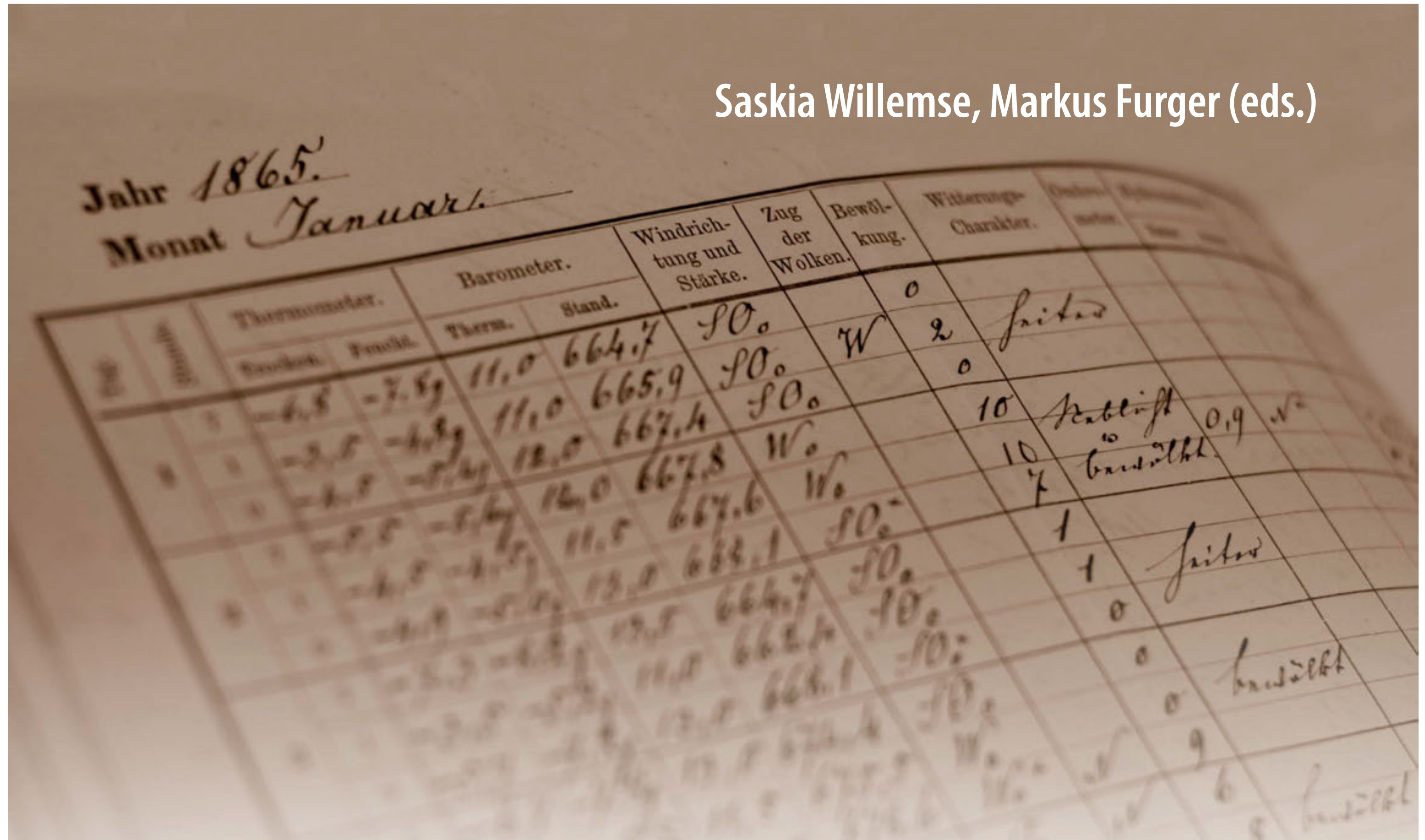

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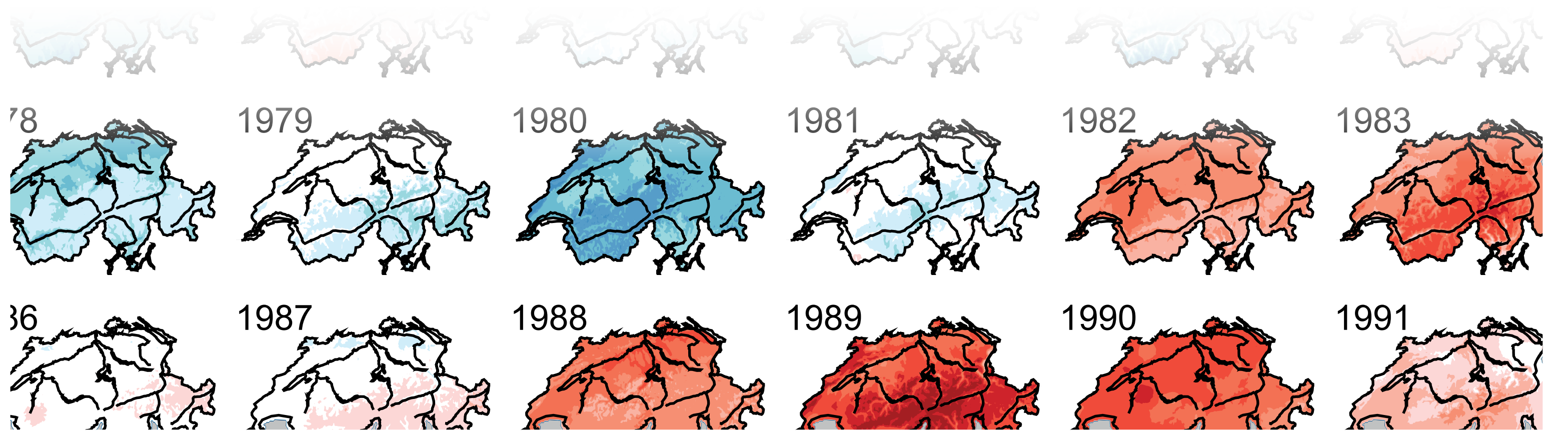


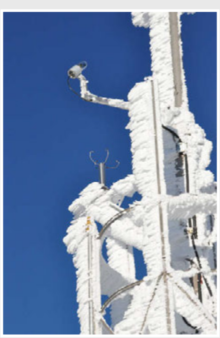


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A book of the Swiss Society for Meteorology

Sponsored by
Federal Office of Meteorology and Climatology MeteoSwiss
Swiss Academy of Sciences

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Cover images

The Swiss maps show gridded annual temperature anomalies with respect to the period 1961–1990. The colour scale ranges from –2.5 (dark blue) to +2.5 °C (dark red). © MeteoSwiss 2016

Images on frontispiece:
Top: Säntis weather station, 2502 m asl, with weather warden couple Haas (left), a visitor and three soldiers, ca. 1920. Photo: Heinrich Haas (Photobibliothek.ch).
Center: Ice and snow accretion on the structures of the weather station on top of Mount Säntis, the automatic instruments are ice-free and operational.
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Bottom: The weather radar station on the Pointe de la Plaine Morte at 2942 m asl, one of the five sites of the MeteoSwiss weather radar network.
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14 Phenology in Switzerland since 1808

Claudio Defila[1], Bernard Clot[2], François Jeanneret[3], Reto Stöckli[4]

[1] retired, last affiliation: Federal Office of Meteorology and Climatology MeteoSwiss, Zurich-Airport
[2] Federal Office of Meteorology and Climatology MeteoSwiss, Payerne
[3] retired, last affiliation: University of Bern, Institute of Geography, Berne
[4] Federal Office of Meteorology and Climatology MeteoSwiss, Zurich-Airport

14.1 Introduction

Phenology studies the timing of annual life-cycle events including the driving factors and involved biotic and abiotic processes (Defila, 1991). The occurrence times of these events – called phenological phases or phenophases – are observed and recorded. Leaf unfolding, beginning of flowering, full flowering, leaf colouring and leaf fall are typical plant phenophases; bird migration and bee activity are examples of observed animal phenophases. Biophysical phenological quantities such as Leaf Area Index or vegetation greenness can be automatically observed on a large scale by satellite sensors and ground-based remote sensing.

Many disciplines make use of phenological data. Geographers, climatologists, agronomists, regional planners and many others appreciate the spatially highly variable phenological signals. Vegetation is present on most land surfaces and exercises a very local-scale variability of phenophases in response to site-specific biogeographical boundary conditions and large-scale climatological forcing. Spatially dense phenological data contains information on biophysical land surface processes which is not present in classical climatological observations. Phenological data are well suited for upscaling meso- or topoclimatic surveys and helps defining seasons (Figure 14.1) (Jeanneret et al., 2011). Site-based phenological information can be combined with satellite-based phenology, classical climatological data and landscape phenological modeling to yield a spatio-temporal mapping of environmental state and function.

Detailed phenological data provide an integrated view of the impact of weather and climate conditions on living systems. Next to the dominant factor of climate, additional factors influence the observed phenological patterns. For plants these are, for example, photoperiod, soil, exposition, genetic differences, human influence or interspecies competition. Land surface vegetation is an interactive part of the climate system. Leaf photosynthesis and transpiration influences cloudiness, temperature, moisture and the carbon dioxide content

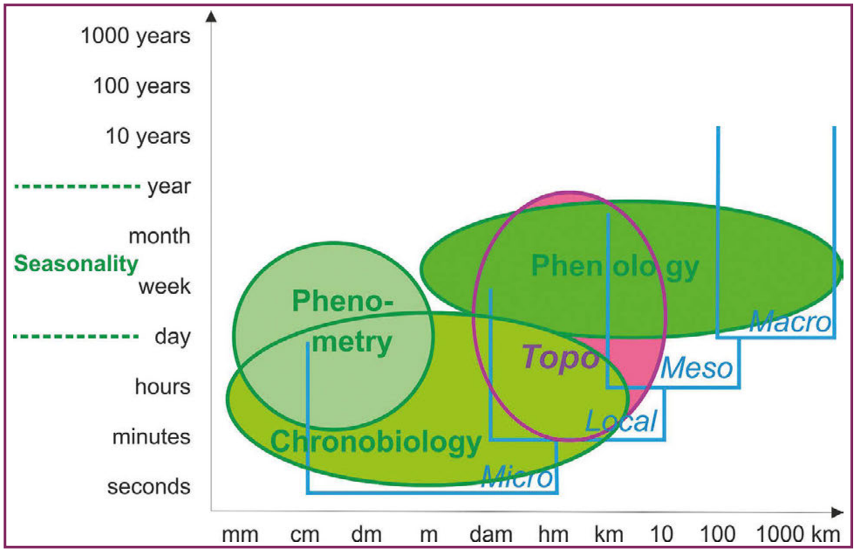

Figure 14.1:
Temporal and spatial scale of biological methods. Phenological data are useful at the topo-scale, embracing local, meso- and macro-scales. On the timescale, the phenology fits from day to year characteristics and is especially valuable for seasonality questions, along with chronobiology dealing with periodic phenomena in living organisms and growth measurements of phenometry.

of the atmosphere on the synoptic to climatological timescales. Leaf phenology, on the other hand, modulates leaf photosynthesis and transpiration through leaf appearance, presence and senescence. It can be linked to the large-scale seasonal to inter-annual climatic variability. The influence of phenological and biophysical states on the terrestrial energy, water and carbon cycle in a variable and changing climate are the most important applications of phenology in the broad field of ecosystem and climate science. A better understanding of this functionality is one of the key challenges for modern phenology. This understanding is needed to maximise the usefulness of phenological observations and to guarantee their continuity into the future. Many applications, such as the modeling of the global water and carbon cycle, prediction of pollen distribution or the spatial analysis of plant and animal diseases nowadays rely on precise and long-term phenological data. The currently observed and statistically significant shifts of seasons in many living systems are very likely an impact of climate change (Rutishauser and Studer, 2007). Seasonality and the analysis of its driving forces is the core business of phenology (Rutishauser et al., 2007; Jeanneret and Rutishauser, 2009b).

Phenology has always been an interdisciplinary research topic serving broad needs, from fundamental terrestrial ecological research to operational climate monitoring. This statement holds true even more in the 21st century.

14.2 The first records

People have always been fascinated by seasonality. For centuries now, individuals have noted the greening or the flowering of plants in Spring, or the first snow or frost at the beginning of Winter: They were the first phenologists (Wegmann, 2005). The world longest phenological time series goes back to year 705 (Sekiguchi 1969). Since then, the date of the full flowering of cherry tree has been recorded every year in Kyoto, Japan by the emperor's administration. It marks the beginning of Spring and gives rise to important celebrations.

In Switzerland, the oldest phenological time series known were recorded by Jakob Sprüngli (1717–1803), who collected weather data and numerous phenological phases. Private initiatives still deliver important datasets, when they are made available. This was the case in Zug since 1993 (Röthlisberger, 2010) and in the Alpine garden at Schynige Platte from 1932 to 1939 and again from 1997 on, where the flowering of alpine plants is recorded at an altitude of 2000 m asl (Hegg et al. 2012).

Two long-term series are available in Switzerland: the bud burst of the horse chestnut in Geneva, officially recorded since 1808 by the head of the General secretariat of the legislative body of the city (Figure 14.2), and the cherry tree flowering in

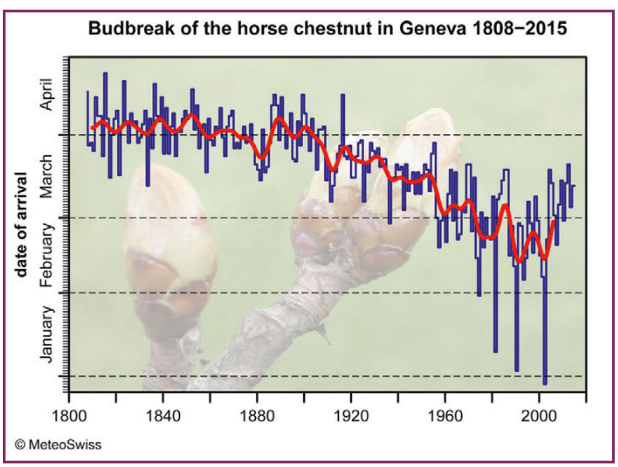

Figure 14.2:
Date of the leaf bud burst of the official horse-chestnut in Geneva, 1808–2015. The red line shows the 20-year weighted average (Gaussian low-pass filter).

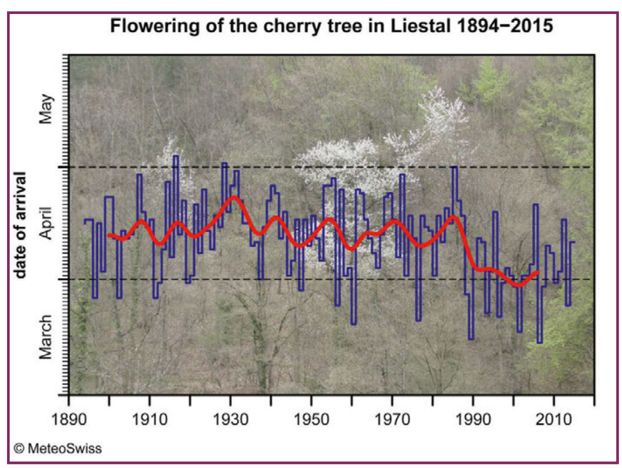

Figure 14.3:
Date of the full flowering of cherry trees in Liestal, 1894–2015. The red line shows the 20-year weighted average (Gaussian low-pass filter).

Liestal since 1894 (Figure 14.3) (Defila and Clot, 2001). Observations will be carried out in the future at both sites.

14.3 Coordinated initiatives

Phenological observations were also made and published on a regular basis in the "Schweizerische Meteorologische Beobachtungen" during the first years of the meteorological networks from 1864 to 1873. The national phenological observations network was founded in 1951 by Bernard Primault, the head of the group of agrometeorology of the Swiss Central Meteorological Institute (MZA, nowadays Swiss Federal Office for Meteorology and Climatology MeteoSwiss). Similar national networks were founded across Europe, inspired by the work of Friedrich Schnelle and colleagues. In the first years, it included some 70 observations sites, 24 wild plants, 12 crops, 3 bird species and the first frost – in total 66 phenological phases (Primault, 1955). Nowadays, the network includes 160 sites in all areas of Switzerland, at altitudes ranging from 200 to 1800 m asl, and includes 26 plant species for a total of 69 phases. The observation program was slightly adapted in 1953 and 1959, and more important changes were introduced in 1996, as a result of a study underlying the possible improvements (Defila, 1991) and the works of an expert group. It was then decided to discard the observations of bird migration, because bird specialists were already performing exhaustive observations in the country (Bruderer, 1996). The observation of crop plants were also limited to grape harvest, haymaking and the flowering of cherry, apple and pear trees, because others were more influenced by the crop varieties selection and agricultural practices than by climatic factors.

The importance of long-term observations has been underlined. To support the work of the observers of the national network, an instructions manual was published in 1957, followed by a second (1962) and a third edition (Primault, 1971). The changes in the program that occurred in 1996 precipitated a new manual including instructions, drawings and pictures as well as much information concerning phenology (Brügger and Vassella, 2003).

The first and only International Phenological Garden (IPG) in Switzerland was created in 1963 in Birmensdorf by the Swiss Federal Institute for Forest, Snow and Landscape Research. The IPG network had been founded in 1959 with the aim of observing clones (owning the same genome) of a list of tree and shrub species planted in gardens in different climatic areas in Europe (Schnelle and Volkert, 1957).

The Bernese topoclimatic network BernClim started in 1970 at the Geographical Institute of the University of Berne (Wanner, 1972; Jeanneret, 1996). It was designed for spatial information that could be applied for landscape planning purposes (Jeanneret and Rutishauser, 2009b, 2012). With three observed sites per 100 km^2 its spatial density allowed modelling of the influence of different topographic factors, such as altitude. Even if that special network lost some of its density over time, it is possible to interpolate phenological details in space. For each point of a grid-based scheme the regression equation for different variables (e. g., altitude, exposition, slope angle) is applied to compute the phenological date and therefore show the topographic specificities in different seasons (Figure 14.4) or in a seasonal synthesis (Rutishauser and Studer, 2007). Beyond the well-known phenological calendars, combined season diagrams can offer a well-illustrated and comprehensible graph. In order to cover seasonal patterns in time outside the vegetation periods, data on fog and snow are recorded in Winter. Snow is an obvious climatic feature of Winter; fog is representative of lower regions with less snow than mountain areas.

An additional special network for frost warnings was founded in 1975 by the MZA for the observation of fruit trees and grapevine at 20 stations in the main production areas of Switzerland in order to prevent damages due to frost. As the sensitivity of these plants to frost varies according to their development stage, real-time information about this stage is important for accurate frost-damage prevention (Defila, 1986). Today, this information is used for pest-prevention purposes as realised by Agroscope in Wädenswil und Changins (Agroscope is the Swiss centre for agricultural research affiliated with the Federal Office for Agriculture).

Forest phenology started in 1993 (Brügger, 1998), and data are collected and stored by the Swiss Federal Institute for Forest, Snow and Landscape Research WSL. Compared to the national network, additional species and at least 10 different individuals of each species at each site are observed, offering another view on spatial aspects and more easily reflecting changing environmental conditions and differentiations of mountain areas. It can also be surveyed with cameras (Brügger, 1998; Brügger et al., 2003; Ahrends et al., 2008, 2009). Important shifts of phenological phases were also described for the past 500 years (Rutishauser, 2009).

In 1994, the Swiss National Park in Engadin set up a phenological network (Defila, 1999). In addition to a few plants and phases observed in the national network, this observation programme includes typical Alpine plants such as the Clusius' gentian (*Gentiana clusii*), the hawks beard, the Winter heath (*Erica carnea*) and the

Actual regional Specifities **2000–2011**

Jura Mountains **Lake of Thoune**

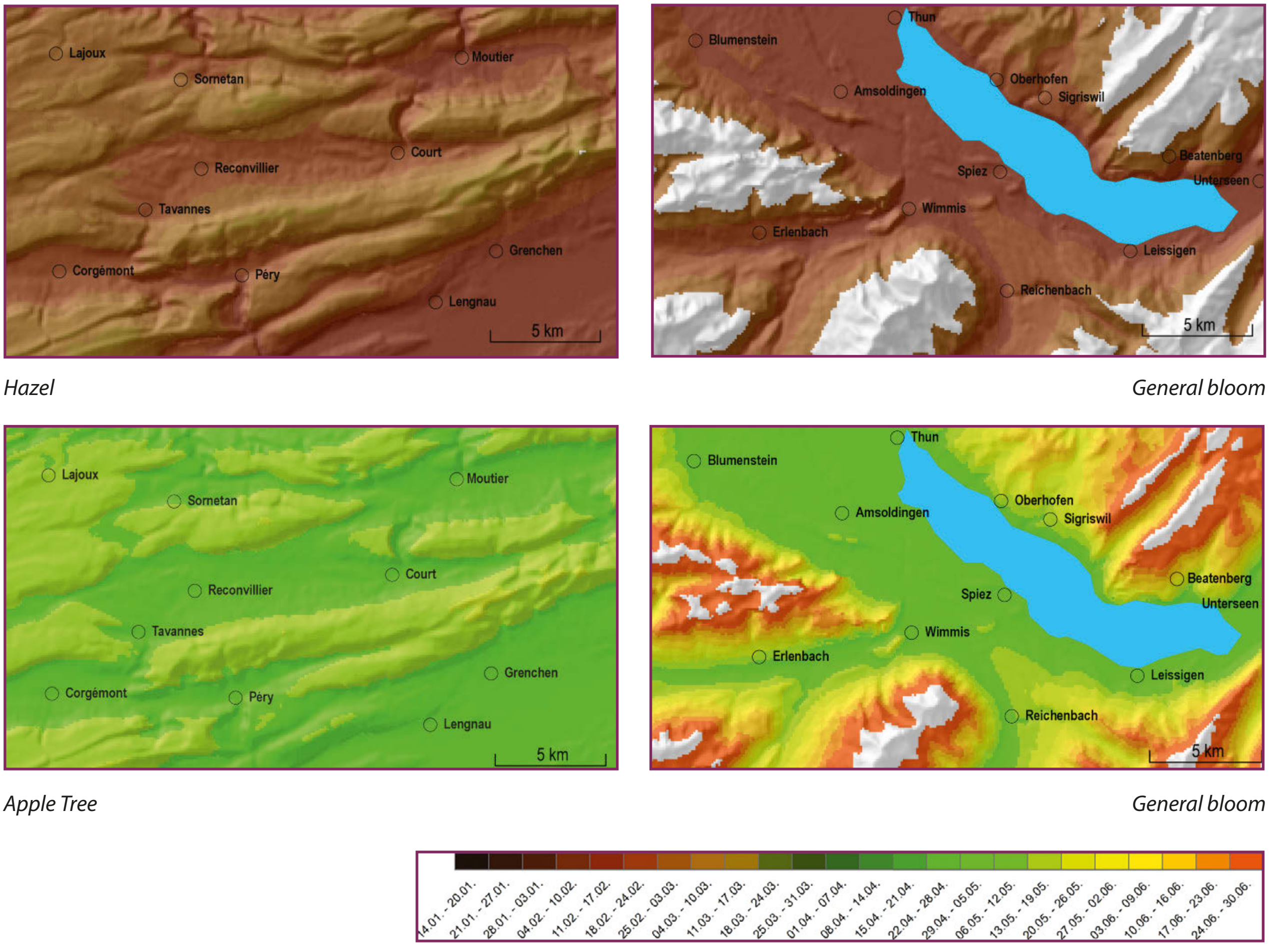

Figure 14.4:
Detailed maps of phenological conditions for the general bloom of hazel (upper maps) and the general bloom of apple trees (lower maps) in a middle mountain conditions (central Jura mountains, left maps) and North Alpine conditions (Thun Lake, right maps), generated with topographic interpolation modelling (Jeanneret and Rutishauser, 2012).

lingonberry (*Vaccinium vitis-idaea*). In three areas (Val Mingèr, Ofenpass und Val Trupchun), the guards of the park observe a total of 11 plant species. Val Mingèr, which has not been visited by the guards since 2009, was then replaced by Val Cluozza.

14.4 Different applications during the 20th century

In the mid-20th century, phenology networks were created in many European countries, e. g., Germany, Austria and Switzerland. The data were primarily used for agricultural purposes, such as the optimal timing of agricultural activities and frost-damage prevention (Primault, 1970). Phenologists were less active during the 1970s and 1980s. Four phenological maps were included in the Swiss Climate Atlas (Primault, 1984). Until the mid-1980s, the original observation sheets were simply archived. Later, all data were retrospectively digitised, which allowed for a detailed analysis. In order to determine whether a particular season occurs early or late, for every station and phenophase, the observations of the data series were separated into five classes according to their date of occurrence. The earliest dates (10 %) were considered to be "very early," and the latest 10 % to be "very late." Data from quantiles 11 to 25 were considered to be "early," and those 75 to 89 as "late." The 50 % around the average were considered to be "normal" occurrences. Such phenological calendars were produced for each station (Defila, 1992). From the mid-1980s, a number of papers were published in scientific journals, so that the awareness about phenology increased among the nature lovers and the public. Annual retrospectives were published in forest and agriculture journals since 1987 and 1989, respectively (e. g., Defila, 2010a, 2010b) and in the MeteoSwiss annals. With the development of Internet, weekly phenological bulletins were made available to a wide audience. More recently, a Spring index showing the mean development of the vegetation in Spring was developed and is regularly updated on the Internet (http://www.meteoschweiz.admin.ch/) (Figure 14.5). Today, phenological bulletins are published regularly in the meteorological bulletins of MeteoSwiss (http://www.meteoschweiz.admin.ch/content/dam/meteoswiss/de/Klima/Gegenwart/Klima-Berichte/doc/klimabulletin).

In order to intensify the exchanges among different groups of persons interested in phenology – such as scientists, observers and users – in 2004 the Swiss Phenology Circle was created, thanks to collaboration between the Geography Institute of the University of Berne and MeteoSwiss. Two excursions were organised and two newsletters were published per year. In turn, this group was at the origin of the foundation of the Commission for Phenology and Seasonality of the Swiss Academy of Sciences (SCNAT) in 2011 (http://www.naturwissenschaften.ch/kps), which continues these excursions and organises yearly phenology symposia in the framework of the Swiss Geoscience Meetings.

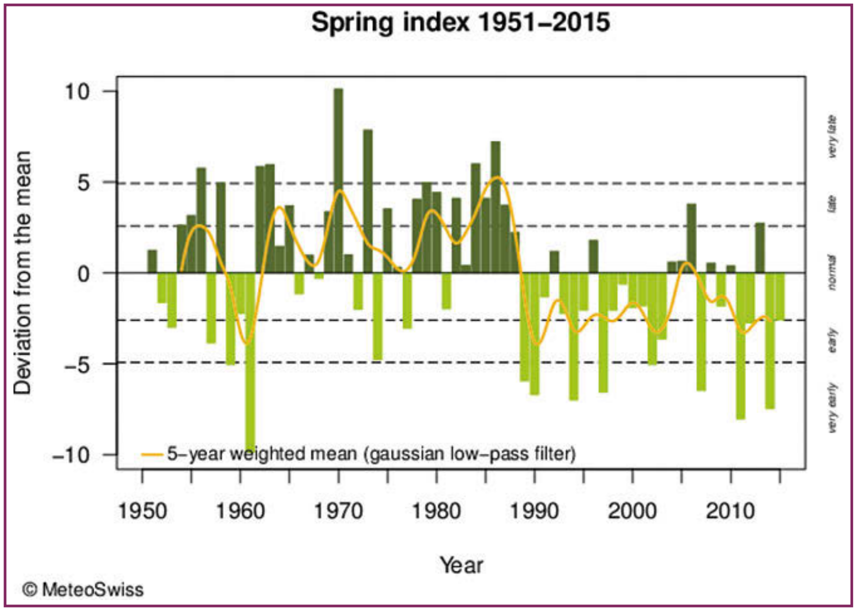

Figure 14.5:
Swiss Spring index, 1951–2015.

Phenology received true recognition during the 1990s, when it came to the attention of the scientific community that phenological data are important indicators of climate change. This reflects the fact that the dates of occurrence of many phases are influenced by the temperature of preceding months (Menzel and Fabian, 1999; Defila and Clot, 2001; Studer et al., 2005, Menzel et al., 2006). The number of scientific publications in peer-reviewed journals increased rapidly, and full sessions on phenology started to appear at international conferences on meteorology and climatology. The interest and awareness for phenology grew both in the media and in the public.

14.5 Modelling the phenological response to climate variability and change

One of the most important phenological highlights of the last years is the observed shift of the date of phenological phases towards ever earlier dates in Spring and early Summer (Defila and Clot, 2001). Similar to other European countries, Spring in Switzerland nowadays starts earlier compared to 50 years ago.

The advance of the flowering phases in Spring now amounts to 20 days, the leaf unfolding to 15 days, whereas no specific signal can be detected among the few observed phases in Autumn. Compared to 50 years ago the colouring of the leaves seems to occur a little earlier, and the leaf fall a little later (Defila, 2004). Such information is of particular interest to plant sciences, agronomy and forestry.

A comparison of phenological time series in the Alps (> 1000 m asl) and at low altitude (< 600 m asl) in Switzerland during the period 1951–2002 showed that the proportion of significant trends is higher in the Alps (42 %) than at low altitude (33 %). The Spring phases at low altitude occur 20 days earlier and over 1000 m asl only 15 days earlier than 50 years before (Defila and Clot, 2005). However, with regard to the duration of the vegetation period at both altitudes, the change is much more pronounced in the Alps, so that productivity there could benefit more from an earlier seasonal start.

A comparison of the fourth IPCC report (Rosenzweig et al., 2007) showed that the calculated prolongation of the vegetation period in Switzerland of 2.7 days/decade for the period 1951 to 2000 (Defila and Clot, 2001) corresponds well to the 2.3 days/decade obtained in Germany for the same period (Menzel et al., 2001), and to the 3.5 days/decade of the IPG for the period from 1959 to 1998. When not affected by long dry periods, a prolonged vegetation period would allow an increase in biomass production, although herbivore insects and plant pests could also benefit from a longer period favourable to their development.

In temperate climate zones like Switzerland the date of Spring phenophases is driven mainly by the temperature in the preceding months; this observation can be linked to recent climate warming. The ultimate proof is gained through phenological models. For instance, a statistical study of the Spring phenophases (Studer et al., 2005) demonstrated that the advance is not linear over time. Rather, a shift occurred at the end of the 1980s, and it was also found that not all plant species or phenophases react with an equal intensity. Studies have documented the co-limitation of both temperature and photoperiod for light-sensitive temperate tree species (Körner and Basler, 2010; Vitasse and Basler, 2013).

Unfortunately, temperature is still the main climatic driver in most ecosystem models, leaf physiology and leaf phenology being treated separately. Many phenological models are accurate only for today's climate and for specific locations and species since statistically they relate the timing of observed phenological events to observed climatic variability. They have been trained specifically with long-term phenological observations restricted to the temperate climate zone, such as the long phenological record of MeteoSwiss. On the other hand, phenological models built for the application in global energy, water and carbon exchange studies lack realism on both the seasonal and inter-annual timescale (Stöckli et al., 2008; Randerson et al., 2009). They show substantial deficiencies for drought-deciduous, tropical, boreal and arctic phenology, where only few ground-based observations exist. Also, these models depend on the continuous availability of a biophysical state of vegetation at the landscape scale rather than on the timing of species-specific and local-scale events like flowering or bud burst. Only the latter information, however, is available from long-term phenological observations, such as the ones described above. So there is a real gap between application needs and the observational capability.

Global satellite observations could be used to validate such models, and they could be used to prescribe phenological variability in the models (Sellers et al., 1996; Lawrence and Slingo, 2004). Satellite phenological observations provide a spatially integrative view of continuous biophysical states (e.g., a daily Leaf Area Index) instead of plant-specific phenological development stages (e.g., phenological phases). Studer et al. (2007) demonstrated that the variability of both methods in the inter-annual start of season is comparable even over complex terrains such as the Swiss Alps when individual ground observed species are composed into a "statistical plant" (Studer et al., 2005). However, atmospheric disturbances, aerosol contamination, calibration errors and view geometry can affect the quality of satellite phenology datasets. They also have gaps for periods of snow cover and when snow covers vegetation. And when only the highest quality satellite observations are used, their key advantage (spatio-temporal information) rapidly vanishes.

Therefore, instead of directly utilizing satellite datasets, only the best quality screened satellite phenological measurements can be employed to parameterise predictive phenology models. The phenology model then serves as a "gap-free," simulated satellite observation. This promising method has, for instance, been applied to reconstruct the climate-driven seasonal, inter-annual and decadal course of global vegetation phenology (Stöckli et al., 2011). It is currently being evaluated at MeteoSwiss to provide a daily updated Leaf Area Index for the numerical weather forecast model COSMO (Figure 14.6). Ground phenological observations serve as a valuable independent validation source for such data-fusion exercises. They are needed to estimate the decadal stability and the climate sensitivity of the modelled phenology.

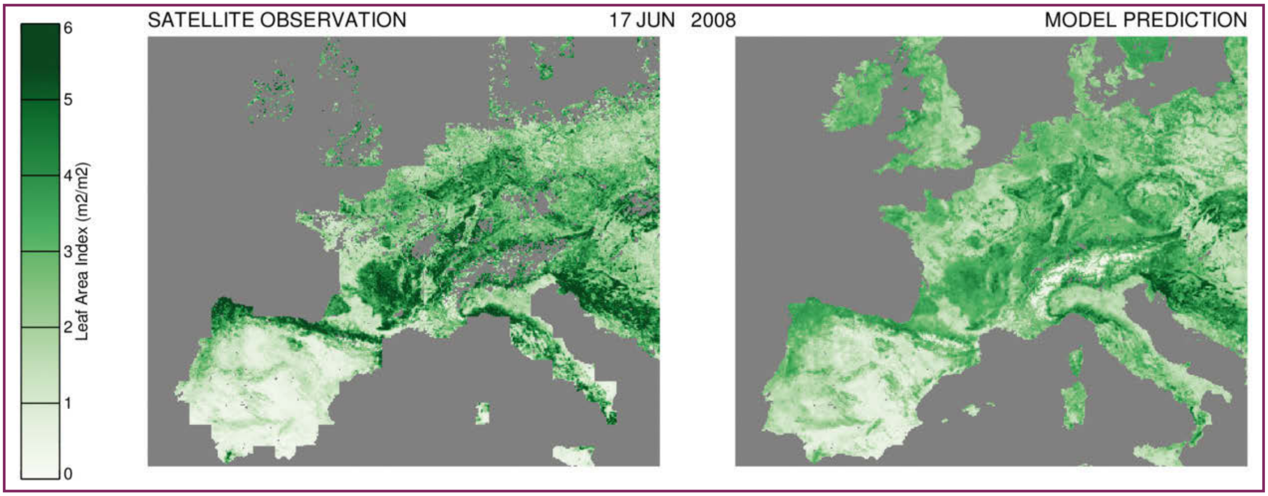

Figure 14.6:
Quality screened satellite-derived MODerate resolution Imaging Spectroradiometer (MODIS) Leaf Area Index LAI (left) and gap-free prognostic phenology model prediction using assimilated MODIS LAI (right) for 17 June 2008 on the COSMO-7 numerical weather prediction model grid.

14.6 International collaborations and citizen science

European Data Platform (COST725 and PEP725)

As a consequence of the development of phenology in the 1990s and early 2000s, the collaboration between European phenologists was strengthened and pushed forward by the COST (European Cooperation in the field of Scientific and Technical Research) action 725: Establishing a European Phenological Data Platform for Climatological Applications (2005 – 2009). At the time, it was one of the largest COST actions, with 28 countries participating. The idea of a European phenological database encountered a large interest. However, some partners proved reluctant to deliver their data. The main problems were the variety of observation methods and the different quality levels of the data, from data that had not been controlled at all to data that had been controlled with advanced methods.

Many publications grew out of from this European collaboration. Two of them give an overview of the works realised: Guidelines for Plant Phenological Observations (Koch et al., 2007), and European Phenological Response to Climate Change Matches the Warming Pattern (Menzel et al., 2006) , co-authored by Swiss partners. In the framework of this COST Action, two projects were funded at Swiss level by the State Secretariat for Education, Research and Innovation SERI: Photometric Evaluations of Phenological Growth Stages in Forest Stands: Applications to Climate Monitoring Using Digital Image Analyses PHENOPHOT (Ahrends et al., 2008) and Inter-Annual Variations in European Phenology Patterns and Their Relation to Climate Change (Studer at al., 2005). As a follow-up of the COST action, the PEP725 (Pan European Phenological database) was created with the goal to maintain and develop the European phenological database (www.pep725.eu).

Global Climate Observing System, GCOS

GCOS was founded in 1992 by the World Meteorological Organisation (WMO) and several other international organisations with the goal to perform systematic climate observations, not only for common parameters such as temperature, precipitations, air pressure, etc., but also for essential parameters in the atmosphere, oceans and overland. Phenological data were defined as relevant climatic variables. From the Swiss observation network, 12 observation stations with long record series in different regions and altitudes as well as the two long data series of the horse-chestnut bud-burst in Geneva since 1808 and cherry tree flowering in Liestal since 1894 were recognised by GCOS Switzerland as important observations to be maintained at long-term (Seiz and Foppa, 2007).

Global Learning and Observations to Benefit the Environment, GLOBE

GLOBE is a worldwide school-based science and education program. It started in 1995 in the USA, with Switzerland joining in 1998. The students are encouraged to get to know, understand and take care of the environment; they are made aware of environmental questions, of the “system Earth” and of scientific methods. Topics such as climate/weather, hydrology and bio indication, soil, land use/biology, remote sensing (satellite data) and phenology are developed. Today, teachers realise phenological observations with their students in several Swiss schools. Some of these results are then used for scientific studies (e.g. Gazal et al., 2008).

PhaenoNet

The Internet platform PhaenoNet was created in 2013 thanks to a collaboration between Globe, the ETH-Zurich and MeteoSwiss. In addition to the national network’s observers, this platform allows schools and indeed every person in Switzerland to contribute to phenological observations by registering observation data online, and thus to spatially densify the observations.

OpenNature.ch

The citizen science platform OpenNature (http://opennature.ch) was launched in Spring 2015. It is directed toward the scientifically interested public who is willing to share their local observations with peer observers and professional scientists across Switzerland. The initiative is part of a growing movement of "citizen science" which aims to involve the public in the scientific collection and analysis of data. Data gathered by OpenNature should also contribute to a better understanding of seasons, plants, animals, weather and climate. A large potential of the website is undoubtedly the strengthening of the community of phenological observers, making phenology a valuable climate change indicator and directing the attention of the public and media to the ever-changing phenology of plants and seasons.

14.7 The future of Swiss phenology

One of the major challenges for phenology science will be to better integrate the historically driven focus on point-scale phenological observations with modern satellite-based spatial information on vegetation state and phenological prediction models to form a consistent and continuous climate service of geospatial climate information on vegetation and ecosystem state for user-driven applications like for instance drought monitoring, insect pest prediction, climate variability and change impact assessment or the combination flowering/airborne pollen. The currently, often temperature-based prediction of phenophases needs to move away from statistical to more process-based modeling of the combined vegetation phenology and physiology driven by a multiple set of limiting climate and biophysical factors including the human influence on ecosystem functioning. This is needed in order to better assess the impact of climate variability and change on phenological timing, but also to quantify the resulting feedback of an earlier Spring on the terrestrial carbon uptake or on for instance Summer drought. Such understanding can be gained only from multi-decadal, ground-based phenological datasets and models that are not only exercised in temperate climate zones like Switzerland, but are also realistic for Mediterranean, tropical, boreal and Arctic climate zones. Embedding national phenology observation networks as part of the global climate science driven by requirements from international climate monitoring initiatives (e.g., GCOS) will better foster the scientific and socioeconomic potential of both biology and climate backed by a really valuable long-term and often voluntary "citizen driven" climate data record of both natural and man-made climate variability and change.

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