Historical Phenology –
Plant Phenological Reconstructions and Climate Sensitivity in Northern Switzerland

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Abstract

The major focus of the PhD thesis *'Historical Phenology – Plant Phenological Reconstructions and Climate Sensitivity in Northern Switzerland'* lies on the analysis of plant phenological observations and plant phenological sensitivity to climate change in Switzerland. During the past five decades winter and spring warming trends have lead to significant advance of the spring phenology of many species and phases. Furthermore, the extraordinary warm autumn 2006 and spring 2007 left their imprint on plant phenology: some plant species had a partial second flowering at the end of the year or extended the flowering until the beginning of winter, and species that typically flower in early spring flowered distinctly earlier after the winter 2007 (Chapter 6). As temperatures are predicted to increase, there is need to understand and quantify climate impacts on plant phenology in the present and in the past.

Back in time phenological observations become scarce. However, a large number of historical observations were recovered and published in Switzerland. In consequence, this thesis tackles the questions of the availability of historical phenological observations for spring and summer seasons of the past three to five centuries and develops methods for their analysis. Historical phenological observations have been known such as the unique collection of more than 4'000 plant and animal phenological observations by the priest Johann Jakob Sprüngli (1717–1803). The chapter 3, *Johann Jakob Sprüngli – pioneer of systematic plant observations and precursor of historical climatology in Europe*, exemplifies the value of historical phenology. It contributes to a first definition of historical phenology that is the art of the interpretation of phenological observations that were collected before or simultanously with networks or proto-networks and contain individual, characteristical meta-information. (Chapters 1 and 9)

The methodological part of this thesis addresses the development of statistical plants derived from observations of the most recent decades in order to overcome limited data availability. Subsequently, a method is introduced to reconstruct statistical plants for centuries back in time. Additionally, we test several tools for the assessment of climate impacts on phenological observations and the change throughout time such as a moving window on linear trends, correlation and sensitivity as well as a Bayesian time series modeling and correlation approach. By statistically linking longterm phenological observations to the environmental forcing we attempt to contribute to a better understanding of present and future phenological modeling.

In the following I present the most important findings of each chapter. The chapter *Climate change and its influence on spring phenology* shows that spring season (March–May) temperature trends 1951–2006 are positive in most regions of the world with 1997–2006 being the warmest decade in Europe

with respect to the past 500 years. The warming has had a strong impact on phenological trends in Switzerland and lead to a general advance of 1.5 days/decade in the period 1965–2002 represented by a multi-species index based on 15 selected phases and calculated by means of empirical orthogonal function analysis (Chapter 2). Similar impacts are found for a statistical 'Spring plant' based on three selected species and the flowering of the cherry tree in the Swiss Plateau region. Thus, we argue that single phenological phases can represent regional trends (Chapter 2).

Subsequently, we present longterm records from historical phenological observations. First, a 280-year long record of the flowering of the cherry tree for the extended Swiss Plateau region during the period 1721–2000 was compiled from 14 independent records. Individual records were altitude corrected to a common reference level (Chapter 2). Second, the chapter *A phenology-based reconstruction of inter-annual changes in past spring seasons* presents a 305-year long statistical 'Spring plant' record as the weighted mean of the flowering of the cherry and apple tree and beech budburst. It was reconstructed for the extended Swiss Plateau region 1702–2006 based on network and historical phenological observations (Chapter 4). Third, a 527-year long time series of grape harvest dates of the Swiss Plateau region was compiled from 1435 single observations for the period 1480–2006 in the chapter *Grape Harvest Dates as a proxy for Swiss April to August Temperature Reconstructions back to AD 1480* (Chapter 5). In addition, observations of the 'Sofortmeldenetz' of the Swiss Phenological Network were used for immediate analysis of the record spring 2007 observations in Switzerland resulting in a preliminary update of the 'Spring plant' (Chapter 6).

Selected results of environmental sensitivity show an observed advance of phenological events of 2–10 days for a general increase of 1°C in spring for the period 1950–2000 (Chapter 2). Explicitely, the chapter *Exceptional European warmth of autumn 2006 and winter 2007: Historical context, the underlying dynamics, and its phenological impacts* indicates that hazel (snowdrop) flowering responds to 1°C warmer February by 11.3 days (8.3) earlier flowering in Germany (Chapter 6). For Swiss grape harvest dates we found that twelve days of grape harvest difference correspond to around 1°C April–August temperature difference. The chapter *Swiss Spring Plant Phenology 2007: Extremes, a multi-century perspective and changes in temperature sensitivity* introduces changing sensitivity by a moving linear regression approach and shows significant changes of the Swiss 'Spring plant' to spring temperatures of 6 days change/degree°C (1950-1980) to 4 days/degree°C (1975-2005). The extraordinarily positive spring temperature anomalies of western central Europe were measured in spring 2007 and lead to 94 new record early observations which were recorded for selected phases and stations in Switzerland. Furthermore, we investigate the relationship between phenology and forcing temperatures with a nonlinear Bayesian correlation approach. The chapter *Time series modelling and temperature impact assessment of phenological records in the last 250 years* indicates that spring phenological variability is not only influenced by spring temperatures of the current year but also by summer temperatures of the preceding growing season.

In conclusion, we present three longterm phenological observation records of the Swiss Plateau region for the past three to five centuries with reconstruction methods, associated uncertainties, extremes, trends and climate sensitivity analyses. Additional modeling approaches are presented in chapters 1 and 10. This PhD thesis underlines the importance of observed phenological evidence of the past to assess the impact of changing climate and address the questions of possible future scenarios in time.