospheric composition in order to fulfil the requirements of the different disciplines within the C2SM community in one model. For the offline tools, a paradigm shift is needed towards a parallel, coupled application in order to have full access to the meteorological fields at each time step and to allow for feedbacks, e.g., between meteorology, atmospheric composition, and land surface processes. C2SM will continue and extend the collaboration between its members intending to bridge scales and disciplines to result in new cutting-edge applications in environmental and impact research. As a science center and with the planned transition of the main model platform to ICON, we will seek to better integrate domain-specific tools in an attempt to address these topics in a more integrative and consistent manner.

7 Implementation

C2SM aims to implement the above strategies and themes through a two-tiered approach. The first tier focuses on the empowerment of the community by providing them support on scientific and technical challenges associated with models and data in weather and climate. The second tier focuses on the implementation of the four strategic foci, for which C2SM plays a critical role in their execution and management. About half of the FTEs of the core team will be devoted to the first tier, while the second half will be devoted to the second tier. The first tier will be carried out through a support desk function, in which the members of the core team split the tasks according to their expertise and time availability. The second tier will be carried out in the form of project teams, led by particular members of the core team, with support by additionally hired project employees.

7.1 Networking & Project Support

C2SM acts as a network by bringing the scientific community together and creating cross-institutional synergies through a number of initiatives and processes: (i) the initialization of joint projects through workshops, (ii) creating networking opportunities by organizing community-wide scientific seminars and technical workshops, (iii) improved flow of information by publishing a four-monthly C2SM newsletter. C2SM also plays a crucial role in the planning and execution of research projects by taking over tasks associated with project planning, execution, reporting, outreach activities, and administration. These tasks will be primarily carried by the executive director working together with the communication person and selected members of the core operations team. High priority for first new joint projects during the 2021-2025 period will be given to the development of the next generation HPC platforms to permit ultra-high-resolution modeling (e.g., in the context of EuroHPC together with CSCS), and the investigation of extreme events across weather, climate, and other natural systems (e.g., aiming for an ETH+ project and supporting a community Sinergia project to be submitted at the next SNF deadline). In addition, the planning for and initiation of the next generation climate change scenarios is viewed as a high priority activity.

7.2 Modeling and Data Support

The core tier one modeling service provided by the C2SM operations team consists in the high-level support of the C2SM members in terms of the development and application of a limited number of modeling systems. The plan is to converge from the currently supported modeling systems, i.e., the regional weather and climate model COSMO, the global chemistry-climate model ECHAM-HAMMOZ and MPI's Earth System Model coupled to HAM, the Community Earth System Model (CESM), and the weather and climate model ICON to primarily ICON. ICON is key here as it will become the main operational modeling system by MeteoSwiss by the end of 2022, and it is also one of the modeling system targeted for transitioning to the next generation coding concepts. Furthermore, it will bring together the regional and global climate modeling communities that, up to now, use different tools. This is expected to create substantial synergies between the different members and will also permit to focus and streamline the support role played by C2SM. Further, this will also substantially foster the collaborations with the MPI for Meteorology, DWD, and CSCS, as well as with the growing international research community using ICON.

C2SM's core operations staff will provide high-level support in the installation and maintenance, debugging, and application of the supported model systems with standardized run packages, and offer its software engineering expertise in coupling previously developed modules to any new supported model system. The core operations team also supports the members in their tasks associated with the management, storage, retrieval, and analysis of "big" data that emanate from observing systems, reanalyses, and models. This includes the development of tools to optimally manage the data and ensure its reliable long-term storage and retrieval, the development of online analyses methods in model simulations, and the development of novel visualization methods. Many of these developments will be undertaken in collaborations with the Swiss Data Science Center (SDSC) and the Computer Graphics Laboratory of ETH.

7.3 Strategic Projects

C2SM's core operation team will also serve as the nucleus for the execution of the four strategic themes, with each theme being led by a dedicated person. These themes will be implemented in the form of projects with clear goals, deadlines, and for a confined period of time, defined by a project team that is constituted out of the user group for each theme. Concretely, the following activities are planned:

1) *Development of next-generation modeling systems*
   One of the first tasks to be implemented will be the partial rewriting and adaptation of the ICON model to reflect modern coding concepts so that it can be optimized flexibly on modern hardware architecture systems, especially those containing GPUs. Specifically, the aim is to re-write ICON using a domain specific language (DSL) approach wherein the core elements of the model, such as the dynamical core, are encapsulated in a set of libraries, which are then called upon and controlled by routines written in a high-level command language. This not only simplifies the interaction of the user with the model, but is also key in order to harness the exa-scale computational power needed to run the model at the very high resolution needed (global (O(km)) and regional (O(< 1km)) to gain significantly improved process understanding in various atmospheric (and possibly oceanic) questions (themes 2-4). In this context, C2SM will contribute substantially to the EuroHPC project currently planned by CSCS (coordination Thomas Schulthess). As themes 2-4 critically depend on the results of theme 1, personnel resources will first be bundled under theme 1 in the first years. The work under theme 1 will include collaborations with Meteoswiss and CSCS at the national level, as well as with MPI for Meteorology and DWD internationally.

2) *High-resolution modeling*
In addition to preparing ICON for ultra-high resolution setups over global domains, C2SM will also develop an ICON-based model chain for regional high-resolution simulations. This will facilitate the transitioning to ICON for many of C2SM's regional modeling groups. This is especially important for those groups who study air quality, land-atmosphere interactions, the carbon cycle, atmospheric transport of tracers and hazardous substances, inverse emission estimation, or urban heat islands. This is because these groups require specific model extensions or coupling with external modules that are not included in the traditional weather and climate models. Such extensions have been developed for the regional and global models used previously in C2SM and will have to be adapted for, and incorporated into ICON. Since some of these extensions are computationally very costly (e.g., reactive trace gases and aerosols, emission estimation using ensemble approaches), the same code optimizations as developed under activity 1) for the core ICON model will be implemented. Additionally, the coupling of external modules will require significant code developments to enable computationally efficient solutions. Once ICON will be ready to be applied in very high-resolution mode, we envisage to gather forces e.g., in an ETH+ grant, to investigate the effects of ultra-high-resolution on important atmospheric quantities such as climate sensitivity, radiative forcing due to aerosol-cloud interactions, and projected global warming to mention a few. The work will be carried out in close collaboration with the modeling groups within C2SM, and possibly with international partners such as MPI-M and DWD.

3) *Developing user-tailored future climate scenarios*
The cycle of the Swiss regional climate change scenarios depends on the IPCC global climate change scenario publication cycle, corresponding internationally coordinated downscaling initiatives and the Swiss governmental agenda. With the IPCC's Sixth Assessment Report expected to be published in 2021-22, we aim to publish a new generation of Swiss climate scenarios a couple of years thereafter. To prepare for this, C2SM will take the lead in developing, running and coordinating regional climate simulations for the Swiss domain. This will be based on the developments emerging from themes 1 and 2. We thus envision that the resources will be shifted accordingly toward this theme in the second half of the five year period aided by the anticipated influx of dedicated project funds to build a full project team. We also anticipate C2SM to a) play an active role in the validation and analysis of climate model outputs for the Alpine domain, b) handle and maintain climate model data, c) work toward semi-operational multi-model projections, d) link to the resources of the COPERNICUS C3S (such as the Climate Data Store), and d) provide community support running dedicated climate model simulations.

4) *Integrating applied environmental and impact sciences into Earth System modeling*
Extreme weather events due to climate change such as intense droughts or extreme precipitation events increasingly threaten our daily lives, food security, energy supply, and economics. It is therefore mandatory to combine forces in weather & climate research and climate impact & risk sciences in order to develop appropriate preparatory and adaptation measures. In particular, chains of events or interactions between weather and the food and energy sectors may lead to compound weather-energy-food extreme events illustrating the need to couple models from the individual sectors for us to be able to gain a proper understanding of how extreme socio-economic events emerge.
C2SM has concrete and immediate plans to engage in this field:

- The scClim project (SNF Sinergia proposal to be submitted in December 2019) aims at exploiting the seamless coupling of kilometer-resolution weather predictions and climate simulations with hail impact assessments for multiple sectors. State-of-the art high-performance computing on GPU architecture with the models COSMO and ICON will be combined with hail observations from radar and hailpads and with specific hail impact models for buildings, cars and different agricultural crops in order to provide hail damage assessment on timescales from days (weather prediction) to decades (climate projections). The

project combines expertise at ETH Zurich, CSCS, MeteoSwiss, Agroscope, and the University of Bern. C2SM will support this project by providing technical support and taking over technical development tasks.

- EXTREMES, a proposal planned to be submitted as an ETH+ grant in March 2020: this collaboration aims at combining models from the weather, food, and energy sectors to gain an understanding of compound extreme events and their effect on climate change. The initiative is coordinated by C2SM and is a collaboration with the Energy Science Center (ESC) and the World Food Systems Center (WFSC) at ETH.

The activities under theme 4 will be carried out in interdisciplinary collaborations with partners at ETH and the C2SM member institutions. Specifically, they will strengthen collaborations with the member institutions WSL and Agroscope, and with groups from risk research.

7.4 Hardware Support

C2SM will continue and enhance the support of its ETH members to acquire the necessary computer hardware and data storage capabilities in collaboration with SIS and CSCS. In addition to organizing and managing the group request for computational nodes, C2SM will continue to act as the central organizing unit for data storage for its members. In the current round, the hardware need of many ETH members of C2SM was taken care of through purchasing shared nodes on the ETH-owned and SIS managed Euler cluster. In the future, C2SM will lead the discussion between the members and potential solution providers (including e.g., CSCS) to find the most attractive and workable solution for the member's hardware needs.

7.5 Training

C2SM focuses its training activities on students ranging from M.Sc. students to post-doctoral fellows. In particular, C2SM will (i) continue organizing the Swiss Climate Summer Schools jointly with the Oeschger Center for Climate Research (OCCR) at the University of Bern and other Swiss institutions and (ii) further establish and improve the technical training for our PhD students and postdocs in the areas of software engineering, modeling, computer sciences, data analysis and management, and visualization. C2SM will take the lead in organizing the Swiss Climate Summer School every second year, with the other years being organized by OCCR. This activity is led by the executive director, working together with a lead PI and the communication person. The technical training, some of which will be jointly organized with ETH's SIS, will consist of courses in (i) advanced use of high-level computing languages (such as python) including visualization, (ii) good practice in software engineering, and (iii) good practice in data management and (iv) optimal use of weather and climate model data by the impacts community.

7.6 Outreach

C2SM will continue to raise public awareness related to climate and weather through a few targeted channels that are specifically geared for a science and technology platform. The primary avenues will be the well-established annual "ETH-Klimarunde" and larger-scale public outreach events such as Scientifica. The outreach activities are led by the executive director working closely together with the communication person.

8 Organization and Management

8.1 Organization

Figure 3 shows the organizational structure of the extra-departmental research center, consisting of the following bodies: members assembly (constituted by all members), steering committee with a chair and co-chair, operations team with an executive director, and an external scientific advisory board. To ensure a strong foundation in all member institutions, they are adequately represented in the steering committee. The chair of the steering committee acts as the director of the research center and reports to ETH's vice-president for research. Four user groups are constituted to capture the four major themes listed under section 6 above in order to optimally serve its members.

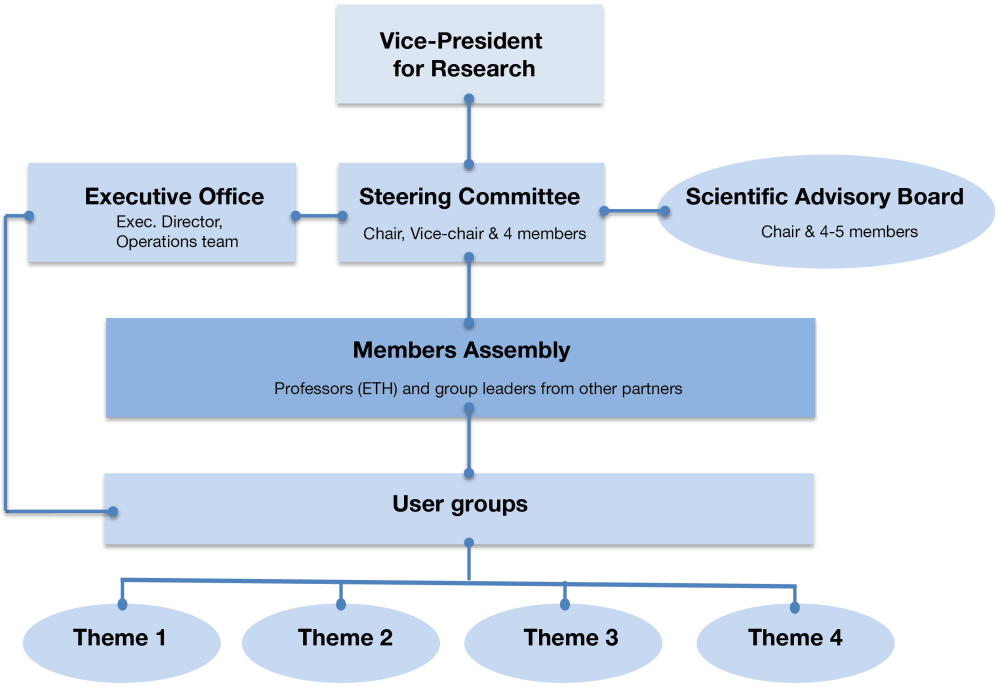

Fig. 3: Organizational chart of C2SM as an extra-departmental research center.

8.2 Management

The executive director oversees the operations team, which consists of the core, as well as the project teams. The core services provided by the executive director and its core operations team are strategically defined by the steering committee (SC) in consultation with the user assembly, and in particular through the user groups. In these groups, the members work together with a lead person from the core operations team and the executive director to identify the main tasks of the lead person on a bi-annual to annual basis. The prioritization of these tasks will be determined against the strategic goals of C2SM. A certain percentage of the tasks for the members of the core operations team can also be defined directly by the SC and the executive director to support specific projects associated with strategic needs for C2SM. The allocation of the resources for the undertaking of the strategic projects will be defined by the SC in consultation with the user assembly. The activities of the project teams are defined through

the C2SM acquired projects, which themselves are identified by the SC on the basis of the strategic needs of C2SM and the opportunities arising.

8.3 Personnel

The core support (first tier) will be largely provided by the personnel that has carried C2SM in the past few years (2 people, 1.6 FTE) and a person whom we just hired at 0.4 FTE using C2SM's reserves. Some of their time will also be freed up for the implementation of the strategic projects. But the ambition laid out in this business plan here requires an expansion of the personnel, especially with regard to the implementation of the strategic projects. Specifically, we anticipate to hire an additional expert in HPC and high-resolution modeling who will take the lead in the transition to domain specific languages as front ends to the next generation of models (cf. Section 7.3 Themes 1 and 2). To strengthen themes 3 and 4, we intend to hire additional staff on climate change scenarios (cf. Sect. 7.3, Theme 3) and on integrating environmental and impact applications into Earth System models (cf. Sect. 7.3, Theme 4). In total, we anticipate a total core staff of about 6 to 7 people for a total FTE of 5.35. The staff will be tasked toward the implementation of the strategic projects in a flexible manner, i.e., their core tasks will shift through time on the basis of the developing needs.

8.4 Space Allocation and IT needs

D-USYS has agreed to continue providing permanent space for the C2SM operations team. At the moment, this space amounts to about 50 m^2, consisting of two offices, namely CHN M15.1 and M15.2. In addition, C2SM project-based employees are usually given a workplace allocated to the group of the project PI. Until now, workplaces have been provided at the Institute for Atmospheric and Climate Science (IAC), MeteoSwiss, and ETH SIS. It is agreed within the C2SM community that this practice will continue in the future.

C2SM's own needs for IT have largely been covered by the IT support group of IAC. IAC has agreed to continue this service in the coming years at no additional cost. The staff of C2SM requires very limited IT infrastructure: individual lap- and bench-tops are provided from the department's IT funds to the C2SM's core operations team at the same conditions as for all employees, i.e., a limited amount of 1000 CHF/year per employee and 100% employment rate. Any procurement beyond this limit, e.g., storage, has to be borne by C2SM through central and project funding. The IT and hardware needs for the community managed through C2SM are covered under section 8.2.

9 Finances

An overview of the anticipated annual income and expenses including FTE information for the period 2021 to 2025 is presented in Table 1: The annual payroll costs of the center amount to about 1.4 Million CHF yr^{-1}, with about 800 kCHF yr^{-1} being used to cover the salaries of the executive director (0.8 FTE) and the core operations team (4.55 FTE). 3.8 FTE of these 4.55 will be allocated to the scientific programmers who (i) will provide technical support to the community through a support desk (1.5 FTE) and (ii) will take a leading role in the implementation of the four strategic foci (2.3 FTE).

We will also allocate 0.2 FTE toward technical training, most likely in collaboration with the scientific IT services of ETH (SIS). Communication and events (0.35 FTE), as well as additional administrative support (0.2 FTE), that is expected to arise from the increased group size and further strengthened collaborations with the member institutions, round up the core team's portfolio.

The other part of the payroll costs cover the salaries of the project staff (600 kCHF yr^{-1}), which we assume to grow to about 4-6 FTEs. These expenses are balanced by project income (assumed to stem primarily from HPC/NWP and the climate scenarios), while the core operation team has to be financed by our core income and any other steady flows of income. The latter incomes also have to finance the other expenses incurring from running the center, namely running costs (ca 35 kCHF yr^{-1}) and events (30-40 kCHF yr^{-1}, depending on whether the annual summer school is carried out in that year).

Annual income [kCHF]		2021	2022	2023	2024	2025
Operations team funds [kCHF]		**868**	**868**	**868**	**868**	**868**
Staff appropriations school board ETH		300	300	300	300	300
Staff appropriations department D-USYS		150	150	150	150	150
Staff appropriations C2SM partners: MeteoSwiss		100	100	100	100	100
Staff appropriations C2SM partners: Empa		70	70	70	70	70
Staff appropriations C2SM partners: WSL		70	70	70	70	70
Staff appropriations C2SM partners: Agroscope		10	10	10	10	10
Membership fees ETH professors		68	68	68	68	68
Staff appropriations: from third-party projects		100	100	100	100	100
Third party project funds to project staff [kCHF]		**600**	**600**	**600**	**600**	**600**
Income infrastructure acquisitions @ETH [kCHF]		**1'170**	**1'170**	**1'470**	**1'470**	**1'470**
Total [kCHF]		**2'638**	**2'638**	**2'938**	**2'938**	**2'938**
Difference income - expenses [kCHF]	**10**	**52**	**21**	**4**	**-27**	**-41**
Annual expenses [kCHF]		**2'586**	**2'617**	**2'934**	**2'965**	**2'979**
Total annual payroll costs [kCHF]	**FTE**	**1'321**	**1'342**	**1'364**	**1'385**	**1'450**
Total Operations Team	5.35	**721**	**742**	**764**	**785**	**809**
Base support (tier one)	1.5	188	193	199	205	211
Project support (tier two)	2.3	288	296	306	314	324
Training*	0.2	28	28	28	28	28
Director and administrative staff	1.35	217	225	231	238	245
Total Project staff (6 FTE)		**600**	**600**	**600**	**600**	**600**
Operating expenses [kCHF]		**65**	**75**	**70**	**80**	**70**
Running costs, travel, hardware acquisition, etc.		35	35	40	40	40
Events		30	40	30	40	30
Infrastructure expenses [kCHF]		**1'200**	**1'200**	**1'500**	**1'500**	**1'500**
Contribution C2SM to infrastructure acquisitions		30	30	30	30	30
Infrastructure acquisitions		1'170	1'170	1'470	1'470	1'470

* in collbaoration with SIS

Table 1: Annual income, expenses, and C2SM staff for 2021-2025.

To finance the core operations, we assume that ETH's executive board (German: Schulleitung, SL) will provide 300 kCHF yr^{-1}. We assume that (i) D-USYS is going to support C2SM with an contribution of CHF 150 kCHF yr^{-1} out of its overhead return (an increase of 50 kCHF yr^{-1} relative to the last 10 years), (ii) MeteoSwiss increases its support from 50 kCHF yr^{-1} to CHF 100kCHF yr^{-1}, Empa continues to provide CHF 70 kCHF yr^{-1}, WSL increases its support level to the same as Empa, i.e., CHF 70kCHF yr^{-1}, and Agroscope pays CHF 10kCHF yr^{-1}, and (iii) the ETH members contribute a slightly increased amount as before, i.e., each associate or full professor pays an annual base fee of CHF 3500. Assistant professors continue to pay CHF 1000 per annum. Project-based funding to the core operations team is envisioned to be doubled in line with the general absolute increase in funding and to provide another ~100kCHF yr^{-1}. This adds to a total income of 870 kCHF yr^{-1} available to finance the core operations team and C2SM's running expenses.

This results in a roughly balanced budget over the 5 years of planning, with a positive balance in the first three years and negative balances in the last two, owing to the anticipated salary increases of the core staff.

The final element in our budget is the data storage and node acquisition on the EULER cluster, which C2SM administers on behalf of the ETH members of C2SM. The anticipated expenses (between 1200 CHF yr^{-1} and 1500 CHF yr^{-1}) are assumed to be provided by the Scientific Equipment Program of ETH's executive board, by the groups requiring the infrastructure, and by C2SM.

Not listed in the budget are the main expenses for the summer school. We assume that these costs will be mostly covered through the school participants' conference fees and the meeting funds provided by Congressi Stefano Franscini. In addition, a substantial contribution of ~10 kCHF is provided by C2SM, which raises the event budget from 30kCHF to 40kCHF in those years in which the school takes place.

10 Conclusion and Outlook

A long-term commitment of all institutions is essential for C2SM to realize its potential and vision. The development of the next generation modeling system for weather, climate, and atmospheric composition on the basis of a tight integration between hard- and software requires a planning horizon of a decade or more. By supporting C2SM (together with CSCS), ETH Zurich, and the other member institutions has now the opportunity to become a major player in the development and application of the next generation models, i.e., those tools that will shape climate and weather research and applications in the years 2021 and beyond.

The case for a long-term commitment by the member institutions to support C2SM is stronger than ever. First, while the benefits for unlocking the potential of new computer systems for Earth system and climate/weather models have become clearer, the scale and timescale of the investment needed to make this happen has become clearer as well. Second, the need for a long-term commitment of the members to the National Center for Climate Services (NCCS) has also become more clearly established, especially with regard to the generation of the third generation Swiss climate scenarios, those following CH2018. Third, the need for a permanent and strong host for model development and service is steadily growing, i.e., a need that C2SM can respond to by offering a relatively unified regional to global modeling system around the ICON model.

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