Advanced Review

Climate change in Switzerland: a review of physical, institutional, and political aspects

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Climate change is clearly discernible in observed climate records in Switzerland. It impacts on natural systems, ecosystems, and economic sectors such as agriculture, tourism, and energy, and it affects Swiss livelihood in various ways. The observed and projected changes call for a response from the political system, which in Switzerland is characterized by federalism and direct democratic instruments. Swiss climate science embraces natural and social sciences and builds on institutionalized links between researchers, public, and private stakeholders. In this article, we review the physical, institutional, and political aspects of climate change in Switzerland. We show how the current state of Swiss climate science and policy developed over the past 20 years in the context of international developments and national responses. Specific to Switzerland is its topographic setting with mountain regions and lowlands on both sides of the Alpine ridge, which makes climate change clearly apparent and for some aspects (tourist sector, hydropower, and extreme events) highly relevant and better perceivable (e.g., retreating glaciers). Not surprisingly the Alpine region is of central interest in Swiss climate change studies.

How to cite this article:
WIREs Clim Change 2014, 5:461–481. doi: 10.1002/wcc.280

INTRODUCTION

The annual mean air temperature in Switzerland has increased by 1.75°C between 1864 and 2012 and is projected to rise more strongly until the end of the century, accompanied by changes in other variables such as precipitation, snow cover, and runoff. What does climate change mean for Switzerland and how does Switzerland deal with it? In this paper we review published literature concerned with observed and projected climatic changes in Switzerland, their impacts, policy and politics of climate change, and

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Conflict of interest: The authors have declared no conflicts of interest for this article.

the public perception. We discuss physical, political, and institutional aspects of climate change and show that climate change in all its facets affects livelihood in Switzerland: Impacts (e.g., on the water cycle, cryosphere, and biodiversity) are discernible and are projected to continue or aggravate. The political system addresses climate change issues by developing strategies and measures for both mitigation and adaptation and by engaging in the international process. Science addresses climate change, and expertise has been built up during the last two decades. Causes and consequences of climatic changes are discussed in the media and are a source of concern to many.

A specifically Swiss viewpoint emerges from its geographic setting as an Alpine country, its standing as a country with high income, education level, and living standard, and its political system which is characterized by federalism and direct democratic instruments. In the following we briefly introduce these aspects as a background of the remainder of the paper.

Climatography, Economy, and Policy

Although a small country, Switzerland encompasses a variety of climates mainly due to the Alps (Figure 1). This arc-shaped, west–east oriented mountain chain leads to large spatial gradients in climate variables.[1,2] The Alps provide a barrier between the temperate European climate and the Mediterranean climate. Typical mountain effects such as Föhn or inner-alpine dry valleys add to the diversity of Alpine climate. The Swiss identity is strongly shaped by the Alps, and Alpine climates are part of it.[3] The orography promotes weather and climate-related hazards such as heavy precipitation or weather-induced gravitational processes. As a consequence, the Alps are often considered particularly vulnerable to climate change (with melting glaciers as an iconic example) and thus are seen as a key region for studying global change[3] and sustainable development.[a] The Alpine focus stood at the beginning of the Swiss climate change research programs in the 1990s (see Box 1) NRP31 'Climatic Changes and Natural Hazards' (1992–1997) and CLEAR ('Climate and Environment in the Alpine Region', 1997–2000).

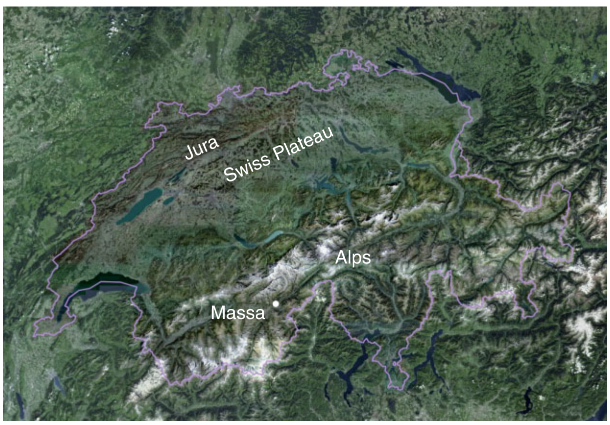

FIGURE 1 | Switzerland is characterized by its variety of landscapes, comprising the Jura Mountains in the northwest, the Alps, and in between the densely populated Swiss Plateau. Massa denotes the runoff measurement station used in Figure 6. (Satellite Image: © CNES/Spot Image/swisstopo, NPOC).

BOX 1

MAIN NATIONAL CLIMATE RESEARCH PROGRAMS FUNDED BY THE SWISS NATIONAL SCIENCE FOUNDATION

National Research Project NRP31 'Climatic Changes and Natural Hazards' (1992–1997)

Swiss Environmental Priority Programme, specifically subproject 'Climate and Environment in the Alpine Region' CLEAR (1997–2000)

National Competence Centre for Research (NCCR) in Climate (2001–2013)

INITIATIVES OF THE SWISS SCIENTIFIC COMMUNITY

Climate Change and Switzerland 2050—Impacts on Environment, Society, and Economy (CH2050)[4] (2007)

Swiss Climate Change Scenarios—CH2011[5] (2011)

Toward Quantitative Scenarios of Climate Change Impacts in Switzerland —CH2014-Impacts[6] (2014)

The majority of the Swiss population does not live in the Alps, though, but in lowland cities and suburbs. Here, other climatic aspects might become important, including heatwaves and droughts, storms and floods, and peaks of air pollution. As a consequence, a range of climatic factors are relevant for Switzerland.

The implications of climate change depend on a country's vulnerability, which is mitigated by its adaptive capacity. Switzerland has a high per capita income and is economically stable. Services are of particular importance in terms of income, whereas agriculture is the dominant land use type by area and produces the typical landscape. Several politically or economically important sectors such as tourism, energy (hydropower as well as river-cooled nuclear power), insurance, and agriculture may be vulnerable to climate change, as are Alpine traffic lines and other infrastructures. Climate change also affects natural systems. Switzerland thus faces a diverse set of challenges.

Vulnerability and adaptive capacity also depend on social infrastructure and governance.[7] The Swiss political system relies on direct democracy. Switzerland has a federalist structure with 26 cantons. Although climate policy is mainly dealt with at the national level, cantons and even municipalities play an important role (e.g., in land use planning). According to the OECD Better Life Index, Switzerland has a high life quality (employment rate, life satisfaction, income), and the education level is generally high.[8]

Since the 1970s and 1980s, environmental concerns have been on the political agenda in Switzerland. Following debates on nuclear power, industrial waste, chemical hazards, and air pollution, climate change became a topic of interest in the 1990s. The past two decades, which form a special focus of this paper, have been instrumental in shaping todays' situation of Switzerland with respect to climate change science, policy, and links to the public.

Structure of the Paper

Climate change in Switzerland is well covered in the peer-reviewed literature. In addition, a number of national reports on specific aspects have been produced, some of which are not peer-reviewed or only available in German, but nevertheless important and hence reviewed here. The paper is organized as follows. We first give an overview of Swiss science and relevant institutions (see Table 1). The next three sections—on observed climate change, scenarios, and impacts—each summarizes first the institutional and historical aspects, then the science. Further sections discuss Swiss greenhouse gas emissions and climate policy and, finally, the public perception of climate change.

SWISS CLIMATE SCIENCE

This section reviews the role of Swiss institutions in climate research[b] and climate research education at University level, the funding structure for fundamental and applied climate research, Swiss climate research profile and output, and participation and leadership in national and international networks.

Climate Research Institutions

The principal carriers of academic climate research are the cantonal Universities (Bern, Zurich, Basel, Geneva, and Fribourg), the two Federal Institutes of Technology (ETH Zurich and EPF Lausanne), and Federal Research Institutes and Agencies such as the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss), the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the Paul Scherrer Institute (PSI), and institutes for aquatic research (EAWAG), agriculture (Agroscope), and materials testing and research (EMPA) (see Table 1). Two important Swiss centers for climate research are the 'Oeschger Centre for Climate Change Research' (OCCR) at the University of Bern and the 'Center for Climate Systems Modeling' (C2SM) at ETH Zürich (with partners MeteoSwiss, EMPA, WSL, and Agroscope). The University of Bern and ETH Zürich offer specialized MSc and PhD programs in climate sciences.

C2SM puts its focus on '*the development and application of climate models operating at various scales to improve our capability to understand and predict the Earth's climate, including its weather systems, chemical composition, and hydrological cycle*' (http://www.c2sm.ethz.ch). The Oeschger Center is broader in its scope, by combining modeling and observations in the areas of global and regional climate dynamics, climate risks and impacts, social sciences, climate economics and policy, and international law (http://www.oeschger.unibe.ch). In addition, the two Federal Institutes of Technology also run a 'Competence Centre for Environment and Sustainability (CCES)', which covers climate aspects.

Swiss climate research is mainly carried out through research initiatives at the level of individual research groups. In addition, Switzerland had several large research programs in the area of climate research. There is typically one at a time (see Box 1). The largest program was the Swiss National Centre of Excellence in Research on Climate (NCCR Climate), a collaborative 12-year long (2001–2013) multi-institutional interdisciplinary program addressing 'Climate Variability, Predictability, and Climate Risks'.[9] The NCCR Climate research network consisted of over 130 scientists from eight institutions and it formed an internationally competitive community in Switzerland. The leading house was located at the University of Bern.

In addition to climate-centered programs, other national research programs (such as NRP61 'Sustainable Water Management') also have strong climate aspects.

Funding Structure

The main extramural funding sources (i.e., aside direct University or ETH funding) for fundamental

TABLE 1 | Acronyms of Swiss Institutions

Agroscope	Research Institute of the Federal Office for Agriculture
C2SM	Centre for Climate Systems Modelling
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
EMPA	Swiss Federal Laboratory for Materials Testing and Research
FOEN	Federal Office of the Environment
MeteoSwiss	Federal Office for Meteorology and Climatology
OcCC	Organe consultatif sur les Changements Climatique (Advisory Body on Climate Change for the Swiss Government)
OCCR	Oeschger Centre for Climate Change Research
ProClim	Forum for Climate and Global Change of the Swiss Academy of Sciences
PSI	Paul Scherrer Institute
SNSF	Swiss National Science Foundation
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research

and applied research are the Swiss National Science Foundation (SNSF), oriented research initiated by Federal Agencies and Offices (Environment, Energy, Public Health, Agriculture, among others) and the Private Sector. For instance, the Swiss reinsurance company Swiss Re was the main industry partner of the NCCR Climate, and the Swiss Mobiliar Insurance Cooperation provides funding for a Chair in 'Climate Risks and Impacts' at the University of Bern.

EU research programs (FPs, ERC, COST, among others) have been particularly important for Swiss climate research. Since the start of FP3 in the early 1990s, Switzerland has participated in dozens of climate-related projects. ETH Zurich hosts the Swiss Climate-KIC offices. Climate-KIC is one of three Knowledge and Innovation Communities (KICs) created in 2010 by the European Institute of Innovation and Technology (EIT) and addresses climate change mitigation and adaptation.

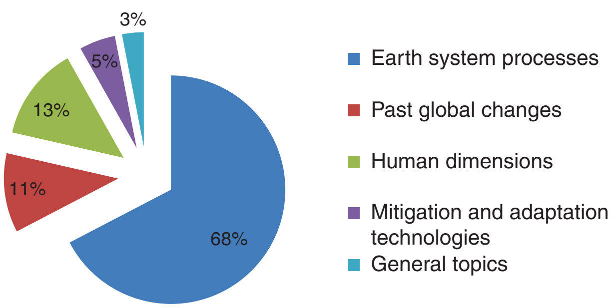

FIGURE 2 | Percentage of scientific papers published by Swiss scientists in areas related to climate change. (Source: ProClim)

Research Profile and Output

The Swiss climate research output is regularly summarized in the 'Global Change Abstracts: The Swiss Contribution (GCA)', a compendium of abstracts of papers on the topic of global climate and environmental change (http://www.proclim.ch/). In this collection, the subset 'Climate change' comprises nearly 1500 ISI indexed papers written or coauthored by Swiss scientists annually (data 2011), of which about 66% are published in the field of climate change-related earth system processes (including atmospheric sciences), 11% in past global changes (PGS), 13% in human dimensions of climate change, 5% in mitigation and adaptation technologies, and 3% in general topics of climate change (see Figure 2). This partitioning reflects the scientific profile, the structure and major topics of the scientific community in Switzerland.

National and International Research Network, Leadership

A national academic network and platform for knowledge exchange with stakeholders is provided by ProClim, the Forum for Climate and Global Change of the Swiss Academy of Sciences founded in 1988. ProClim acts as the interface between academia, public administration, politics, the private sector, and the public. In 1996, the Federal council founded the 'Organe consultatif sur les Changements Climatiques' (OcCC; Advisory Body on Climate Change) for the Swiss Government.

The federal administration [State Secretary of Research and Innovation, Federal Office of the Environment (FOEN), MeteoSwiss, among others] liaise with international governmental organizations such as the World Meteorological Organisation (WMO), the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC), and others, while the Swiss Academy of Sciences networks with the nongovernmental research organizations such as the International Council for Science (ICSU) with its global environmental programs (IGBP, WCRP, DIVERSITAS, IHDP). Swiss climate research contributes to international science services and hosts several international project offices, e.g., for 'Past Global Changes' (PAGES, within IGBP), 'Stratospheric Processes and their Role in Climate' (SPARC, within WCRP/WMO), the World Radiation Center (WRC) and others. Swiss scientists were very supportive in the IPCC process from its beginning in 1992 and have expanded their involvement through the present. In IPCC AR5, Switzerland participates with the co-chair of Working Group I, several lead authors, contributing authors, a review editor, and it hosts the Technical Support Unit for IPCC Working Group I at University of Bern.

OBSERVED CLIMATE CHANGE IN SWITZERLAND

Observing Change

The first Swiss meteorological network was established in 1863 and gradually extended to include upper-air measurements (1942), phenology (1951), radiation (1991), and other observing systems. MeteoSwiss is responsible for climate monitoring in Switzerland. Monitoring of other climate variables such as greenhouse gas concentrations, glaciers, and runoff is carried out by other institutions.[10] Switzerland contributes to global climate monitoring that started with the establishment of the Global Climate Observing System (GCOS) in 1992. MeteoSwiss hosts the national GCOS office, and acts as a competence center for Alpine Meteorology and Climatology.[11,10]

The Swiss meteorological surface network was to a good part automatized in 1980. Since 2004, the transition into a new meteorological network referred to as SwissMetNet[12] has been taking place. In the early 1990s, within projects NORM90 and KLIMA90, MeteoSwiss reevaluated and homogenized its climate data. For high quality climatological monitoring (and as Swiss contribution to the GCOS networks), the Swiss National Basic Climatological Network (NBCN) was set up in 2007, and carefully homogenized data, suitable for climatological trend analysis, have become available[13]. At the same time, also other monitoring networks were reviewed and their continuation was ensured.[11] This data were also the base for early climate change studies in Switzerland.[13–17] In the following we review the observed changes in meteorological variables in Switzerland since 1864.

Observed Change

Surface Air Temperature and Freezing Level

Swiss annual surface air temperature has increased by +1.75°C between 1864 and 2012, which corresponds to a linear trend of about +0.12°C per decade (Figure 3). Temperature trends have accelerated substantially for more recent time periods. Annual temperatures have increased by about 0.13–0.20°C per decade (spatial range across the country) over the last 100 years (1913–2012), by 0.34–0.47°C per decade for the last 50 years (1963–2012),[18] and between 0.28 and 0.55°C per decade for the last 30 years (1983–2012). This is roughly two (last 100 years) to three (last 30 years) times the globally averaged temperature trend[19] and is in agreement with the trends in other parts of western and central Europe. In the last 30 years, the trends were largest (highly significant) in spring and summer whereas less pronounced and mostly insignificant in autumn and winter. Since 1961, the zero degree level has risen by 60 m per decade in winter to 75 m per decade in summer.[20]

Precipitation

In the last 100 years (1913–2012), most stations show no significant trends in annual mean precipitation (Figure 4). Precipitation trends are very sensitive to the chosen period. On the seasonal scale, significant increases are found for some stations in winter largely due to an increase in the first half of the record. No significant trends are found for other seasons, and trends are also insignificant or inconclusive during the last 50 years (1963–2012). During the last 30 years (1983–2012), mean precipitation is predominantly decreasing in winter and spring; for a minority of the stations, the trends (−10 to −22% per decade) are significant. Increases are found in summer, although these increases are significant only in the central parts of Switzerland. No clear tendencies are found for autumn. Of large interest are also changes in extreme precipitation. Schmidli and Frei[21] investigated trends of heavy precipitation and wet and dry spells in Switzerland during the 20th century (1901–1999). They found statistically significant increases in heavy precipitation measures in winter and autumn. In spring and summer, the heavy precipitation and the spell-duration statistics did not show significant trends.

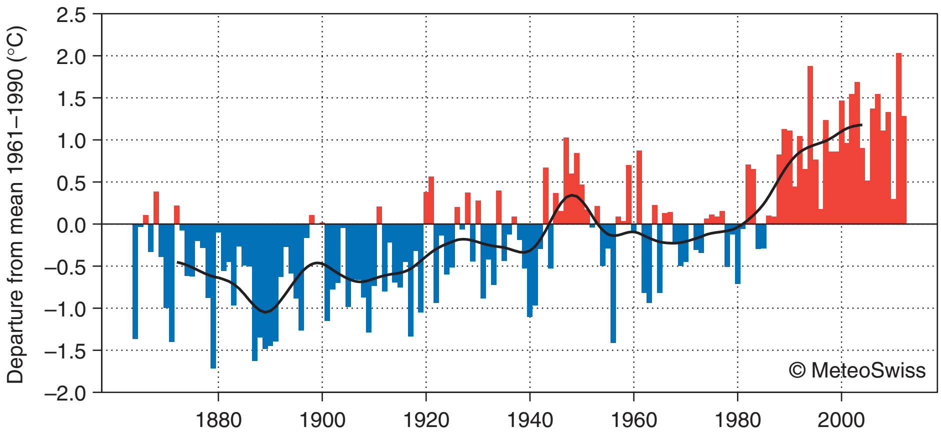

FIGURE 3 | Annual mean temperature anomalies in Switzerland 1864–2012 shown as deviation from the mean of 1961–1990 based on 12 long series of the National Basic Climatological Network (NBCN). Years with positive anomalies (warmer) are shown in red and those with negative anomalies (cooler) in blue. The black line shows 20-year Gaussian low pass filtered data.

Snow Cover and Glaciers

Swiss snow variability and trends have been analyzed based on remote sensing data back to 1985,[22] and based on station data back to the 1950s,[23] to 1931[24,25] and to 1864.[26] All studies found a decrease of the Alpine snow pack since the mid-1980s especially at low altitudes (<1300 m asl)[24] which was shown to be predominantly linked to an increase in local temperature.[23] There is also a shortening of the snow season at all altitude levels.[27] Scherrer et al.[26] showed that for several snow parameters, the lowest values since the late 19th century were found in the late 1980s and 1990s. In the last 10 years, however, a change toward more days with snow pack at low elevation stations is observed, highlighting the role of decadal variability. Clear decreasing trends in snowfall days relative to precipitation days are found since the 1960s.[28] Marty and Blanchet[29] found in the last 80 years for all altitudes decreases in extreme snow depth. Negative trends are observed for extreme snowfalls at low and high altitudes.

Swiss glaciers have been receding since around 1980. In terms of mass, the current loss rate for a sample of eight Alpine glaciers is estimated as 2–3% per year.[30]

Sunshine Duration and Fog

The evolution of sunshine duration is very similar to the evolution of surface solar radiation, which has been discussed extensively in literature under the terms of solar dimming and brightening.[31] Sanchez-Lorenzo and Wild[32] found that all sky surface solar radiation has been fairly stable with little variations in the first half of the 20th century, unlike the second half of the 20th century that is characterized by a dimming from the 1950s to the 1980s and a

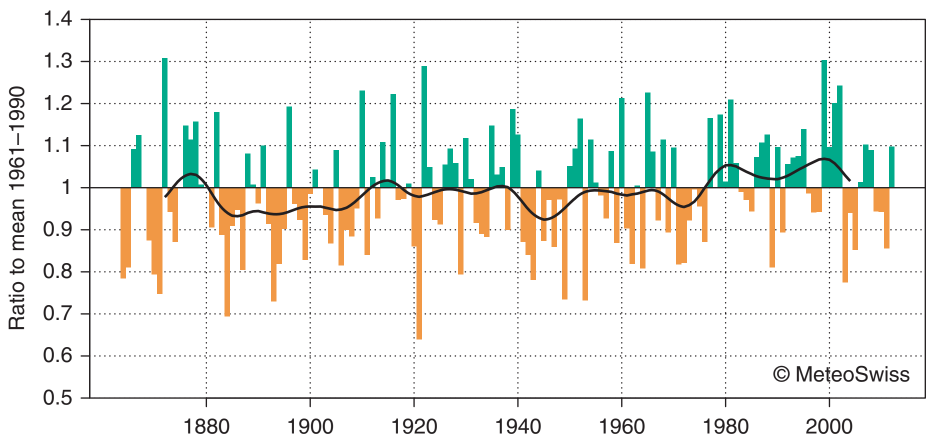

FIGURE 4 | Annual mean precipitation in Switzerland 1864–2012 shown as ratios to the mean of 1961–1990 based on 12 long series of the NBCN. The years with ratios greater than 1 (wetter) are shown in green and those with ratios lower than 1 (dryer) in brown. The black line shows 20-year Gaussian low pass filtered data.

subsequent brightening. This is reflected in sunshine duration, which has increased by roughly 250–400 h or almost 20% north of the Alps and by roughly 10% south of the Alps[30] from 1980 to 2011. The number of very sunny days (relative sunshine duration >80%) shows significant increases since the 1980s, whereas the number of very cloudy days (relative sunshine duration <20%) decreases.[30] Scherrer and Appenzeller[33] showed that the decade 1984–1993 was the foggiest and 1999–2008 the least foggy decade since 1901. In the most recent years a return toward the climatological mean could be observed. Measurements of downwelling longwave radiation in Switzerland show a significant increase since the early 1990s.[34]

Heat Waves, Droughts, Winter Storms, Thunder Storms, Hail, and Tornados

Over the period 1880 to 2005, the length of summer heat waves over Western Europe, including Switzerland, has doubled and the frequency of hot days has almost tripled.[35] In terms of standardized anomalies, the heat wave of 2003 was a 5-σ event, while the strongest previous event in 1947 was a 3-σ event.[36] No conclusive statements can be made about strong droughts in Switzerland. For southern Switzerland, Rebetez[37] found increases in moderate droughts during the 20th century. Most Swiss stations show an increase in the maximum number of consecutive days without precipitation; however, the trend is not statistically significant.[30] The literature provides no conclusive results about winter storm trends in Europe including Switzerland.[38] Storm damages in Swiss forests increased.[39] Instrumental measurements from Zurich as well as reanalysis data show an increase in extreme winds between the 1950s and the 1990s, but a decrease since.[40–42] For thunder storms, hail, and tornados, evidence for changes is more scant.[4]

Phenology

An increasing number of studies, based on the Swiss observing network since 1951 or satellite data since 1982,[43] show evidence of a shift in plant development toward an earlier onset in spring as a consequence of climate change. Spring and early summer phases are directly influenced by temperature. Averaged over 15 spring pheno-phases, a trend of 1.5 days/decade was observed from 1965 to 2002, with a clear shift in 1988.[44] Series of single spring plants showed trends toward earlier appearance from −1 to −2.8 day/decade, stronger at lowland stations than at sites of higher elevation.[44,45] The correlation with temperature is high, while precipitation does not influence the main phenological pattern.[44,46] No clear trends are seen in autumn. Defila and Clot[47] found a prolongation of the vegetation period of 13.3 days from 1951 to 2000, similar to trends in other European regions.[48]

CLIMATE CHANGE SCENARIOS FOR SWITZERLAND

Producing Climate Scenarios

At the global scale, climate change scenarios have been compiled on a regular basis since 1990, coordinated by the IPCC. Scenarios for Europe, based on regional models nested into global models, have first been prepared by Giorgi et al.[49] In recent years, individual countries have started to develop regionally focused climate scenarios to inform their stakeholders and decision makers, e.g., the United Kingdom in 2002.[50]

In Switzerland, the first climate projections were obtained from statistical[51] or dynamical[52] downscaling of global model results, or from surrogate scenarios obtained with a regional model.[53,54] These early attempts were continued in the aforementioned projects NRP31 and CLEAR[55] (see Box 1), which initiated the creation of a 'Swiss climate community'. This community started to provide information on future climate to users.[56,57]

At about the same time, i.e., in the 1990s, with future climate change becoming a topic of high political and societal relevance, the link between policy makers and science was institutionalized with the foundation of ProClim and OcCC (see Table 1). One of the first reports coordinated by OcCC focused on changes in heavy precipitation and flooding under climate change.[58]

In 2007, the growing Swiss climate research community released a first national climate report under the umbrella of OcCC and ProClim.[5] This comprehensive report included a set of Swiss climate scenarios for the years around 2050,[59,60] also known as 'CH2050 scenarios' or 'CH2007 scenarios' (see Box 1), and a broad, mainly qualitatively described overview of expected impacts on various sectors in Switzerland, such as agriculture, ecosystems, water management, health, energy, tourism, infrastructure, and insurances.

With the experience gained during NCCR Climate and a growing climate science community, a multi-institutional collaboration between C2SM, MeteoSwiss, ETH Zurich, the NCCR Climate, and OcCC (see Table 1, Box 1) led to the development of a new set of Swiss climate scenarios, which were published in the CH2011 report.[4] These Swiss Climate Change Scenarios CH2011 serve as a common, consolidated basis for impact studies in Switzerland. Providing consistent and state-of-the art information required specific analyses and an enhancement of established methods.

The CH2011 Swiss climate scenarios, which are described in the following, rely heavily on results from the large European research project 'ENSEMBLES'[60] and the Fourth Assessment Report of the IPCC.[61] The ENSEMBLES project provided a unique set of regional climate simulations over Europe that allows deriving scenarios in a multi-model approach. In addition, new statistical methods have been developed enabling a better quantification of uncertainties in climate projections and the derivation of probabilistic estimates.[62,63] The CH2011 report was externally reviewed.

The CH2011 projections serve as a common basis for political recommendations and many impact-related studies such as the Swiss climate change adaptation strategy,[64] the CC Hydro project exploring effects of climate change on water resources[65] or the CH2014-Impact initiative. The feedback from applications and users helps to identify knowledge gaps and to develop data sets which match user needs. As a result the scenarios have been extended to include more regional[66] or localized information.[67] A range of studies has also addressed extreme events, among these are heat waves and summer temperature variability,[68,69] heavy precipitation events,[70] and wind storms.[71] Key developments will also be published in a CH2011 extension series. Currently, most of the efforts are still based on voluntary contributions in an academic environment, but with the current international and national activities aiming to strengthen climate services, a more sustainable process may be established.

Swiss Climate Scenarios

The CH2011 projections focus on changes in temperature and precipitation, reflecting the main quantities for which information is available and required by the users. Probabilistic seasonal mean changes are provided using a multi-model approach for three representative regions of Switzerland and for three different future pathways of anthropogenic emissions.[72] In addition, daily mean scenarios are made available both on a regional basis and at individual observational sites by downscaling, mainly to fulfill the needs of impact models that often require high resolution.[73] Expected changes in extremes are discussed based on a comprehensive literature review and on an analysis of climate indices in individual climate models.

The report shows that Swiss climate is projected to depart significantly from present and past conditions in the course of the 21st century (Figure 5). Mean temperature will very likely increase in all regions and seasons. Summer mean precipitation will likely decrease by the end of the century all over Switzerland, while winter precipitation will likely increase in Southern Switzerland. In other regions and seasons, models indicate that mean precipitation could either increase or decrease.

Along with these changes in mean temperature and precipitation, the nature of extreme events is also expected to change. The CH2011 report indicates more frequent, intense, and longer-lasting summer warm spells and heat waves while the number of cold winter days and nights is expected to decrease. Projections of the frequency and intensity of precipitation events are more uncertain, but substantial changes cannot be ruled out. In addition a shift from solid (snow) to liquid (rain) precipitation is expected, which would increase flood risk primarily in the lowlands.

Projection uncertainties were derived using a Bayesian methodology. However, given conceptual limitations of the global and regional climate modeling approach, the CH2011 report refrains from interpreting the projection uncertainties in a probabilistic way. Additionally incorporating expert judgement, a 'lower estimate', 'medium estimate', and 'upper estimate' were defined and displayed with boxes as in Figure 5.

CLIMATE CHANGE IMPACTS

Assessing Climate Change Impacts

Climate change impacts at a global level were assessed in the first IPCC Assessment report in 1990; work that had partly grown out of assessments of atmospheric change (air pollution, ozone loss, UV radiation), but encompassed all aspects of climate impacts. In Switzerland, responses of forests and grasslands to climate change were studied in the 1990s,[74,75] and in several NRP31 (see Box 1) subprojects impacts on various areas such as tourism,[76] agriculture,[77,78] economy,[79] and natural hazards were studied and published in individual reports.

One of the first comprehensive summary reports on climate change impacts in Switzerland was the aforementioned 2007 report 'Climate Change and Switzerland 2050—Impacts on Environment, Society and Economy'[5] (see Box 1). The report targeted a broad audience and adopted a midterm perspective focusing on the year 2050 and a variety of sectors.

Following this report, a number of sectorial reports have been produced (many commissioned by government agencies, reflecting the need for information for policy makers), covering health,[80]

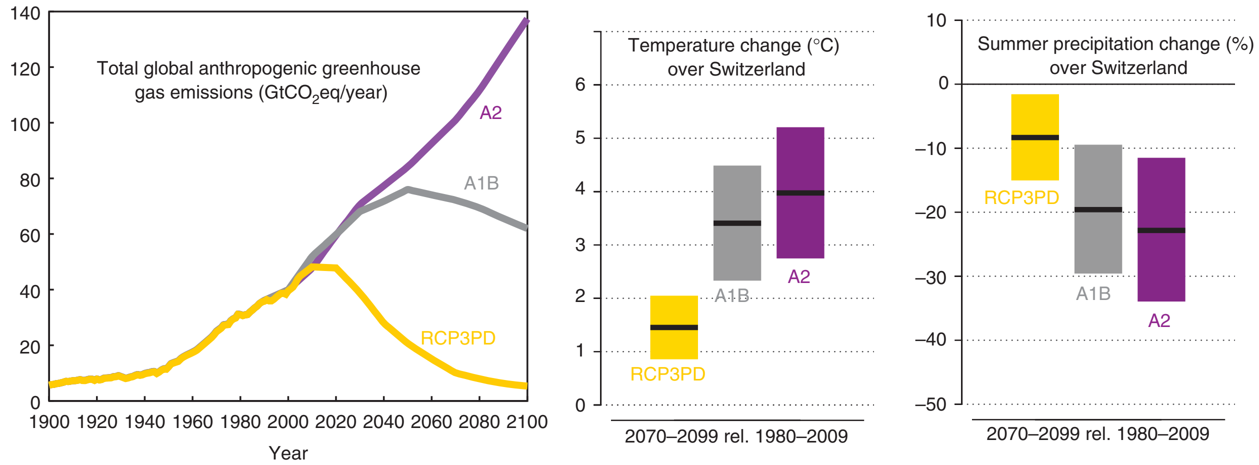

FIGURE 5 | The three pathways of past and future anthropogenic greenhouse gas emissions used in CH2011, along with corresponding projected annual mean warming and summer precipitation change over Switzerland for the 30-year average centered at 2085 (Reprinted with permission from Ref 4. Copyright 2011 C2SM, MeteoSwiss, ETH, NCCR Climate, and OcCC and Reprinted with permission from Ref 6. Copyright 2011 C2SM, MeteoSwiss, ETH, NCCR Climate, and OcCC.)

hydropower,[81] water resources,[65] runoff,[82,83] tourism,[84] and other sectors.

To complement these sectorial reports and the more qualitative assessment of 2007,[5] the Swiss scientific community launched an effort to quantify climate change impacts in a coordinated manner, with a standardized framework, and for the whole of Switzerland. Based on the new climate change scenarios for Switzerland CH2011 (see previous section and Box 1), and with major progress in impact modeling, the community has produced the report 'CH2014-Impacts',[6] which comprises a collection of currently quantifiable impacts with no claim to be comprehensive. CH2014-Impacs deals with climate change impacts on a short-, mid-, and long-term perspective and for three emissions scenarios.

Projected Climate Change Impacts

Climate-induced changes have already become apparent in the last decades. Studies have shown, e.g., the melting of Swiss glaciers since around 1980,[30] trends toward earlier grape harvests,[85] an increase in agricultural area suitable for grapevines,[86] an increase of lowland forest species at mid-elevation,[87] and an upward shift of the occurrence of pine mistletoe and an extension of the fungal fruiting season.[88] In the following we summarize the literature on projected impact for selected sectors (water resources, agriculture, forestry, and tourism), while other topics such as health or natural hazards cannot be covered in this paper.

Impacts on Hydrology

With respect to the hydrological cycle, river runoff regimes are projected to shift from snow-controlled to rain-controlled under climate change[6,65,81] (see also Figure 6). Winter discharge is projected to increase at the expense of decreasing summer discharge.[83] The reason lies in projected changes in the cryosphere, in the precipitation increases (decreases) projected for winter (summer), and in projected changes in evapotranspiration. Large areas are projected to be deglaciated by the end of this 21st century based on the A1B scenario translating to a volume loss of 85–95%.[6] Additionally, multi-day snow cover is projected to become a rare phenomenon in the Swiss plateau, whereas snow depth and duration will be significantly reduced at higher altitudes.[6,89]

With respect to future hydropower generation, a recent report[81] found that the total quantity of water that can be utilized for power generation may increase due to a more equal seasonal distribution of the runoff. On the long term (2085), however, decreasing production is expected for high altitude, glacier-fed catchments. In the lowlands, low-runoff situations may become more common.[65]

Impacts on Agriculture

Projected temperature change and changes in the hydrological cycle also affect vegetation and crops. A moderate increase in temperature may lead to increased yields of maize,[90,91] and grassland productivity may benefit from more favorable temperature and radiation conditions[92,93] and an extended growing season.[6,94,95] However, projections to the end of the 21st century suggest an increase in production risks due to more variable weather.[96,97] This includes drought risks[98] leading in some regions to a higher

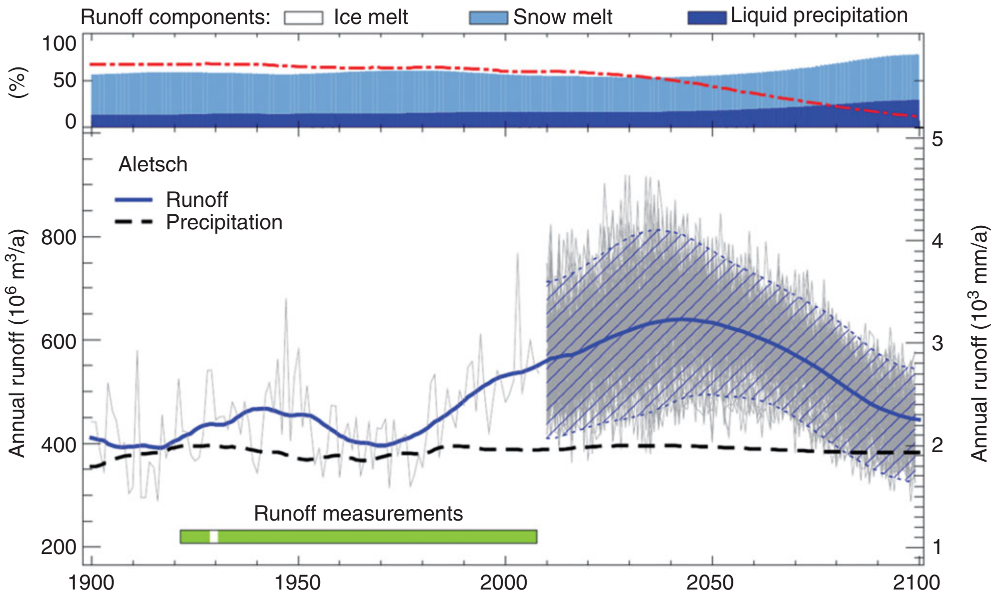

FIGURE 6 | Observed and modeled annual mean runoff at Massa (blue and gray curves) (see Figure 1 for location), a catchment that includes the Aletsch Glacier. The dashed line indicates annual mean precipitation. Top: Contribution of ice melt, snow melt, and rainfall to runoff and fraction of glaciated area (red dashed). (Reprinted with permission from Ref 65, Copyright 2012 FOEN)

water demand that could exceed the limits of surface water availability for irrigation.[95,99] Rising temperature maxima increase the risk of heat stress in livestock.[95,100] Because of more frequent and intense rainfalls during the winter/spring seasons, and due to changes in rainfall erosivity and reduced soil cover,[101] soil erosion risks are likely to increase,[96,102] in particular in northern parts of the Alps.

Impacts on Forests

In Swiss forests, climate change is expected to affect tree species distribution in particular for the two most important tree species of Switzerland, Norway spruce, and European beech. For strong warming (A1B, A2 scenarios) spruce and beech are at risk in large parts of the Plateau region[6] in line with findings for European forest land being suitable only for Mediterranean oak forest type with low economic value and reduced carbon sequestration by 2100.[103] Even a warming of only 2°C was found not to be safe for ecosystem functions in dry regions, while in wetter regions forests may be comparatively resistant to warming.[104]

Impacts on Tourism

Projected reduced snow cover directly impacts the snow-dependent winter tourism[105] which could substantially decrease the number of snow-reliable areas under high emission scenarios.[6] Some of this reduction could be compensated by expanded application of artificial snowmaking, which would, however, require substantial investments and entail costs and nonnegligible environmental impacts.[6,106–108] Müller[84] identifies not only the lack of snow, but also the lack of a 'winter atmosphere', the scarcity of water (for artificial snowmaking), and the possible increase of natural hazards, and adaptation costs (e.g., costs of changing the offer toward less snow-dependent activities) as important factors. When the reduction in snow cover in competing international destinations is taken into account, simulations suggest that Swiss winter tourism could actually increase its revenues.[109,110]

SWISS CLIMATE POLICY

In this section we present the performance of Switzerland in terms of stabilizing its CO_2 emissions and meeting its commitment under the Kyoto Protocol. Next, we present Swiss climate policy and how it was gradually defined in the political process. This section also addresses the adaptation strategy that is being developed and implemented and Switzerland's contribution to international policy making.

Global and Swiss Climate Targets

Switzerland contributed to the drafting of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and ratified it 1993. The UNFCCC calls for a stabilization of 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. Rich countries such as Switzerland are explicitly called upon to contribute to global efforts. Specific targets were set in the 1997 Kyoto Protocol, which Switzerland ratified in June 2003.

With the ratification of the Protocol, Switzerland committed itself to reduce its net emissions of six greenhouse gases by 8% over the period 2008–2012 compared to 1990. This target was copied from that of the European Union. Before ratification of the Kyoto Protocol, a target limited to energy-related CO_2 emissions was set in the CO_2 act of 2000 (10% below the 1990 level in the period 2008–2012). It was assumed that this would be sufficient to meet the 8% Kyoto reduction target for all six greenhouse gases, considering that the former amounted to 80% of the latter.

The targets under the Kyoto Protocol and the CO_2 act are shown as horizontal lines in Figure 7. Based on the latest estimates, the targets for the period 2008–2012 can be met both under the Kyoto Protocol and the CO_2 act. Under the Kyoto Protocol, the use of flexible mechanisms contributes substantially to meeting the targets. Afforestation and forest management are estimated to contribute 1.7 million tons of CO_2 per year. The use of certified emission reductions (CERs) will contribute another 2.8–3.0 million tons of CO_2 per year.

For the Post-Kyoto period, despite disappointing results in the international arena, the Parliament approved a revised CO_2 act that entered into force in 2013 and sets a Kyoto-type target for overall greenhouse gas emissions 20% below the 1990 level in 2020 (square in Figure 7). The act has a provision that this target could be tightened by the government to a maximum of 40% in the context of an international agreement. Like the earlier act, the revised act requires as a general rule that the emissions mitigation takes place within Switzerland, yet it allows for 'appropriate' recognition of abatement obtained abroad.

The overall target was broken up into three sectorial intermediate targets for 2015: −22% in the buildings sector, −7% in the industry sector and stabilization at the 1990-level for the transportation sector. All these targets imply actual reductions relative to the current and to the predicted business-as-usual levels.

Based on various simulations, Switzerland can pursue an ambitious reduction target with moderate costs for the economy.[111–119] Even the concurrent phase out of nuclear power does not alter this result.[120,121] The Swiss government decided in May 2011, after the Fukushima accident, that the existing nuclear power plants will not be replaced when they reach the end of their service life. The level of electricity supply is to be assured through increased energy efficiency and the expansion of hydropower and new renewables. Only if this proves insufficient, fossil-fuel-based electricity production and imports will be expanded. In that case, all additional CO_2 emissions will have to be compensated.

Swiss Greenhouse Gas Emissions

Switzerland belongs to the countries with the best environmental indicators in the OECD, including greenhouse gas emissions. It contributed 0.17% of world CO_2 emissions in 2000. Its 5.3 tons of CO_2 emissions per inhabitant per year (6.3 tons of CO_2 eq.) is only half the OECD average (12.2 tons), but above the world average of 4 tons of CO_2. Relative to GDP, Switzerland emitted 0.26 tons CO_2/1000 USD compared to an OECD average of 0.74. Note, however, that if emissions abroad related to Swiss consumption are taken into account, Swiss emissions are comparable to those of other Western European countries. The total primary energy supply per Swiss inhabitant is 3.4 t crude oil equivalent, which is below that of other Western European countries, but almost twice the global average.

An inventory of Swiss CO_2 and greenhouse gas emissions exists for the period 1990–2011 (Figure 7), but depending on the political framework (see next subsection), different metrics are used. Under the Kyoto Protocol, all CO_2 emissions as well as emissions of other greenhouse gases are accounted for (Figure 7, red curves), while under the national CO_2 act (2000–2012), only energy-related CO_2 emissions are taken into account (e.g., excluding emissions from refineries, waste and incineration, geogenic emissions from cement production, and others), and they are corrected for interannual temperature variability due to the large contribution of room heating (blue curve in Figure 7). Around 80% of the Swiss greenhouse gas emissions are energy-related CO_2 emissions (ca 75% of Swiss energy consumption is from fossil fuels).

Instruments of Swiss Climate Mitigation Policy

Switzerland addresses its mitigation target with a combination of measures in various areas. The main foundations are the federal act on the reduction of CO_2 emissions ('CO_2 act') of 2000 and the federal energy act of 1998. The CO_2 act relied in a first phase on voluntary efforts, to be complemented, if insufficient, by a CO_2 tax. The energy act called for extensive collaboration with the private sector to promote both energy efficiency and renewable energy. In addition, Switzerland relied on various existing policies and

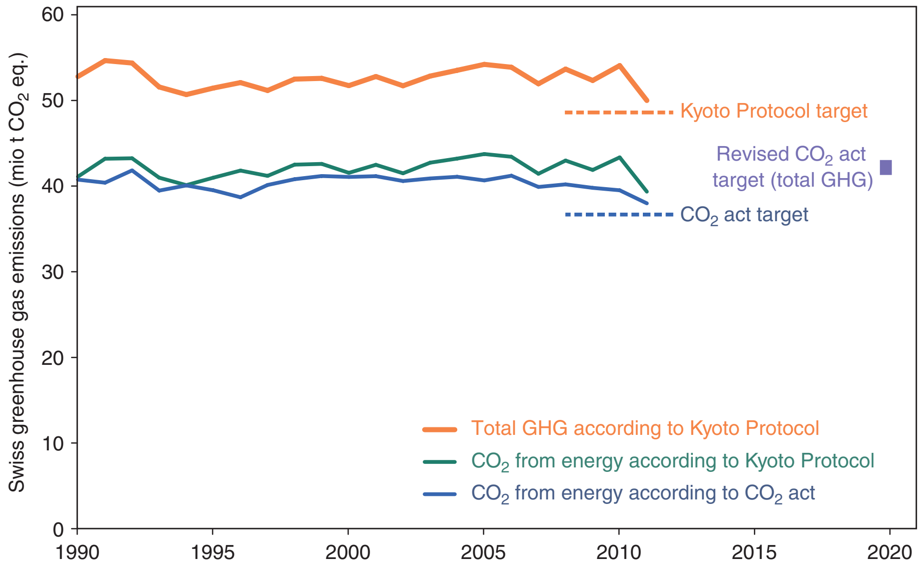

FIGURE 7 | Swiss greenhouse gas emissions since 1990 according to the Kyoto Protocol and the CO_2 act. Targets are indicated with dashed lines.

measures that have a direct or indirect impact on GHG emissions to meet its emissions targets.[122] They concern energy, agriculture, forestry, transportation, and environmental protection and use a mix of economic instruments, regulation, public investments, and voluntary approaches. Economic instruments encompass subsidies for energy conservation, particularly in buildings, the development of renewable energy sources, and the reduction of intensive agriculture. Taxes on gasoline, which have a revenue purpose, increase its price at the pump by about 50–60%, and a new incentive tax was introduced in 2001 on heavy goods vehicles. Regulation is widespread in energy production and consumption, both in the form of technical prescriptions and emission limits. Legislation limits the reduction of forest size since 1876 (the ratification of the forestry law). Finally, the promotion of hydro- and nuclear power (the latter until the end of nuclear power plant service life) and of public transportation also contributes to lower the CO_2 intensity of the Swiss economy.

However, the voluntary efforts plus complementary measures could not possibly meet the target without the tax.[123] This was predicted by several simulations of the development of the Swiss economy and its energy use, some commissioned by the Federal administration.[124–128] It was therefore necessary to prepare the second phase of the CO_2 act with the CO_2 tax. To avoid the tax on motor fuels, the Swiss Petrol Union launched a 'climate penny' (or 'climate cent') proposal.[129] Under this proposal, a contribution of 0.015 CHF (ca 0.015 USD) would be levied on every litre of gasoline and diesel to feed a fund that would buy carbon reduction certificates abroad and, in Switzerland, subsidise energy conservation and substitution.

This proposal marked a turn in Swiss climate policy and reanimated discussions about the introduction of different CO_2 instruments. As earlier studies on Swiss climate mitigation policy showed,[130,131] an important reorganization of actors in the policy process took place: Between the first phase of voluntary measures (1995–2000) and the second phase where new instruments (e.g., tax and climate penny) were negotiated (2002–2008), political parties, industry and transport representatives changed positions and strategies. The voluntary agreements were no longer a sufficient solution; the actors had to decide between supporting the tax or the climate penny.

A deadlock between a 'pro-environment coalition' and a 'pro-economy coalition'[132] was broken through two 'policy brokers'—a Federal agency and a center-right party.[133] They proposed the CO_2 tax only on heating and process fuels and the climate penny on motor fuels. The latter was introduced in October 2005 by a private organization independent from the Federal administration. The CO_2 tax on heating and process fuels was only introduced in January 2008. It took the Parliament almost four years to agree on its rate and modalities.

The tax was initially set to 12 CHF/tCO_2 (ca 12 USD/tCO_2) and raised to 36 CHF (ca 36 USD/tCO_2) in 2010. Large emitters and energy-intensive firms could be exempted, provided that they committed to reduce their emissions by an equivalent amount. This opportunity was grasped by more than one third of the

Swiss economy. Gradually their commitments were transformed into registered emissions rights, which are tradable among concerned firms. The CO_2 act of 2000 stated that the revenues of the CO_2 tax were to be fully redistributed to the population and economic sectors. The Parliament decided to reserve a large share for subsidies to energy refurbishments of buildings.

The revised CO_2 act of 2013 prolongs the CO_2 tax on heating fuels, first at the level of 36 CHF/tCO_2, then rose to 60 CHF/tCO_2 (ca. 60 USD/tCO_2) in 2014, with a third of its revenues to be channelled into the promotion of energy conservation in buildings. As to the transport sector, the two coalitions again were in opposition concerning the reduction target (less so concerning the instruments[130]). The government finally decided that motor fuel importers must compensate 5–40% of the implied CO_2 and a binding CO_2 target is introduced fleet-wise for new cars (130gCO_2/km by 2015).[134] Large industrial emitters are granted emissions rights that should become tradable on the EU-Emissions Trading System in the near future.

Adaptation

The IPCC Fourth Assessment Report[61] established that despite the efforts being made by the international community to mitigate the increase of atmospheric greenhouse gas concentrations, climate change cannot be avoided but merely reduced. This result made many industrialized countries investigate climate change impacts, some with considerable investments in data collection and modeling, and develop their own adaptation strategy. As shown above the Swiss scientific community is improving its understanding of climate change impacts in Switzerland. The improved understanding allows an assessment of climate change impacts, though mostly qualitative, as potentially sizable. The insights of an earlier assessment[5] made the Federal Council include adaptation to climate change as a complementary second pillar next to mitigation in the revised CO_2 act.[134] Article 8 of the act mandates the federal government (1) to 'coordinate measures to mitigate and cope with damages to people and assets which could occur due to increased greenhouse concentrations' and (2) 'to arrange for the development and provision of fundamentals needed to implement such measures'.

For the implementation of Article 8 the Federal Council is developing an adaptation strategy, the first part of which was adopted in 2012.[135] Key elements of the first part of the Swiss adaptation strategy are (1) general objectives and principles, (2) sectorial strategies for those sectors most affected by climate change in Switzerland and (3) a discussion of the most significant challenges Switzerland is facing in adapting to climate change.

In the second part of the adaptation strategy (to be adopted in spring 2014), adaptation measures are presented and coordinated in a joint action plan. As key elements, the action plan contains a summary of the Federal Administrations measures to achieve the sectorial adaptation goals as defined in the first part of the strategy and an outline of coordinated approaches to tackle the cross-sectorial challenges.

At this stage, the strategy is still mainly qualitative, without a strong scientific base for setting priorities. To address this deficiency, the FOEN (Federal Office for the Environment) is conducting a nation-wide analysis of climate change induced risks and opportunities (to be completed in 2016).

Participation in International Negotiations

In international climate negotiations and since the late 1990s, Switzerland adopted the position of a nonaligned country.[136] As a non-EU member state, it developed strategies to gain access to the highest levels of negotiation by weaving partnerships with groups of very heterogeneous states. In 1999 for instance, Switzerland participated within the UNFCCC in the creation of the Environmental Integrity Group (EIG) with Mexico, South Korea, Monaco and Lichtenstein. None of the EIG member belongs to any of the four key blocks in climate negotiation (G77, China, USA, and EU). Concerning mitigation issues, the position of Switzerland is close to that of the EU. The country supports the 2° target and aims at reducing its emissions by 20% by 2020 (relative to 1990).

Since 2006 and the UNFCCC Conference in Nairobi, the mandate of the Swiss government includes the proposition of a global CO_2 levy designed to provide the means to fund adaptation in developing countries. Also in 2013, at the COP19 in Warsaw, Switzerland reconfirmed this position by promoting the Green Climate Fund, emphasizing that transparent financing mechanisms and the inclusion of a large number of donors would be necessary.[137] Thus, more strongly than in its domestic climate policy, Switzerland aims at the introduction of incentives and financing mechanisms and the commitment of the private sector to promoting international adaptation instruments.

PUBLIC PERCEPTION OF CLIMATE CHANGE IN SWITZERLAND

Institutions operating observing systems report climate change and science informs us about the causes.

However, the public perception of climate change does not correspond directly to the observed changes and their explanations. This has been a matter of research internationally during the past years. Obviously, media coverage and interpersonal communication matter[138]; hence, the media themselves play a role[139] as well as the means of communication, e.g., through visualisation.[140] Further, personal factors matter. The public perception of climate change is related to personal experience, knowledge, education, and trust in societal actors such as administrative agencies and scientific institutions.[141] Expectations have also been shown to affect perception of climate change.[142] In this Section we review studies on climate change perception in Switzerland.

Climate Change Perception, Environmental Concern, and Knowledge

Surveys on public perception of climate change in European countries (including Switzerland) show that climate change is perceived by most respondents as real and partly man-made. Many feel that their personal comfort will be at risk.[141,143,144] The public perception of climate change is related to the level of environmental concern, which increases with the level of education.[145] According to surveys, Switzerland exhibits a very high level of environmental concern in an international comparison, though unchanged since the 1990s.[145]

However, the same studies also show that a high level of environmental values does not preclude misconception with respect to climate change,[141] and this is also found for Switzerland, despite an increase in people's knowledge related to CO_2.[143] Climate change is not necessarily perceived by the European public as a domestic issue[141] and the same was found for Switzerland (e.g., farmers were more concerned about the consequences in southern countries than in Switzerland[146]).

Media coverage on climate change in Switzerland is not well studied. Studer[147] analyzed the coverage of the four IPCC Assessment Reports in newspapers from the German and French-speaking parts of Switzerland. The newspapers focused on attribution, model projections, and impacts on specific regions (Switzerland, Africa, coastal regions). In addition, topics such as uncertainties or the relation between science, politics, and the public were raised. Newspapers from the German speaking part of Switzerland followed more closely the wording of the IPCC reports and reported more often on natural sciences or the science-policy interface, while the French-language newspapers chose a simpler language and reported more often on economical and political aspects.

FIGURE 8 | Stamp visualizing temperature change and retreating glaciers in Switzerland, issued 2009 (© Die Post).

Perception of Retreating Glaciers and Extreme Events

Most respondents in a recent global survey[144] indicated that they have personally experienced climate change and this is an important factor in the perception of the problem.[141] Climate change in a narrow sense (a change in temperature or precipitation over a 30-year period) can hardly be perceived sensually, but only indirectly through phenomena which the individual relates to climate change, such as shifting seasons, retreating glaciers, or an extreme weather event.

For Switzerland, retreating glaciers play a special role, as glaciers are part of the Swiss identity. It is thus interesting to briefly discuss the perception of glacier changes and specifically their visualization in the course of time (see also Figure 8). For agricultural communities in the Swiss Alps, growing glaciers were primarily a threat. In the early 19th century, glaciers were 'discovered' as beautiful landscape elements by early travellers and became a motif in protoromantic and romantic paintings.[148] In the late 19th century, the ice age theory, which revived age-old fears of an eternal winter, made glaciers a symbol of climate change.[149] Glaciers and palm trees combined in one scenery were used in the early 20th century to illustrate ice ages and climate change, and in the late 20th century to illustrate global warming. The same motif was used in tourist advertisement since the late 19th century—and today—to illustrate the diversity of the Alpine landscape.[149]

Today, palm trees ragged by strong winds illustrate changes in extremes, and pairs of glacier photos (then and now) stand for relentless warming (e.g., in the movie 'An Inconvenient Truth'). A climate change iconography developed.[140] Although clearly a consequence of climate change, retreating glaciers are also a pictorial symbol with a long and changing history, which might affect current perception.

Similarly, experienced extremes or disasters are often perceived as signs of climate change. Particularly, the heat wave of 2003 had a large impact on public perception of climate change in Switzerland. As the human lifespan is too short to perceive changes in very rare events, perceived extremes need to be confronted with a societal memory[150] or scientific interpretation. In Switzerland, natural disasters were frequent in the 19th century, but the traditional disaster memory was largely lost during the 1910s to 1970s period, when only few natural disasters occurred (termed 'disaster gap'[151]). Today, natural disasters are often depicted in the media as related to climate change (e.g., a land slide in Brienz, Switzerland, in 'An Inconvenient Truth') even if they are not, highlighting the difficulty of perceiving climate change through experienced extremes.

CONCLUSION

Similar to most other western European countries, Switzerland has experienced a pronounced temperature increase during the past century. The annual mean air temperature has increased by 1.75°C over the past 150 years. Temperature is projected to rise even faster until the end of the century, depending on the emission scenario, accompanied by changes in other variables such as precipitation, snow cover, and runoff.

So, what does climate change mean for Switzerland? Impacts of climate change have been observed in the cryosphere, biodiversity, and other areas. For the future, runoff regimes are projected to shift from snow-controlled to rain-controlled, agriculture will face increased heat stress for livestock, and tree species distribution will change. The tourist industry will have to cope with shorter ski seasons and the urban population will be exposed to more heat days, to name just a few of the expected impacts.

How does Switzerland deal with climate change? The topic of climate change is well rooted in political and public discussions in Switzerland. Swiss climate policy has long relied on mitigation and specifically on voluntary measures, which are supplemented by a CO_2 tax on some fuel categories. The Federal Government has recently acknowledged adaptation as a second pillar next to mitigation and is in process of establishing an adaptation strategy. There is an internationally well-embedded scientific community, which during the recent years has produced a consistent set of climate scenarios and a quantitative although not comprehensive climate change impact report based on these.

This current situation is the product of a development that started 20 years ago, as is shown in this review. Climate change became a topic of public concern in Switzerland in the early 1990s. Through a sequence of national research programs, Swiss climate research has built up significant expertise since that time, formed a community, and an institutionalized interface between science, the public, policy makers, and private stakeholders developed. During the same period, a Swiss climate policy emerged and was gradually defined in the political process.

While Switzerland shares many facets of climate change, climate change science and the public discourse with other Western European countries, a specifically Swiss aspect is its Alpine setting. The Alps make climate change more apparent and for some aspects (tourist sector, hydropower, and extreme events) particularly relevant and perceivable (e.g., retreating glaciers). Not surprisingly the Alpine region is of central interest in Swiss climate change studies.

NOTES

[a]At the 1992 Rio Conference, Switzerland was instrumental in inserting the Chapter 'Sustainable Mountain Development' into Agenda 21.

[b]Climate change is understood in a broad sense encompassing atmospheric and planetary research, climate system science, climate impacts on natural and managed ecosystems, and human dimensions of climate change.

ACKNOWLEDGMENTS

The authors wish to thank Céline Dizerens for her support in formatting the manuscript.

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