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Climate Scenarios for Switzerland CH2018 – Approach and Implications

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ABSTRACT

To make sound decisions in the face of climate change, government agencies, policymakers and private stakeholders require suitable climate information on local to regional scales. In Switzerland, the development of climate change scenarios is strongly linked to the climate adaptation strategy of the Confederation. The current climate scenarios for Switzerland CH2018 - released in form of six user-oriented products - were the result of an intensive collaboration between academia and administration under the umbrella of the National Centre for Climate Services (NCCS), accounting for user needs and stakeholder dialogues from the beginning. A rigorous scientific concept ensured consistency throughout the various analysis steps of the EURO-CORDEX projections and a common procedure on how to extract robust results and deal with associated uncertainties. The main results show that Switzerland's climate will face dry summers, heavy precipitation, more hot days and snow-scarce winters. Approximately half of these changes could be alleviated by mid-century through strong global mitigation efforts. A comprehensive communication concept ensured that the results were rolled out and distilled in specific user-oriented communication measures to increase their uptake and to make them actionable. A narrative approach with four fictitious persons was used to communicate the key messages to the general public. Three years after the release, the climate scenarios have proven to be an indispensable information basis for users in climate adaptation and for downstream applications. Potential for extensions and updates has been identified since then and will shape the concept and planning of the next scenario generation in Switzerland.

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Practical implications

National climate scenarios based on a set of climate model projections are increasingly important to consider in long-term adaptation and mitigation planning, providing user-tailored information on the expected changes in climate. Over recent years, many countries and organizations have started producing country-specific climate scenarios with dedicated products such as factsheets, brochures, web-tools, tailored data, in order to enable downstream applications and to form a decision-support basis for climate action planning (e.g., KNMI21 in the Netherlands, UKCP18 in the UK, CH2018 in Switzerland, 'Climate Change in Australia', NCA4 in the US).

The extent and setup of the value chain in the processing from pure climate model data down to user-specific climate indicators and communication campaigns differ from country to country. For instance, this includes the overall goals and drivers of the initiative, the underlying scientific approach in the process chain, specific choices made during the workflow, how user needs are integrated, how the governance is structured under institutional and political boundary conditions, how results are distributed and communicated and how they feed back on the re-adjustment of the process chain.

The aim of this article is to contribute to an international exchange by presenting the whole framework of the CH2018 climate scenarios released at the end of 2018, to share experiences made and to report on the lessons learned in producing the CH2018 climate scenarios and their uptake among user groups. On a practical level, this exchange may contribute to guidelines and/or best practices in the production of national climate scenarios that are to date still limited on an international level. It may also help other countries with similar challenges to take up the presented framework, when setting up and planning their nation-wide climate scenarios or it may be useful to take up parts of the approach presented here, concerning scientific choices, choices on communication measures or user-integration measures.

In Switzerland, a continuous dialogue with users from the start of the project has proven to be indispensable to generate climate scenarios in a user-oriented way. User needs with respect to content were substantially shaping the scientific process and the scope of the scientific analysis in CH2018. User needs concerning dissemination were shaping the communication concept and how information was distilled towards user groups through dedicated products.

As the CH2018 project developed, a scientific consensus emerged across research groups as how to consistently extract climate information from the EURO-CORDEX climate model projections. For instance, this encompassed the agreement on a consolidated model set, a common procedure to determine and communicate uncertainties and limitations of the products, and the determination of common analysis periods and regions. This consolidated procedure enabled extracting relevant information for a technical report with an executive summary and headline statements that in turn served as a basis for deducing key messages of CH2018.

Along with the scientific concept, products and services were planned in a dedicated communication concept. This ensured a targeted communication of the key messages in the form of user-oriented products toward specific user types. Practitioners (people working for instance in the governmental administration, organizations or engineering and consulting companies) served as the main target group of the CH2018 scenario products. For this group, dedicated web factsheets – produced in a standardized way - provide the most relevant facts and figures according to their region of interest. For further information, the users are then directed towards a web atlas where the archive of material is presented in a user-friendly way. The web atlas consists of 22,000 preprocessed and standardized graphics and breaks down the multi-dimensionality of future climate information by providing information on altitude dependence, temporal development, sectorial indices, spatial imprints and many other parameters. Furthermore, the web atlas is the vehicle to provide users easy access to data for subsequent studies. In essence, it is a practical climate service tool that enables and fosters climate adaptation planning in Switzerland.

To increase the uptake of the key messages and services of CH2018, a narrative approach with fictitious persons was chosen to convey messages to the broader public. In retrospect, this approach left a considerable impact on the media and the social media landscape in Switzerland. It was heavily used to pitch stories prior to the official CH2018 release and it is further carried over by other priority themes of the National Centre for Climate Services (NCCS).

With the CH2018 scenarios publicly available for more than three years, questions and requests directed to the producers of the climate scenarios arise. Typically, they can be grouped either into requests for an extension of the existing scenarios, guidance on their interpretation and concrete use and requests on further aspects of communication or dissemination measures. This article discusses the response to the most frequent requests and questions. This may help other climate services on an international level to take up ideas for their implementation cycles of scenarios. Some of the requests to be tackled are low-hanging fruits, while others need large research efforts and are therefore left to a new cycle of climate scenarios available in a few years.

Reflections on the process of how to generate national climate scenarios such as those presented here feed back on the planning of the next cycle of climate scenarios in Switzerland. Presenting the scenarios as a consolidated effort between academia and research institutions in Switzerland has proven to be an important cornerstone for a successful uptake in the user community. Another learning from CH2018 is the importance of elaborating new climate scenarios in close dialogue with users, with a dedicated communication concept and a rigorous scientific concept from the start of the project. Taking into account these three perspectives in parallel increases the chance of reaching a sustained impact on the user community in Switzerland and of promoting the scenarios as a climate service that is regularly consulted for decision-making in support of climate adaptation and mitigation.

1. Introduction

Climate change is ongoing and accelerating, thereby adversely affecting more and more aspects of nature, society and economy (IPCC, 2014; 2021). As an Alpine country, Switzerland is particularly impacted by these changes. For instance, already today, Switzerland has experienced a long-term warming around two times higher than the global average (Scherrer and Schwierz, 2018). As a consequence, snow cover has diminished, hot days and heavy precipitation have become more frequent and more intense, the vegetation period has prolonged and the zero-degree line has risen (Marty et al., 2017; Scherrer and Schwierz, 2018; Scherrer et al., 2021).

To reconsider the long-term planning and adapt to the multi-sectoral climate impacts that can be anticipated, federal, cantonal, and local authorities, policy makers and other stakeholders require a solid basis for decision making. This essential climate service is provided in the form of climate change scenarios informing on the future climate of the next decades ahead to support climate adaptation and mitigation.

In Europe, many countries have taken up this need by developing and publishing national climate scenarios regularly (e.g. KNMI14 and KNMI21 in the Netherlands (KNMI, 2015), UKCP09 and UKCP18 in the UK (UKCP, 2018), CH2011 and CH2018 in Switzerland (CH2018, 2018; NCCS, 2018) or ÖKS15 in Austria (ÖKS15, 2015)). This is further supported by the worldwide effort of the Global Framework for Climate

Services (GFCS) in order to actively develop national climate services, including climate scenarios (Hewitt et al., 2020).

How such scenarios are scientifically developed, how they are distributed and communicated, and how users are integrated with the production process differs largely from country to country. Skelton et al. (2017) attributed these differences to three distinct typologies of use-inspired research in climate science for decision-making: (i) innovators, (ii) consolidators and (iii) collaborators. Each typology prioritizes specific aspects that are further shaped by social and scientific values: scientific advancement (innovators), exchanges and networks (consolidators) and user-needs (collaborators). A further contributing factor to country-wise differences is the presence of various actor groups and disciplines at the interface between users and producers of climate scenarios at the local scale (Rössler et al., 2017).

Internationally, guidelines or best practices on how to generate national climate scenarios from a scientific point of view down to communication and user integration are still limited so far (e.g. Hewitt and Stone, 2021). It is therefore imperative to exchange knowledge and experiences regarding national approaches, as countries share similar challenges in the production chain. This paper contributes to this international exchange by presenting the Swiss approach of the latest cycle of national scenarios (CH2018, 2018).

Switzerland has a long-standing history in generating national climate change scenarios based on an intense and effective collaboration between academia and government agencies (Brönnimann et al., 2014). The first comprehensive national report "CH2007" was published in 2007 (OcCC, 2007), followed by a second report in 2011 (CH2011, 2011). These scenarios served as the basis for impact studies in several sectors in Switzerland, among them a comprehensive report on a wide range of climate change impacts (CH2014-Impacts, 2014) and an assessment report on climate change effects (SCNAT, 2016). Furthermore, the climate scenarios in Switzerland laid the fundamental basis for designing its climate change adaptation strategy and action plans at the federal level (FOEN, 2012; FOEN, 2014).

After their publication, several shortcomings of the CH2011 scenarios have been documented and tackled (Bosshard et al., 2015; Fischer et al., 2015a; Fischer et al., 2016; Kotlarski et al., 2017; Zubler et al., 2014) laying the foundation for an updated cycle of climate change scenarios. Other reasons were the inclusion of the scientific findings from the fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013), the use of a new generation of climate model simulations over Europe (Jacob et al., 2014), the application of improved downscaling methods (Ivanov and Kotlarski, 2017; Rajczak et al., 2016), and the availability of seven additional years of observations, allowing to place the new scenarios in an updated climatological context.

This paper presents the general approach taken to establish the CH2018 scenarios from different perspectives and how it innovates from the previous CH2011 scenarios: project management (Chapter 2), user engagement (Chapter 3), the scientific framework (Chapter 4) and communication (Chapter 5). Chapter 6 reflects on the lessons learned since the publication of CH2018.

2. Background and overview of the project CH2018

Since 2014, the Federal Office of Meteorology and Climatology MeteoSwiss has the official mandate from the Swiss Federal Council to regularly provide up-to-date climate change scenarios at the local to regional scale (FOEN, 2012; FOEN, 2014; FOEN, 2020). Similar to the CH2011 scenarios, the development and coordination of the CH2018 scenarios were ensured by a close collaboration with ETH Zurich and the Center for Climate Systems Modeling (C2SM) as main research partners next to MeteoSwiss. Additionally, the project was run as a priority theme of the NCCS founded in 2015. ProClim – the forum for climate and global change of the Swiss Academy of Sciences - and the University of Bern were taken on board as additional project partners. The involvement of five leading Swiss climate institutions under the umbrella of the NCCS ensured that the new scenarios integrate a diverse portfolio of research and climate services expertise.

The CH2018 scenarios were launched in the form of six climate service-oriented product groups (Fig. 1) in November 2018 at a half-day event at ETH Zurich with 670 registered participants. The launch was accompanied by a large media coverage: CH2018 was on the front page of the leading Swiss newspapers and was the topic in several news broadcasts of the Swiss Radio and Television in all language regions. Together with CH2018, the new website of NCCS (https://www.nccs.ch) was launched as well, with the CH2018 scenarios as an integral part of it and with the web atlas as one of the most visited sites of the webpage to date. The timing of the CH2018 launch was chosen so that the new findings can contribute to the Federal Government's second action plan on climate adaptation (FOEN, 2020).

The development of CH2018 can be roughly split into four project phases of different lengths:

In the initial phase (first project year), the scope of the new scenarios was framed and potential contributions from the project partners were collected. For the scoping, two internal workshops were organized and a one-day international workshop was held at ETH Zurich with ten invited European climate scenario experts. Additionally, a comprehensive survey on user needs regarding climate scenarios was conducted (Chapter 3).

In the second project year (concept phase), the findings from the user survey were consolidated to frame the goals of the project. Additionally, a large number of resources was spent on the scientific methodological developments and to find a consistent conceptual procedure throughout the whole project (Chapter 4).

The longest project phase was the actual realization of the climate scenarios (third and fourth project year) in form of the six different products. Among these, the technical report served as the cornerstone for deducing other communication measures. Finally, the last project phase was devoted to the operationalization of the six products and services at MeteoSwiss as decision support basis for dealing with climate change in Switzerland.

Regarding resources, in total 70 persons contributed to the development of CH2018: the largest work load was devoted to the description of the scientific work in the technical report. This report – elaborated by 39 scientists from nine research institutions (matching the ones enlisted as affiliations of the authors of this article) – was internally reviewed. Additionally, an external review with 22 leading international experts ensured the quality of the scientific approach. While the technical report was published in English only, the other products were made available in the three Swiss national languages (German, French, Italian) and English. The translation was one of the challenging aspects in the coordination of the product generation. A considerable amount of work also went into the translation of the scientific results for laypeople through the design of appropriate communication measures.

The main partners, ETH, MeteoSwiss, and C2SM, were involved in all project steps and decisions were jointly made. ETH predominantly led the scientific innovations and accuracy of the outcome. C2SM established the link between the international modeling community and the authors of the technical report with a central data repository of simulation data to facilitate the analysis. Further, they were co-responsible for the coordination of the overall project and greatly contributed to the communication concept of the project. MeteoSwiss as mandating institution held the main responsibility for the project, coordinated the development of products and established the link to users.

3. User engagement

In order to make the CH2018 scenarios actionable, three distinct ways of eliciting users' needs have been maintained, that are detailed in the following:

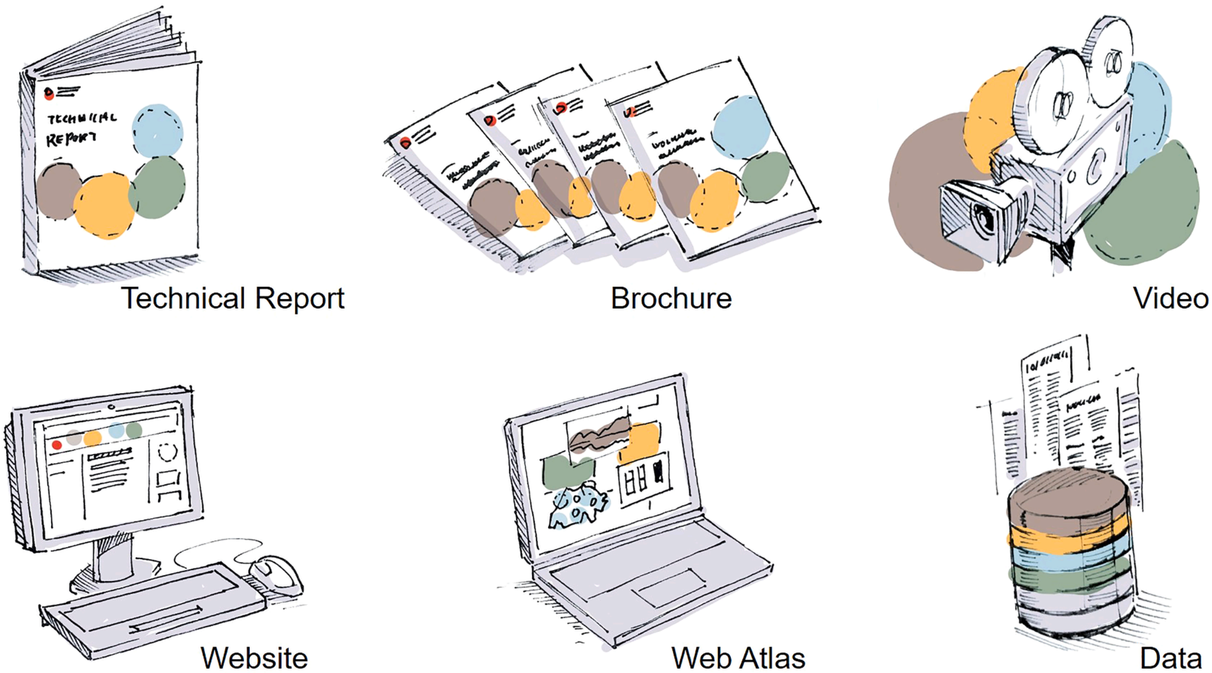

Fig. 1. Overview of the different product groups of CH2018 launched in November 2018 in Switzerland.

(a) User survey: In the run-up to CH2018, a comprehensive survey was conducted by an external consulting company for a better understanding of the user types of climate scenarios and their needs (MeteoSwiss, 2016a). The survey addressed organizations from all climate-relevant sectors and involved representatives from administration, research, and private companies across Switzerland. The survey consisted of group interviews with key stakeholders, a questionnaire answered by more than one hundred users (return rate of 45%), and two specific workshops on dissemination. Additionally, the survey results were consolidated at a national symposium with approximately 150 participants. Although the survey cannot be regarded as representative of the whole user community, important conclusions could be derived that shaped the framing of CH2018.

The survey results also allowed to identify three main types of users, which differ in terms of knowledge on climate issues, specific needs on climate scenarios and the level of usage:

- *Intensive users*: mainly researchers handling large climate scenario data for further use in in e.g. impact and/or adaptation studies.
- *Practitioners*: usually from administrations, consulting firms or companies performing simple calculations with scenario data for specific aspects; lower background knowledge on climate and very limited time for data processing.
- *Mediators*: usually from media, non-governmental organizations or educational institutions translating scenario information to laymen.

Note that Skelton et al. (2019) recently suggested an extended classification of users based on the same survey results. We nevertheless refrain from using a new classification, as the user types presented here were the ones available at the start of the project and hence framed the outcome of CH2018.

Practitioners account for almost half of all climate scenario users in Switzerland, followed by intensive users and mediators with equal share (~25% each). The survey results also unveiled that practitioners (e.g. sector-specific associations) play an important role in the translation of complex climate information from intensive users towards end-users within their respective sectors.

Regarding content, many users of climate scenarios called for an expansion of the range of data offered compared to CH2011. The most frequent request was the need for quantitative information on extremes - an aspect that was handled qualitatively only in CH2011. Another requirement often expressed was the consistency of the scenario data across different variables and the need for higher temporal (i.e. sub-daily information) and spatial detail than was the case in CH2011.

In terms of dissemination, it turned out that, the more intensive the use of scenarios, the stronger the wishes are for more detailed and comprehensive information. The less intensive the usage, the more important becomes the need for comprehensibility, clarity and support when disseminating results.

Based on the experiences with the previous CH2011 scenarios and on the results from the user survey, recommendations for a new cycle of climate scenarios were formulated (MeteoSwiss, 2016b):

1. Address all three user types and give more weight to practitioners as the largest group of users.
2. Allocate more resources for professional communication and dissemination.
3. Bundle knowledge on climate change with those on climate impacts.
4. Allow for more personal consultation on proper data use.
5. Keep dissemination for intensive users simple (e.g. no need for elaborated download web-portals, as these are the most experienced users).

(b) *External sounding board:* The perspective of users was further considered by an external sounding board that advised the project lead on user needs throughout the project duration. Furthermore, to test the applicability of the generated localized scenario data, two prototype impact simulations were run while developing the scenarios. Regular exchanges also took place with the project leaders of downstream priority themes of the NCCS that subsequently used the prototype CH2018 scenario data.

(c) *Sectoral user workshops:* Additionally, 29 sectoral experts working in local administration attended two transdisciplinary workshops to discuss challenges they face in their work regarding climate adaptation, and how CH2018 can assist them. Skelton (2020) reported on differences in sectoral experts' uptake of climate information in their work related to their 'cognitive' proximity or distance with climate scientific concepts as well as their different decision-making capacity.

4. Scientific framework

The rationale behind the scientific framework of the CH2018 climate scenarios was to provide an approach that (a) is *consistent* through all analyses and statements of CH2018, (b) provides *robust* and *relevant* information on the reported climate change signals, and (c) is scientifically *consolidated* among all involved authors and institutions. The methodological chain for generating a multi-model ensemble in consistency across scenarios and spatial resolutions is presented in Sørland et al. (2020).

As a common basis for all analyses served the projection data obtained from the European Branch of the Coordinated Regional Climate Downscaling Experiment (EURO-CORDEX). The EURO-CORDEX initiative provides a comprehensive set of regional climate projections at a horizontal resolution of 12 and 50 km for Europe by coordinating various regional climate model (RCM) simulations driven by various global climate models (GCMs) under a controlled setup (Giorgi et al., 2009; Jacob et al., 2014; Kjellström et al., 2018; Kotlarski et al., 2014; Coppola et al., 2020).

The available model simulations cover different emission scenarios ranging from a strong mitigation scenario implying swift and substantial reductions in global emissions (RCP2.6) to continued emission growth until the end of the century (RCP8.5) (IPCC, 2013). As an intermediate emission scenario, RCP4.5 was additionally considered for all analyses.

To ensure consistency across the different analyses in CH2018, the underlying model data set was held constant representing the availability of simulation data from EURO-CORDEX in May 2017 except for simulations excluded due to quality issues (CH2018, 2018). Several simulations exhibit problematic values in limited regions relevant for Switzerland, including substantial and unrealistic snow accumulation over the Alps, and a strong wet bias along the northern Alpine rim with a very low correlation with its driving GCM. These issues were communicated to the respective modeling groups. Nine RCM simulations were additionally excluded due to errors detected in the GCM forcing files, while some simulations were omitted based on recommendations from their creators.

In total, the final model set used for CH2018 consists of 68 simulations carried out by seven different RCMs driven by nine GCMs. Compared to the predecessor scenarios CH2011, the model ensemble is more than four times larger and also involves a larger number of GCMs. This consolidated model data set in daily granularity on the native model grid was the common starting point to deduce all specific analyses in CH2018 (Fig. 2).

4.1. Localized datasets at daily resolution

For many users, the current spatial resolution of RCMs is too coarse to derive climate information at the local scale in complex topography. As a circumvention, the commonly used method of quantile mapping (QM) was applied as a statistical downscaling technique, matching the distributions of coarsely resolved simulated and local-scale observed climate variables in the reference period. Specifically, a correction function was derived for each day of the year and then applied to the simulated values over the full simulation period 1981–2099, resulting in localized and bias-corrected transient data series in daily resolution. Thus, the statistical approach corrects systematic biases of the climate models and implicitly overcomes scale-discrepancies (Themeßl et al., 2012; Kotlarski et al., 2017).

The QM method was applied to each of the 68 climate model simulations and to each variable separately in two variants: (a) downscaling to single measurement stations ("DAILY-LOCAL") and (b) to 2 km × 2 km grid points across Switzerland ("DAILY-GRIDDED") (Feigenwinter et al., 2018). The number of provided variables depends on the available observation data. For DAILY-LOCAL a complete set of seven meteorological variables (mean, max. and min. temperature, precipitation, relative humidity, global radiation, and near-surface wind speed) could be calculated, while for DAILY-GRIDDED the application of QM was only possible for the variables mean, max. and min. temperature and precipitation.

The QM approach outperforms a simple delta change approach as applied in CH2011 (Bosshard et al., 2011) in several aspects: First, the resulting time series are transient and provide absolute values and are therefore directly applicable to drive impact models. Second, the temporal structure of the simulated variable is preserved at the local scale. Therefore, potential changes in the temporal structure such as spell lengths or interannual variability are also present in the localized time series.

Despite many advantages, the QM method also entails some limitations due to its purely statistical approach (Gutiérrez et al., 2018; Ivanov et al., 2018; Maraun et al., 2010). These limitations together with some practical guidance (e.g. in the treatment of inter-variable consistency) are communicated to users via a dedicated section in the CH2018 Technical Report and via a specific data documentation of the QM-derived scenario products. One of the limitations concerns the analysis of extreme changes at the local scale. Since the correction function for high and low quantiles is subject to large uncertainties and the bias of simulated extreme values outside of the observed range is not explicitly considered, it is possible that the change signals of extreme indices differ between the local scale and the overlying model grid point (i.e. without QM step). A modification of the raw models' mean climate change signal can to some degree also occur for moderate indices, seasonal means and other aggregations (Maraun, 2013). Another limitation is that the QM method will correct biases regardless of the quality of the simulation in representing a variable. This issue was found to be important for wind estimates as the deviations from model to model are huge and some models are even not able to simulate the height dependence of surface winds at 10 m (Graf et al., 2019).

4.2. Calculation of climate indices

To make robust quantitative statements on the future climate in Switzerland, a number of indices (in total 40), including extremes and percentile-defined threshold exceedances, were calculated on the model grid only (Table 1, left column) as was done for quantifying and communicating changes in the mean (Chapter 5).

In order to provide relevant information at the local scale, a total of eight commonly used absolute threshold indices were calculated with the datasets DAILY-LOCAL and DAILY-GRIDDED (Table 1, right column). One of these indices measured the combined effect of high temperature and humidity levels to indicate heat stress level exceedances (Casanueva et al., 2019).

Compared to the predecessor scenarios CH2011, the list of 48 user-specific indices is considerably larger in number and includes quantitative estimates on future changes in extremes based on previous work (Fischer et al., 2013; Fischer and Schär, 2010; Frei et al., 2006; Rajczak et al., 2013; Rajczak and Schär, 2017). Furthermore, new innovations in the calculation of precipitation indices were taken up (Schär et al., 2016).

Based on user requests, this list is continuously being extended over the coming years. For instance, specific agricultural indices have recently been added to the list of localized indices (Tschurr et al., 2020), as well as extreme temperature indices representing the urban heat island effect of larger Swiss cities (Burgstall et al., 2021).

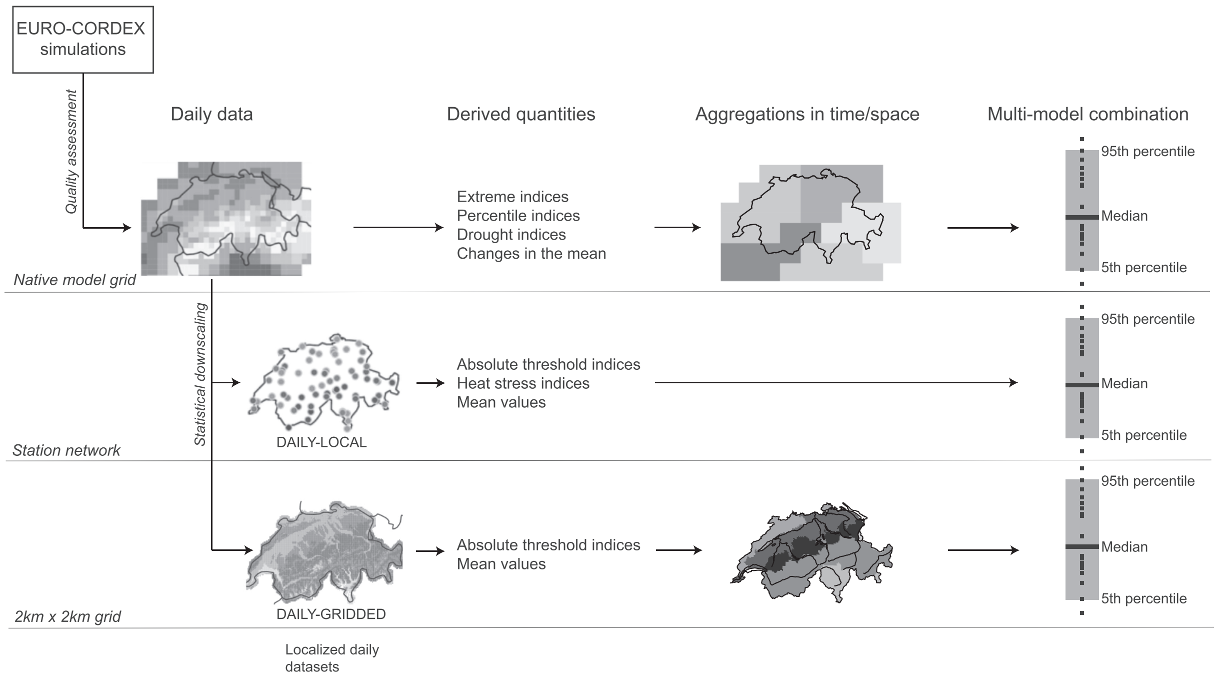

Fig. 2. Overview of the scientific framework to generate robust climate information and tailored data in CH2018 from a set of available RCM-GCM-simulations from EURO-CORDEX. Figure modified from CH2018 (2018).

4.3. Aggregations in time and space

To provide robust change estimates, the simulated data were spatially and/or temporally aggregated. Common definitions of regions and periods ensured consistency across the scientific analyses. Where possible, the definitions were kept the same as in CH2011, allowing one to compare the new scenarios with the older ones. This was an explicit request by users in the user survey.

For climate analyses on the native model grid, the spatial aggregation split Switzerland into five climatologically distinctive regions of similar size, ensuring comparable stochastic variability in the regional averages (Fig. 2). To provide quantitative information for the whole of Switzerland, the median of the projected changes over these five model regions was used. To aggregate the DAILY-GRIDDED data, a different set of five smaller-scale regions (Fig. 2) was used as defined in collaboration with climate adaptation planers (MeteoSwiss, 2013).

Regarding temporal averaging, all future changes were calculated with respect to the reference period 1981–2010. Besides comparability with CH2011, the choice of this reference period also had the advantage to direct users toward supplementary climate monitoring information from MeteoSwiss as this was the official normal period at that time. For the future, the three periods 2020 – 2049 (“2035”), 2045 – 2074 (“2060”), and 2070 – 2099 (“2085”) were used.

4.4. Generation of a multi-model set

The procedure explained so far treated individual model simulations separately. In order to infer a robust assessment of the climate change signals and to estimate structural uncertainty for each RCP, a multi-model estimate had to be constructed out of the available ensemble of opportunity (Fischer et al., 2012; Knutti et al., 2010; Rajczak and Schär, 2017; Zubler et al., 2016). This process was further complicated by inter-dependencies and sparsity of the multi-model matrix of RCMs, GCMs and RCPs as provided by EURO-CORDEX:

- Different number of simulations per RCP.
- Different number of dynamically downscaled GCMs.
- Different number of involved RCMs.
- Availability of the same GCM-RCM pair at two spatial resolutions (12 km and 50 km).
- A pair of simulations sampling internal climate variability (different initial conditions of the driving GCM).

These practical challenges were resolved in several steps that are described in full detail by Sørland et al. (2020). In brief, the core of the multi-model set were the simulations following the RCP8.5 scenario with the largest number of simulations. To avoid inter-dependencies from simulations available at two spatial resolutions but with the same GCM-RCM configuration, only the higher-resolved simulation (i.e. 12 km run) was retained[10]. Similarly, only one of the two simulations that differ solely in the initialization was included. To avoid a substantial reduction of the ensemble size, simulations from closely related, but not identical RCMs (e.g. the same RCM, but different model versions and different resolutions) were treated as separate models. To reach a consistent number of simulations for all RCPs for an uncertainty assessment, the model matrix was statistically filled for RCP4.5 and RCP2.6 by a time-shift-based pattern-scaling approach using simulated global mean temperature as a control parameter (Herger et al., 2015). In essence, from an existing RCM simulation for RCP8.5 a 30 yr-period is used as surrogate in which global temperature change matches the one of the target simulation (e.g. a given GCM simulation for RCP4.5).

By this approach, a consistent information basis with 21 simulations for each individual RCP was obtained, with the obvious inter-relations among models removed. However, it ultimately remained an ensemble of opportunity. The ensemble range therefore could not be expected to capture the “full” scientific uncertainty of the climate change signal that is spanned by emission uncertainty, model uncertainty, and internal variability (Hawkins and Sutton, 2009). Any statistical range derived from this model set should therefore be interpreted in the context of broader expert knowledge. In CH2018, an empirical quantile range of

[10] For maps showing the median of the multi-model ensemble on the model grid an averaging method was applied that first averages the information on the coarser 50-km grid. This average, regridded to the 12-km grid is then combined with fine-scale anomalies from the simulations at 12-km grid.

Table 1
The 48 quantified climate indices in CH2018 on the native model grid and at the local scale (station locations and 2 km grid) after applying the QM approach. The indices on the native model grid were published as change values over 30 yr-means, while the localized indices could be provided as absolute values in transient mode from 1981 to 2099. "TX" ("TN") refers to the max. (min.) daily temperature. "R" stands for precipitation, "Rx" is the max. precipitation. Percentile indices for daily precipitation were calculated relative to all days (wet and dry days) (see Schär et al., 2016).

	Native Model Grid (40 indices)	Localized (8 indices)
Temperature indices	Hottest day of the year (TXx) Coldest night of the year (TNn) Warmest night of the year (TNx) Coldest day of the year (TXn) Hottest week of the year (TXx7d) TXpYY% (YYth percentile of TX with YY = 90, 95, 99%) TNp5% (5th percentile of TN) Exceedances (in days) of 95th and 99th percentile in reference period (>TX95P, >TX99P) and vice versa with cold extremes	Summer Days (TX > 25 °C) Hot Days (TX > 30 °C) Tropical Nights (TN > 20 °C) Frost Days (TN < 0 °C) Ice Days (TX < 0 °C)
Precipitation indices	Wet-day frequency and intensity (R > 1 mm/day) Max. of D = 1-day, 3-day and 5-day precipitation (RxDd) RpYY% (YYth all-day percentile f daily precipitation with YY = 90, 95, 99%) Return levels of D = 1-day, 3-day and 5-day precipitation with return periods of YY = 5, 10, 20, 50, 100 years (xDd.YY)	
Combined indices		Heat stress indices based on wet-bulb temperature (TW) Max. of wet-bulb temperature (TWx) Number of days above 22 °C (TWg22)
Drought indices	Max. number of consecutive dry days (CDD) Standardized precipitation index for 3-month acc. Precipitation (SPI3) Precipitation minus evapotranspiration (P-E) Standardized soil moisture anomaly (SMA)	

90% (5% to 95% quantile difference) was used to descriptively characterize uncertainty. However, such a range does not necessarily cover a probability of 90%, as some feedbacks or external forcings may be missing in the models. The probability that the true values will lie in this quantified range was estimated to be about two-thirds and communicated as a "likely" range, consistent with the treatment of CMIP5 ranges in IPCC (2013).

4.5. *Deducing headline statements*

The methodological chain as summarized above and in Fig. 2 allowed to systematically compare the effects of climate change according to different future emission pathways. To draw robust statements on the future climate in Switzerland, the quantitative analysis with the model simulations at hand had to be supported by further lines of evidence: in particular the consistency with (a) past trends and variability from observations and initial condition ensembles, (b) with studies on continental and global scales, (c) with high-resolution model runs at 2 km, and (d) with physical process understanding. Furthermore, the uncertainties obtained in seasonal mean changes were thoroughly compared to other quantifications of uncertainty including weighted ensembles with Bayesian models (Buser et al., 2009; Kerkhoff et al., 2015) and other data sources.

This way, a number of robust headline statements could be formulated in the executive summary of the technical report (CH2018, 2018), supported by quantitative estimates based on the analysis on the model grid level (see Fig. 3 as an example for Western Switzerland). These statements outline a number of significant changes for the future climate of Switzerland. Temperatures in Switzerland will very likely rise with unmitigated climate change with a larger warming rate than the global mean. Lower elevations will experience a reduction in snowfall sums and snow cover. In summer, both a reduction in wet days and a tendency toward drier soils and longer periods without rain are likely in response to strong warming. This is accompanied by an increase in heatwaves and extremely hot days and nights, especially in low-altitude areas. Furthermore, the CH2018 assessment shows consistent evidence that heavy rainfall extremes have become more frequent and intense, and that this trend will continue in a warming climate.

5. User-tailored information distillation

Identifying and communicating the key information for the three different user types (Chapter 3) was a key focus in producing CH2018. Based on the technical report, its executive summary and headline statements, further specific user-oriented communication measures were developed and rolled out. A comprehensive communication concept ensured that the publication of these communication measures comes in a concerted action and reaches out to the specific target groups via appropriate dissemination channels. The communication concept was centered on a number of key messages, and covered among others the planning of measures from print products to web tools, press releases, pitching of stories and the official launch event itself. Furthermore, a number of measures beyond the launch event were included, too.

In the following, the focus lies on the distillation of information that led to the six main product groups (Fig. 1). This can be schematically aligned in a pyramid (Fig. 4) informing about climate change in Switzerland in different depths, while addressing specific user types. The higher up in the pyramid, the more condensed the information of CH2018. Hence, the products at the top of the pyramid (video/social media) are targeted for mediators, while the technical report at the bottom is primarily meant for intensive users. As recommended in the outcome of the user survey, more weight is given to the practitioners as the largest user group with the products web atlas, web factsheets, and the brochure.

Premises in the development of products along this pyramid were to echo the key messages in all products, to keep consistency in content, to have a recognition of the scenarios as a whole and to design the products with an affordable amount of resources. The following chapters present the main characteristics and the concept for each product group.

5.1. *Technical report*

The technical report (CH2018, 2018) treats in detail the methodological developments and scientific results as summarized in Chapter 4. This comprises an analysis of the climate model projections in Switzerland, their interpretation with existing literature, and with observed trends. A chapter "Reference climate and recent change" describes the drivers of Swiss climate and presents changes in mean and extreme climate over the past 150 years and thus sets the stage for the projections. Chapter "Natural climate variability, detection, and attribution" brings the observed trends together with model simulations and discusses resulting challenges. These chapters are a major advancement compared to the previous scenarios CH2011. The technical report also covers a quantitative and qualitative comparison with CH2011, and gives guidelines on how to best use the scenario data for climate

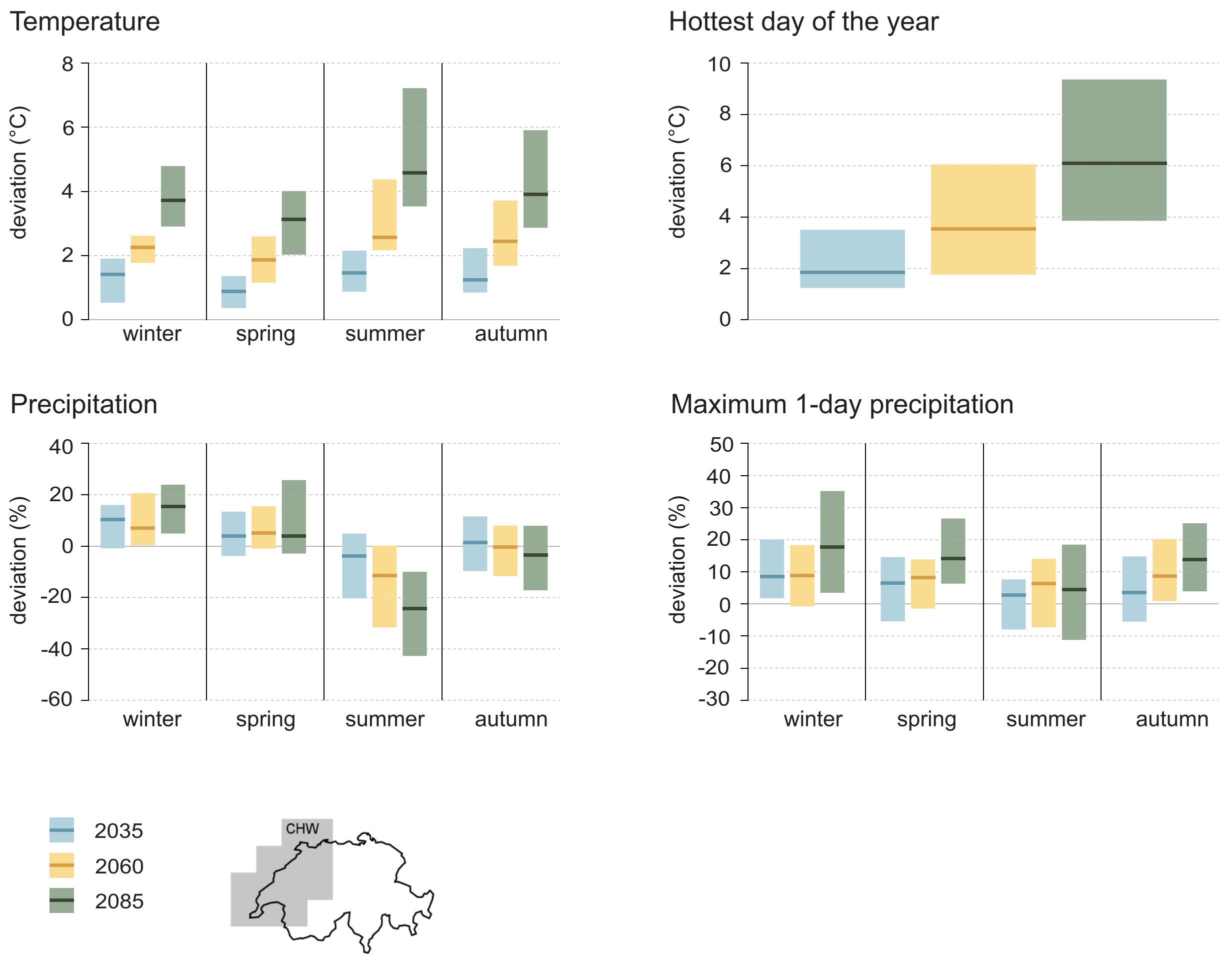

Fig. 3. Projected changes in Western Switzerland of seasonal mean temperature and precipitation and the respective daily maximum index assuming the RCP8.5 emission scenario. Shown are the deviations from the reference period 1981–2010.

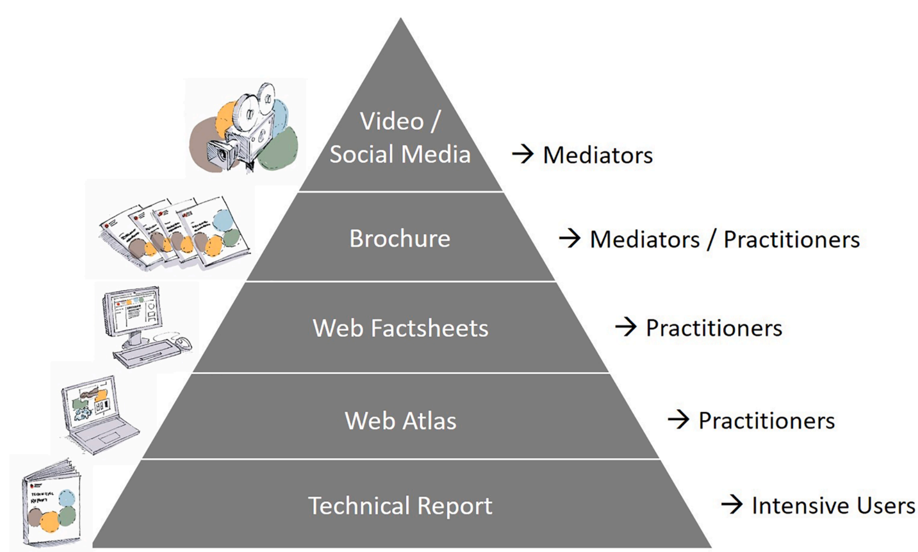

Fig. 4. Pyramid of information distillation along the different CH2018 products. The targeted user types are shown on the right.

adaptation purposes. Furthermore, it also shows limitations of the data sets provided, e.g. future wind changes (Graf et al., 2019). The information of the technical report is summarized by an executive summary supplemented by headline statements.

Since the target audience of the technical report are intensive users that are familiar with working in a scientific environment, the report was treated as a scientific document available as a PDF in English. Likewise, the scientific data targeted at intensive users (i.e. DAILY-GRIDDED and DAILY-LOCAL) are disseminated in a rather simple way with access to an FTP-server as recommended from the user survey (Chapter 3).

5.2. Web atlas

To characterize climate change in relevant terms for a broad range of practitioners, seven standardized types of graphs were defined that provide information on multiple aspects of future climate change in a simplified way (Fig. 5). Two graph types make use of the data at station level, four are constructed with the downscaled output at 2 km resolution and one uses the spatially aggregated data at the model grid level. Altogether, the graph types inform the user on the evolution of certain indices and variables in time, on their spatial variation, and allow comparing the effects of emission scenarios. Additionally, altitude profiles are provided per region. Where possible, the observations in the

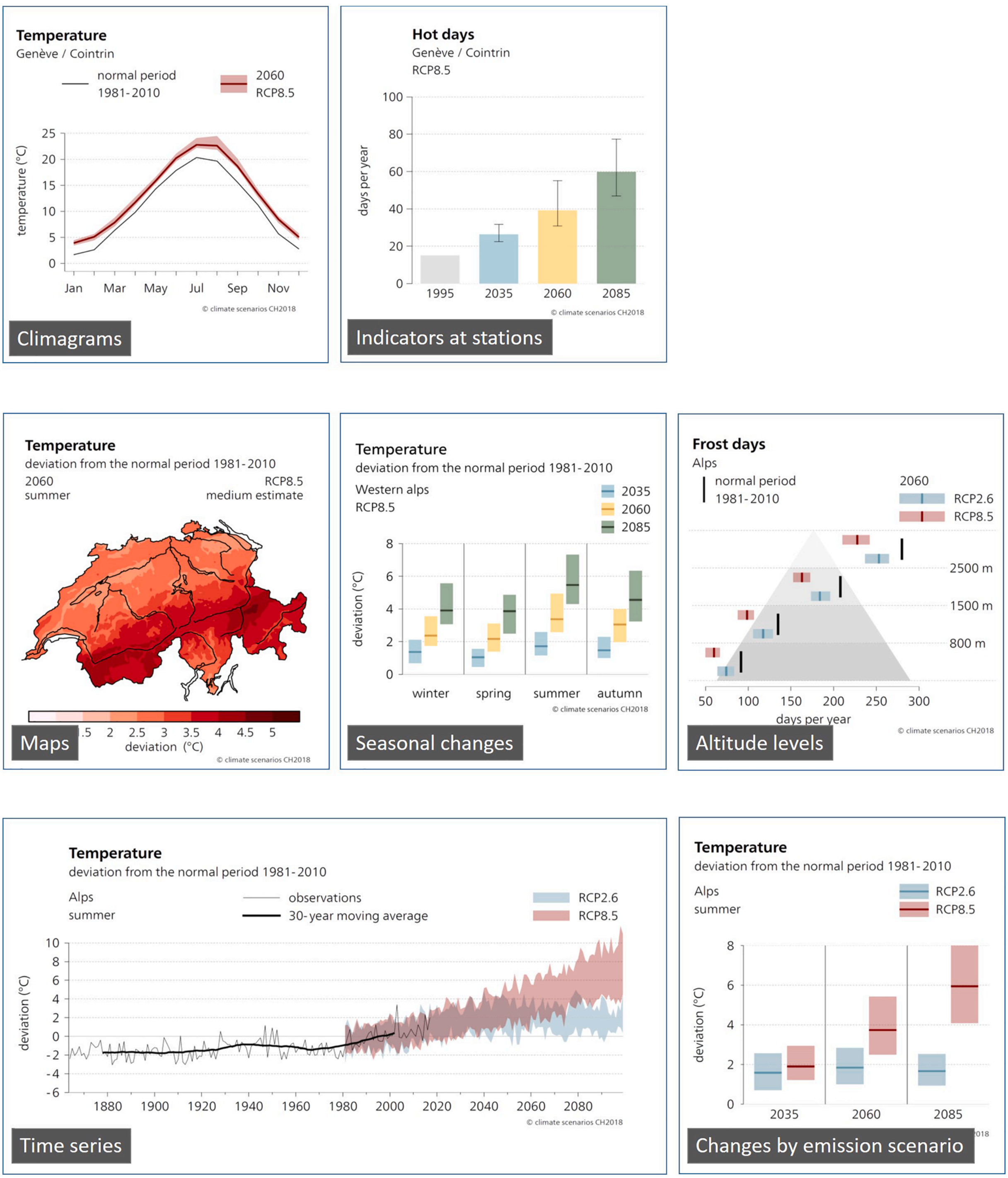

Fig. 5. The seven graph types of the web atlas give users the possibility to explore climate change in Switzerland.

reference period is included to put the projections into context.

The web atlas is also the vehicle for disseminating ready-to-use datasets for practitioners in the format CSV. These data contain all necessary information to reproduce the corresponding plots. The data of CH2018 are freely available following the license conditions of CC BY 4.01. A DOI number for the data (https://doi.org/10.18751/Climate/Scenarios/CH2018/1.0) has been created and a citation to the technical report is required when using the data.

The set of graph types was calculated for all analyzed regions, stations, seasons, future periods, and all three emission scenarios. Thus, the online collection of around 22,000 graphics, available in PNG and PDF format helps users to explore the future climate in Switzerland. In collaboration with an external graphic designer, professional layouts were developed to standardize the graphics for direct use in downstream products such as the brochure and web factsheets.

For these products, an information distillation was purposely applied based on the experience in the application of CH2011 for climate adaptation by focusing on a “weak” and “strong” emission scenario (RCP2.6 und RCP8.5) in the period 2060. To communicate changes from the multi-model set with associated uncertainties, values inside the bandwidth of the 5–95% empirical interval were labeled as “possible changes”, median values as “expected changes”.

5.3. Web factsheets (web-based regional facts and figures)

The web-based regional facts and figures give practitioners as web factsheets a standardized overview of the expected climatic change in their region using the graphical output of the web atlas. For each of the five bio-geophysical regions, information is provided with the same set of indices/variables presenting the major changes for the region as a whole, altitude profiles and evolutions at selected stations within the region (see Fig. 6 as an example for the Swiss plateau). To put the projections in context, a description of today’s climate is provided as supplementary information. The websites with regional information are complemented by Swiss-wide facts and figures regarding mean changes, indicators and extremes.

For each graphic, an interpretation example helps the reader understand and interpret the plot. Consequently, the readers are directed toward the web atlas to interactively explore all aspects of climate change in Switzerland.

5.4. Brochure

For the brochure (NCCS, 2018), the information was further condensed to match the needs of the target group. The 24 page-brochure is centered on four key messages based on the headline statements of the technical report that - in the absence of climate mitigation – bring large challenges to multiple sectors in Switzerland: increase of dry summers, heavy precipitation, hot days, and snow-scarce winters. Each of these four central aspects of future change is exemplified by a fictitious person affected in the year 2060 (Fig. 7). Taken together, the four fictitious persons represent several generations and cover different parts of Switzerland including different language regions. With climate mitigation measures largely alleviating the adverse effects of climate change in Switzerland, a fifth key message is brought forward. An infographic at the beginning of the brochure introduces the headline statements in a narrative way (Fig. 7). This is complemented by presenting the key numbers of mean change. The infographic serves both as a summary and a table of content for the whole brochure.

On two pages, each key message is then further substantiated with more detailed information presented along with the same concept (Fig. 8): the main body text explains the key message taking into account the climate model projections, the physical understanding, and the trends from observations. This is complemented by tabulated numbers of changes in key indicators for a typical Swiss region. In this way the possible ranges are specified (i.e. 5–95% quantile range), except for extreme precipitation for which the median values were taken due to the strong influence of the statistical uncertainty (CH2018, 2018). To give the reader a hands-on impression of the future world and to evoke emotions in the reader, a small paragraph with 1–2 sentences in present tense is constructed that represents a statement of the future focusing on the largest possible changes. Furthermore, to exemplify the relevance of the respective key message, a quote of an affected stakeholder of a well-known organization in Switzerland is included.

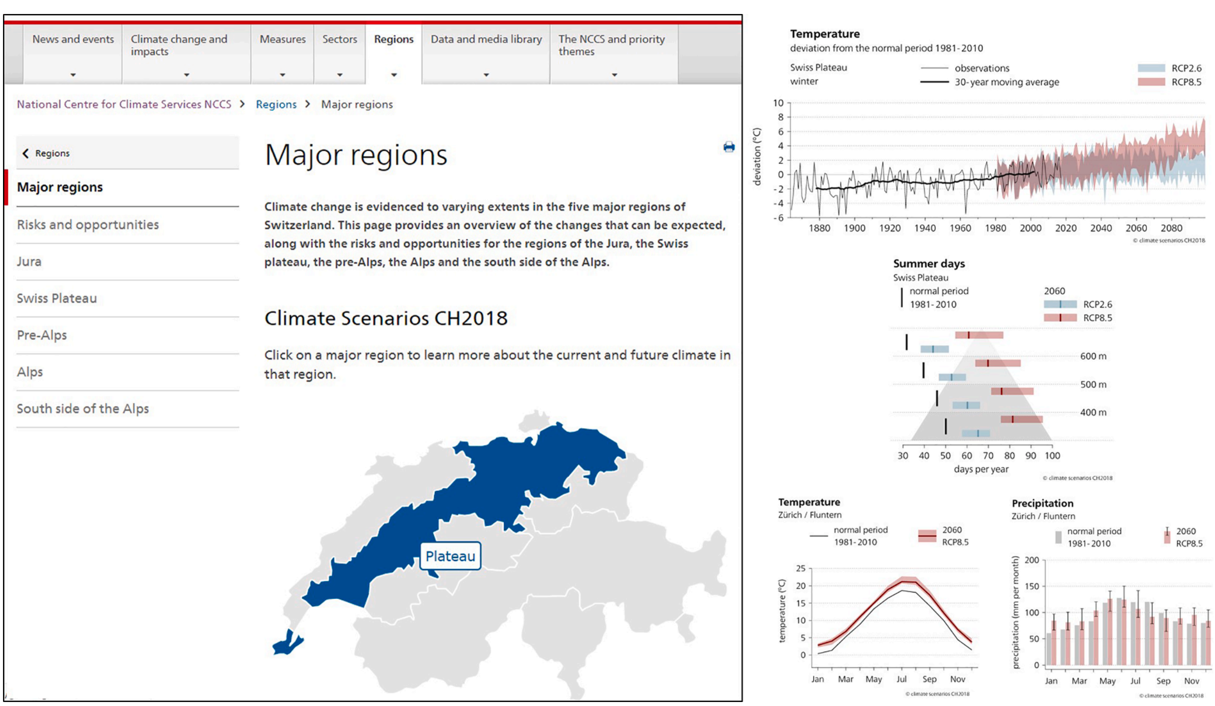

Fig. 6. Example of the web-based regional facts and figures in the Swiss Plateau. The graphics on the right show part of the material chosen to inform the reader of the expected changes over the region in full detail.

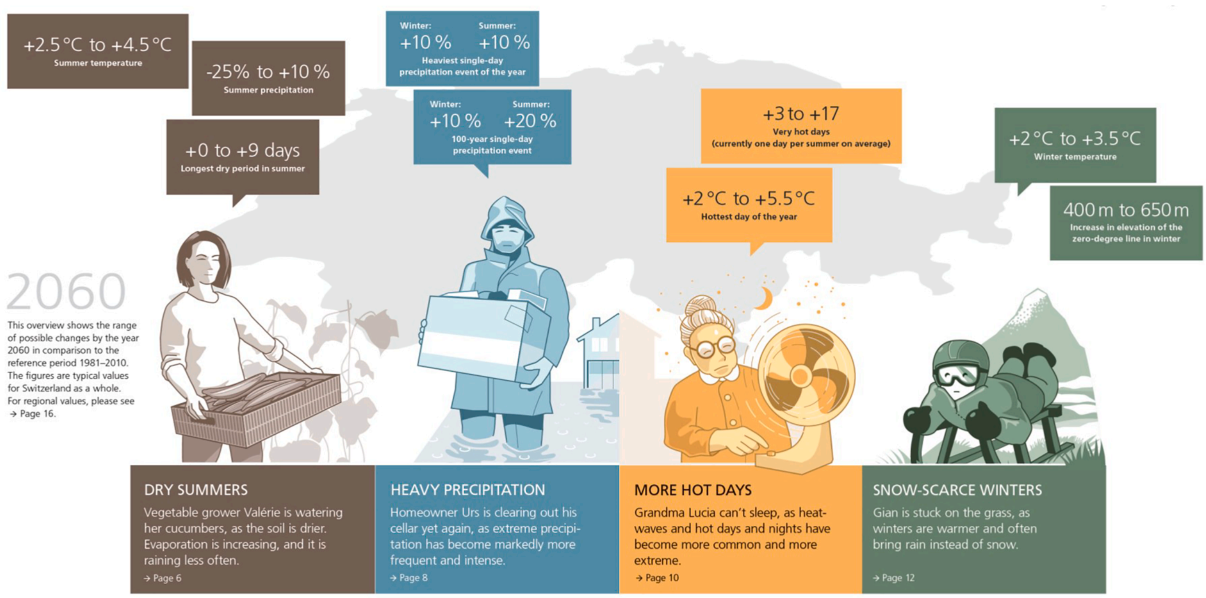

Fig. 7. Infographics of the brochure (NCCS, 2018) with the narrative approach using four affected persons in Switzerland in the year around 2060. Each story is introduced by a small personalized summary of the key message. Typical values for changes are additionally stated for each of the headlines.

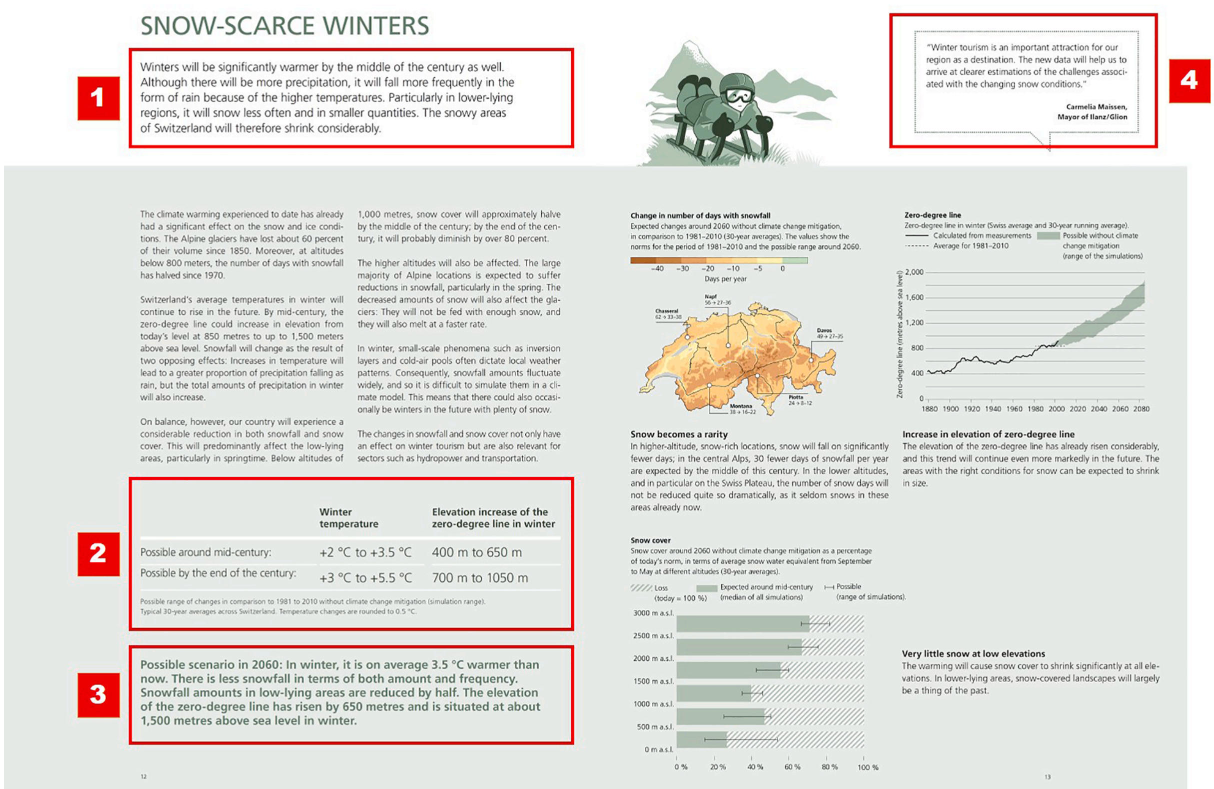

Fig. 8. Double page of the brochure explaining one of the four narratives (NCCS, 2018). The numbers point to conceptually different sections of the double-page beyond the main text. (1) headline statement of the technical report, (2) key numbers of projected changes, (3) scenario text of the future, and (4) stakeholder statement.

5.5. Video / Social media

To increase the uptake of the CH2018 climate scenarios and to reach out to the general public, the narrative approach of the brochure was further utilized as a corporate identity for all products of CH2018. They are also the main element of an animated video of around two minutes in length presenting the five key messages with the fictitious persons as main actors. Through pitching of stories, the narrative approach could also be well used for a social media campaign to advertise the final event prior to the official launch date.

6. The scenarios in practice

In retrospect, the publication of the CH2018 scenarios was successful in reaching out to the primary target group of practitioners. One indicator for this was the increased request for presentations of CH2018 at administrations, organizations, and companies after the official launch at regular intervals. Another indicator was the large number of offers to place CH2018 and its headlines in sector-specific practitioner journals. These articles are regarded as a good opportunity to multiply the information to new end-users. They encompassed, for instance, publications in journals of a canton (Holthausen et al., 2019), on natural hazards (Fischer and Kotlarski, 2020), and on housing (Fischer and Wehrli, 2020).

For intensive users, the local datasets are probably the most important product of CH2018. These specialized data were so far (March 2022) requested by >157 users. This number is much higher compared to the users of CH2011 data. Moreover, several of the registered users are multipliers, as they re-distribute the data within their institutions. Hence, the total user number is likely much higher. The majority of them come from research institutions or companies specialized in scientific analyses. Besides hydrologists with most requests for the local datasets, many users were registered within the sectors forest, health, agriculture, glaciology, natural perils, economic analysis, biodiversity, and energy.

With the data and information applied in practice, a number of questions and demands have been brought forward in dialogue with the users over the past three years (Supplementary Table, left column). Typically, these requests and questions can be grouped into (A) requests for an extension of the existing set of scenarios, (B) guidance on the interpretation and use of the scenarios, and (C) requests on further aspects of communication and dissemination measures. The list of collected requests is neither representative nor complete, but it gives a first impression of the obvious requests and problems with the data and information at hand. The right column of the Supplementary Table shows the way how parts of these requests have already been tackled over the past three years. In the following, a summary of the requests and questions is given.

The requests for an extension of the existing set of scenarios (A) can be clustered into: higher *resolution* (either in space and/or time), more *consistency* among the different multi-model analyses of CH2018 (including a complete set of variables/indices for all disseminated datasets), between standard monitoring analyses for the past/current climate by MeteoSwiss and the CH2018 scenarios, and consistency among the producers of national scenarios in particular between neighboring countries. Moreover, more information on *extremes and other indices* is an often voiced request. Ideally, the disseminated data are additionally provided for individual years complementary to 30 yr means to allow studying variability changes. Also, it turns out that users request more physical explanations of the climate change signals.

A large number of the so-far obtained questions regarding the use of the scenarios (B) cluster around difficulties with the *selection and treatment of individual model simulations and emission scenarios* at the local scale. Often, users are forced to make a sub-selection of the available model simulations due to limited resources. This sub-selection should ideally reflect multiple aspects of change. For instance, individual simulations should feature particular drying and warming signals, while simulating above-average changes in a certain extreme index. An optimal selection is very challenging and strongly depends on the intended use, as the ranking of a specific simulation compared to the full ensemble can be very different for different indices/variables, regions, and time periods (Fischer et al., 2015b; Chapter 10.4 in CH2018, 2018). What would be needed here for a thorough decision basis is a multivariate approach such as the one in operation at the German Weather Service (Dalelane et al., 2018) built from earlier studies by Sanderson et al. (2015). Further questions arise on the correct application of the *coarse-resolved indices* to the local scale.

Regarding communication and dissemination aspects (C), many requests have been put forward to bring *more context* to the projected changes by providing analogue cases, either by comparing them to observations at other stations or individual events in the past or by comparing future projections in a particular month to today's climatology at a different time of the annual cycle. Further, to reach more people, the information should be better aligned to people's everyday life, so that emotions are evoked. This also concerns the often requested need for information for *sub-regions*. Users would like to identify themselves with regions that are of concern in their everyday life (e.g. cantonal regions). Moreover, the information and data should be *application-ready,* for instance to serve as input for GIS applications.

Overall, the uptake of and feedback on CH2018 across intensive users, practitioners and mediators was very positive based on direct feedbacks, requests and statistics on data download.

7. Conclusions

The publication of the climate scenarios CH2018, seven years after CH2011, accomplished an output that was far beyond that of its predecessor in terms of uptake, scope, and innovation. The narrative approach with the key messages and key numbers was directly taken up by the media that reported on the publication of CH2018. This highlights the importance of user-oriented communication toward a successful uptake of climate scenarios in the community and beyond. Other important innovations of CH2018 include quantitative information on extreme changes and other specific indices, transient time series at the local scale for seven variables, the design of user-oriented products based on user integration and co-design from the start of the project, and innovative dissemination channels to convey messages and data to the appropriate user types. In retrospect, the recommendations given in the outcome of the user survey could all be fulfilled. Given the feedback from practitioners, the impact community, the international community, and from the media, CH2018 can be regarded as a success story. The scenarios now build the key basis for assessing climate impacts in Switzerland, such as hydrological scenarios (FOEN, 2021), and for planning national and sub-national adaptation measures (FOEN, 2020).

The regular provision of Swiss climate change scenarios remains a federal mandate of MeteoSwiss for the long-term future. Hence, new scenarios taking into account the updated future scientific state and new user needs are expected in a few years from now. The planning for new climate scenarios in Switzerland is already well underway. One of the central pillars in the generation of climate scenarios is its consolidation among the leading climate institutes in Switzerland as in the previous assessments since the early 2000s.

The successful institutional collaboration will hence be continued and intensified in the years to come, thereby combining the strengths of the individual partners. In particular, the experience of MeteoSwiss in long-standing operationalization for weather forecasting should be better exploited. This concerns the long-standing experience with user consultation and dialogue, building and maintenance of dissemination channels, and operational data management and archiving. On the other hand, C2SM is a key hub to put scientific advancements into quasi-operation. In particular, this concerns the link to the CORDEX- and CMIP-community by running and contributing regionalized climate model simulations regularly and setting up a corresponding model database. In addition, the linkage to the Copernicus Climate Change Service (Buontempo et al., 2020; Thépaut et al., 2018) and its Climate Data Store (Raoult et al., 2017) will likely be an important step to set up a quasi-operational chain in the production process, in particular for updating the scenarios for a standardized set of indicators. Furthermore, it is the aim to intensify the collaboration with neighboring countries (esp. Germany and Austria) in order to have consistent future climate information across borders.

Another strategic thread guiding the development of the new scenarios is scientific advancement in the years to come and to focus on new methods and results. In particular, a new generation of global and regional climate simulations is already mostly completed in the context of the CMIP6 framework considering the combined SSP-RCP scenarios of the IPCC (Eyring et al., 2016). An update to the CMIP6 framework would be essential to harmonize the provided scenarios for Switzerland with the latest assessments from the IPCC, in particular the IPCC Special Report on 1.5 °C global warming (IPCC, 2018) and the IPCC 6th Assessment Report (IPCC, 2021). This would allow the computation of projections for Switzerland corresponding to scenarios with a stabilization at 1.5 °C of global warming (SSP1-1.9) compatible with the aims of the Paris Agreement.

The increasing availability of high-resolution model ensembles at kilometer-scale (Kendon et al., 2020; Schär et al., 2020) represents another key advancement in the coming years enabling explicit representation of deep convection, refined parameterizations of key processes, and improved simulations of critical mesoscale phenomena important for the complex topography of Switzerland (Ban et al., 2014, 2015). A first comprehensive ensemble at such convection-permitting scale has recently become available through the CORDEX-FPS on Convective Phenomena over Europe and the Mediterranean (Ban et al., 2021; Pichelli et al., 2021).

The third strategic thread of development is the alignment of the scenario generation process according to user types and their needs. The collection of questions and requests obtained so far (Chapter 6) helps to define the scope and the future work. More new findings on the practicality of the scenarios will be expected from key major programs using the current CH2018 scenarios as an input, such as the pilot program on climate adaptation, the downstream priority themes of the NCCS, and a new NCCS program on cross-sectoral climate impacts to be started in 2022. A continuous dialogue with users remains essential to improving the user orientation when generating new climate scenarios. The NCCS plays a key role in this process acting as an interface between producers and users.

Given these expected developments in the coming years, the plan for generating new climate change scenarios in Switzerland is two-tiered: in the short-term (until 2025) it is planned to extend the current scenarios with new RCM simulations from CMIP5-driven GCMs, to continuously collect user requests and perform new calculations and analyses where possible. Scientific findings should be updated where necessary and experiences should be gained by running a pilot study with the application of a 2 km climate model ensemble. In the long-term, it is planned to fully re-calculate the scenarios based on a new multi-model dataset that includes an ensemble of convection-permitting simulations. By then, improved statistical and stochastic downscaling techniques will be available to be implemented for the case of Switzerland. This will contribute to the new generation of Swiss climate scenarios that fully replace CH2018.

With this two-tiered approach and following the above-mentioned strategic threads of development the route is set for the coming years to continue the successful path in producing climate scenarios in Switzerland. From the ad-hoc and bottom-up collaborations between academia and administration ten to fifteen years ago, the collaboration has been largely professionalized. The calculation of national climate scenarios can nowadays be seen as a true public service to society. It is still the long-term vision that this public service is fully exploited by all climate-affected stakeholders to trigger the climate service value chain (Hewitt et al., 2020). Climate scenarios should eventually become a natural source of consultation for decision-making as is nowadays the case with weather forecasts.

CRediT authorship contribution statement

A.M. Fischer: Project administration, Conceptualization, Methodology, Writing – original draft, Validation, Visualization. **K.M. Strassmann:** Project administration, Conceptualization, Methodology, Writing – review & editing, Software, Validation, Visualization, Formal analysis. **M. Croci-Maspoli:** Writing – review & editing, Supervision, Conceptualization. **A.M. Hama:** Writing – review & editing, Supervision, Conceptualization. **R. Knutti:** Writing – review & editing, Supervision, Conceptualization. **S. Kotlarski:** Writing – review & editing, Supervision, Conceptualization, Methodology, Data curation, Formal analysis, Validation, Visualization. **C. Schär:** Writing – review & editing, Supervision, Conceptualization. **C. Schnadt Poberaj:** Writing – review & editing, Supervision, Conceptualization. **N. Ban:** Writing – review & editing, Formal analysis, Validation. **M. Bavay:** Writing – review & editing, Formal analysis. **U. Beyerle:** Data curation, Software, Writing – review & editing. **D.N. Bresch:** Writing – review & editing, Methodology. **S. Brönnimann:** Writing – review & editing, Formal analysis. **P. Burlando:** Writing – review & editing. **A. Casanueva:** Writing – review & editing, Formal analysis, Validation. **S. Fatichi:** Writing – review & editing, Formal analysis. **I. Feigenwinter:** Writing – review & editing, Data curation, Formal analysis, Validation. **E.M. Fischer:** Writing – review & editing, Methodology, Formal analysis, Validation, Visualization. **M. Hirschi:** Writing – review & editing, Formal analysis. **M.A. Liniger:** Writing – review & editing, Supervision, Conceptualization. **C. Marty:** Writing – review & editing, Formal analysis. **I. Medhaug:** Writing – review & editing, Formal analysis. **N. Peleg:** Writing – review & editing, Formal analysis. **M. Pickl:** Software, Writing – review & editing, Formal analysis, Validation, Visualization. **C.C. Raible:** Writing – review & editing, Methodology. **J. Rajczak:** Writing – review & editing, Methodology, Formal analysis, Validation, Data curation, Visualization. **O. Rössler:** Writing – review & editing, Formal analysis. **S.C. Scherrer:** Writing – review & editing, Methodology, Formal analysis, Validation. **C. Schwierz:** Writing – review & editing, Supervision, Conceptualization. **S.I. Seneviratne:** Writing – review & editing. **M. Skelton:** Writing – review & editing, Formal analysis. **S.L. Sørland:** Writing – review & editing, Methodology, Formal analysis, Validation, Visualization. **C. Spirig:** Writing – review & editing, Data curation, Software, Visualization. **F. Tschurr:** Writing – review & editing, Data curation, Software, Visualization. **J. Zeder:** Writing – review & editing, Data curation, Software. **E.M. Zubler:** Project administration, Data curation, Software, Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2022.100288.

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