4 — Temperature-based climate indices for sector-specific impact assessment

- summer days
- tropical nights
- frost/ice days
- growing season length
- heating/cooling degree days

– Climate indices facilitate the interpretation of expected future climate change for specific sectors and stakeholders.

– In the projections for the 21st century, trends toward more tropical nights and summer days, a longer growing season, but fewer frost and ice days are seen. Heating degree days are projected to decrease, cooling degree days to increase.

– The magnitude of the projected changes is strongly dependent on the considered greenhouse gas scenario. Under the mitigation scenario RCP3PD, the expected changes are much less pronounced than in the non-intervention scenarios A1B and A2.

– In the Swiss Alps, climate indices and their changes vary greatly with elevation.

‹ By the end of the century, the growing season may start as early as mid-February in the lower parts of Switzerland (flower buds opening on a cherry tree near Geneva; photo: Dorothée Baumann).

4.1. INTRODUCTION

Many expected climate change impacts are related to fixed temperature thresholds through physical processes. For instance, the frequency of temperatures below the freezing point has an impact on Alpine glaciers, permafrost and runoff hydrology (Chapters 5 and 6); similarly, distinct biophysical temperature thresholds limit agricultural production (Chapter 9) or may affect the development of various ecosystems (Chapter 7 and 8). Furthermore, a wide range of socio-economic sectors may suffer from impacts caused by extreme events rather than from average seasonal changes (Rahmstorf and Comou, 2012; Hansen et al., 2012; Klein Tank et al., 2009; IPCC, 2012). A prominent example is the record-breaking hot summer of 2003, which had substantial socio-economic and ecological impacts in Switzerland (OcCC, 2003), and increased mortality by ten thousands of heat-related deaths across Europe (e.g., Vandentorren et al., 2004; Schär and Jendritzky, 2004, Garcia-Herrera et al., 2010, Robine et al., 2008). Similarly, unusually cold winter temperatures may lead to travel disruption, cold-related enhanced mortality and increased energy consumption (e.g., Cattiaux et al., 2011).

In this chapter, changes in climate indices are presented to facilitate the interpretation of climate change and its impact for specific sectors. A climate index is a statistic typically calculated from daily temperature or precipitation series. A common type of index is the number of days on which a certain threshold is exceeded. Due to methodological limitations (Section 4.2) the analysis is limited to indices based on temperature thresholds. They are defined mostly following the recommendations of the World Meteorological Organization (WMO; Klein Tank et al., 2009) and include:

- Number of **summer days**: average number of days per year with maximum temperatures ≥ 25°C.
- Number of **tropical nights**: average number of days per year with minimum temperatures ≥ 20°C.

- Number of **frost days**: average number of days per year with minimum temperatures < 0°C.
- Number of **ice days**: average number of days per year with maximum temperatures < 0°C.
- **Thermal growing season length**: average number of days in a year between the first occurrence of a 6–day period with daily mean temperatures > 5°C and the first occurrence after July 1 of a 6–day period with daily mean temperatures < 5°C.
- **Heating degree-days**: annual average sum of differences between outside daily mean air temperature and the base temperature inside the building (20°C) on days with mean temperatures < 12°C (SIA, 1982).
- **Cooling degree-days**: annual average sum of differences between outside daily mean air temperature and the base temperature of 18.3°C, above which cooling is assumed to be needed.

Projected changes in summer days and tropical nights inform heat-related impact assessments, while frost and ice days quantify the conditions relevant to cold-sensitive impacts. Growing season length is relevant for the agricultural sector and plant ecology, heating degree-days, and cooling degree-days are indices tailored to the economic and energy sector.

4.2. METHODS

The projection of future fixed-threshold indices from climate simulations is challenging since small temperature biases (systematic differences between model simulation and observations) may lead to large biases in fixed-threshold indices. Therefore, the most robust approach to date is to impose the climate change signal onto observed temperatures (delta-change approach; Chapter 3).

The basis for the calculation of the indices listed above are the CH2011 scenarios "DAILY-GRIDDED" (Chapter 3) and km-scale observational temperature data from MeteoSwiss (Frei, 2014). The temperature change projections are based on daily mean temperatures, but are applied to minimum or maximum temperatures also, depending on the climate index. The indices are calculated for all uncertainty estimates (lower, medium, and upper), all greenhouse gas scenarios (A1B, A2, and RCP3PD) and all scenario periods (2035, 2060, and 2085) corresponding to the full "scenario cube" (Chapter 2, Figure 2.2). The indices are expressed as an annual mean for a 30-year period. The reference period covered by observational data is 1980–2009. More details are provided in Zubler et al. (2014a; b). Only long-term projections (2085) are discussed here because the intermediate periods do not add qualitatively new information.

A considerable limitation of the delta change approach is that the statistical distribution of climate variables is just shifted by the mean change value and its shape is assumed to be constant in time (Chapter 3). For this reason, caution is needed when the delta change approach is applied in the context of very rare events. For example, both a shift and a broadening of the distribution of summer temperatures could increase the frequency of events like the heat wave of 2003 (Schär et al., 2004; Scherrer et al., 2005; Fischer et al., 2012b). However, recent studies demonstrated that within certain bounds, changes in the exceedance of moderate temperature thresholds can be well approximated by a simple uniform shift in the temperature distribution (Fischer and Schär, 2010; Ballester et al., 2010; Lustenberger et al., 2014). Fischer et al. (2012b) suggest that the variability of temperatures increases for summer and decreases for winter. Under this assumption the delta change approach tends to underestimate the changes in indices such as tropical nights or ice days.

The delta change approach was not extended to precipitation-based indices since a mean shift does not sufficiently capture the possible changes in precipitation amount or frequency (Rajczak et al., 2013). In addition, there are regions on the globe where precipitation extremes increased although mean precipitation shows a decrease (Frich et al., 2002; Alexander et al., 2006).

4.3. RESULTS

All of the investigated temperature-based indices show clear imprints of the overall warming in Switzerland. However, based on the different thresholds and definitions, the projected changes in indices strongly depend on elevation and geographical region.

Today, the largest number of **summer days** in Switzerland is found in the valleys of the Ticino and along the northern shore of Lake Geneva. In these regions, about 60–70 summer days occur in an average year of the reference period, while typical values in the Swiss Plateau range from 20 to 60 days (Figure 4.1 a). By the end of the 21st century, the increase for RCP3PD over these regions is about 15–25 summer days (Figure 4.1 b). An average increase by about 30–70 summer days, or roughly a doubling, is projected for A1B (Figure 4.1 c) in the lower parts of Switzerland. Scenario A2 is very similar to A1B and therefore not shown.

Tropical nights are rare today in Switzerland. The only regions where tropical nights occur occasionally are the lowest section of the Ticino valley, the northern shore of Lake Geneva and some Föhn valleys (Figure 4.1 e). However, during the extremely hot summer 2003, seven tropical nights were recorded in Basel. Toward the end of the century, tropical nights are expected to occur in most parts of the Swiss Plateau, except for RCP3PD (Figure 4.1 f). In A1B (Figure 4.1 g) and A2, an average of 10–30 tropical nights are projected along the Aare and Rhine rivers, and up to two entire summer months with tropical nights in the Ticino and on the northern shore of Lake Geneva.

The increase in summer heat-related indices is largest in valleys even though the warming is not more pronounced there. Owing to the spatially rather homogeneous warming pattern, the increase in summer heat-related indices mirrors topography. A similar pattern is also seen on the European scale (Fischer and Schär, 2010). The upper elevation limit for summer days rises by about 400 m toward the end of the 21st century in A1B and A2, such that summer days may occur even above 1700 m asl (Figure 4.1 d). Tropical nights, currently not experienced above 500 m asl, may appear at elevations above 1400 m asl toward the end of the 21st century (Figure 4.1 h).

Warming is expected to cause a reduction in the number of frost days and ice days and to prolong the growing season (Frich et al., 2002). The fraction of the Alps experiencing **frost days** on more than one third of the year is projected to shrink considerably in the non-intervention scenarios A1B and A2 (Figure 4.2 c, blue colours). In the lower part of Switzerland, the corresponding number of frost days is projected to decrease from about 60 days to less than 30 days in some areas, while the number of **ice days** decreases from currently 25–45 to about 0–10 days (Figure 4.2 f–h). Thus, in the A1B and A2 scenario ice days disappear almost completely along the Ticino river and the shores of Lake Geneva based on the delta change approach (Figure 4.2 g). The strongest decrease of frost days is found at elevations above 3000 m asl (Figure 4.2 d). For ice days the strongest decrease of more than two entire months for the A1B and A2 scenario is found at similar elevations (Figure 4.2 h).

In A1B and A2, the **thermal growing season length** increases considerably in most parts of Switzerland. An extension by about 2 months is projected for the medium estimate of A1B in the lower part of Switzerland (Figure 4.2 k,l). Thus, according to the thermal index used here the growing season may start already in mid-February in these regions. In RCP3PD the increase of the thermal growing season length is projected to be limited to about 2–4 weeks until the end of the century (Figure 4.2 j).

Rising ambient temperatures are expected to reduce heating and increase the cooling demand in Switzerland (Chapter 10). A reduction of **heating degree-days** by 25–27% is found for the A1B scenario on the Swiss Plateau (Figure 4.3 a–d), where most of the population lives (medium temperature projection). The reduction decreases with higher elevation to about 15–20%.

At current temperatures, there is only little demand for cooling, with 50–200 **cooling degree-days** in an average year of the reference period (Figure 4.3 e). Toward the end of the century, however, cooling demand may increase to more than 400 cooling degree-days in some of the most populated areas in the scenarios A1B and A2 (Figure 4.3 g,h). This corresponds to an increase of the demand by a factor of two to eight. In the south of Switzerland, more than 1000 cooling degree-days are projected under the scenarios A1B and A2 (Figure 4.3 g,h). Above 1500 m asl, cooling degree-days are zero in the reference period (Figure 4.3 e), but the scenarios A1B (Figure 4.3 g,h) and A2 indicate a potential cooling need by the end of the century even at these elevations.

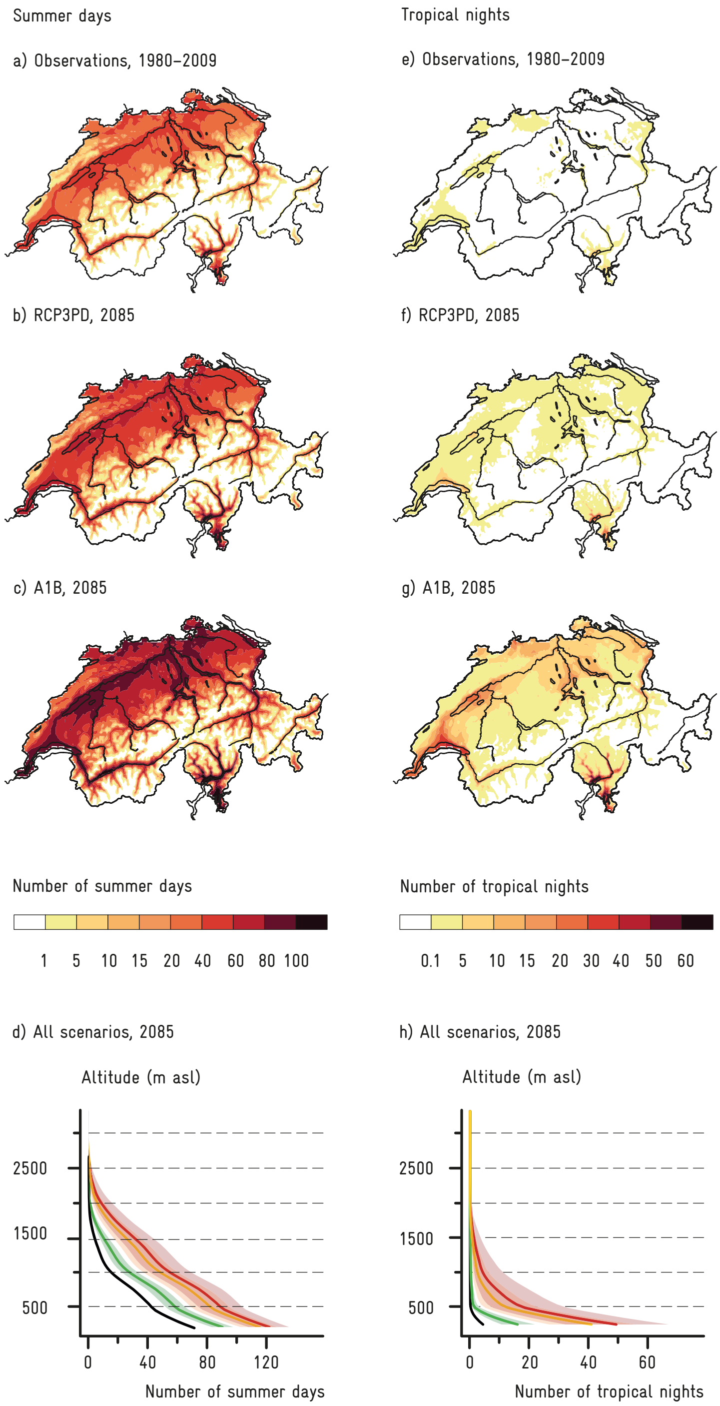

Figure 4.1: Number of summer days (left) and tropical nights (right): (a, e) 30-year mean over observations in the reference period 1980–2009, medium estimates of (b, f) the RCP3PD scenario (2085), and (c, g) the A1B scenario (2085). A2 is similar to A1B and is not shown as a map. (d, h) Vertical structure for all scenarios: In (d, h) the black line indicates the observations. The scenarios are displayed as follows: RCP3PD (green), A1B (yellow), and A2 (red). The lines in (d, h) correspond to mediums of height bins of 100 m over all grid points within Switzerland. Shading indicates the range from the lower and the upper estimate of each greenhouse gas scenario, respectively. Spatial variability is not displayed in the bottom panels.

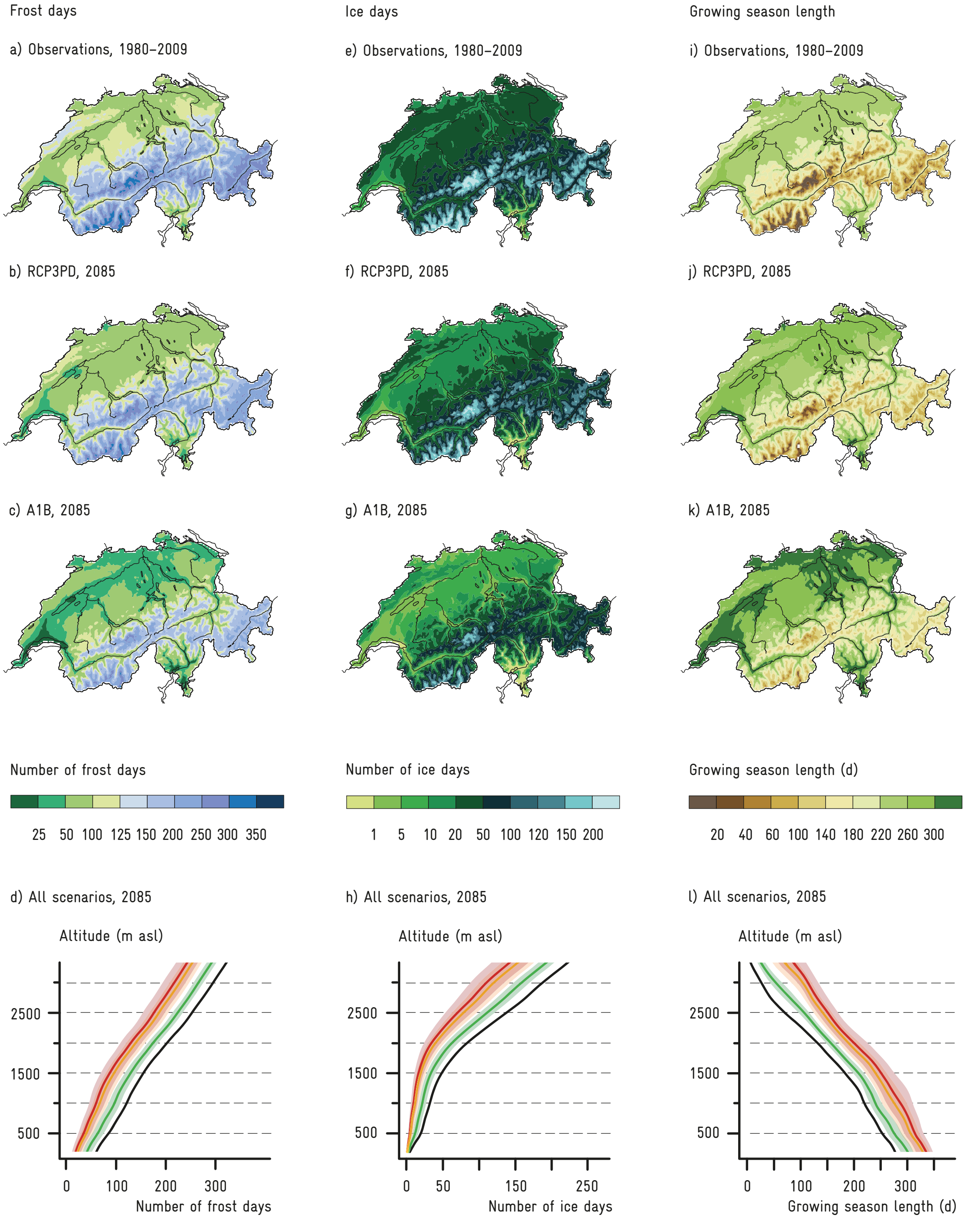

Figure 4.2: Number of frost days (left), ice days (middle), and growing season length (right): (a, e, i) 30-year mean over observations in the reference period 1980–2009, medium estimates of (b, f, j) the RCP3PD scenario (2085), and (c, g, k) the A1B scenario (2085). A2 is similar to A1B and is not shown as a map. (d, h, l) Vertical structure for all scenarios: In (d, h, l) the black line indicates the observations. The scenarios are displayed as follows: RCP3PD (green), A1B (yellow), and A2 (red). The lines in (d, h, l) correspond to mediums of height bins of 100 m over all grid points within Switzerland. Shading indicates the range from the lower and the upper estimate of each greenhouse gas scenario, respectively. Spatial variability is not displayed in the bottom panels.

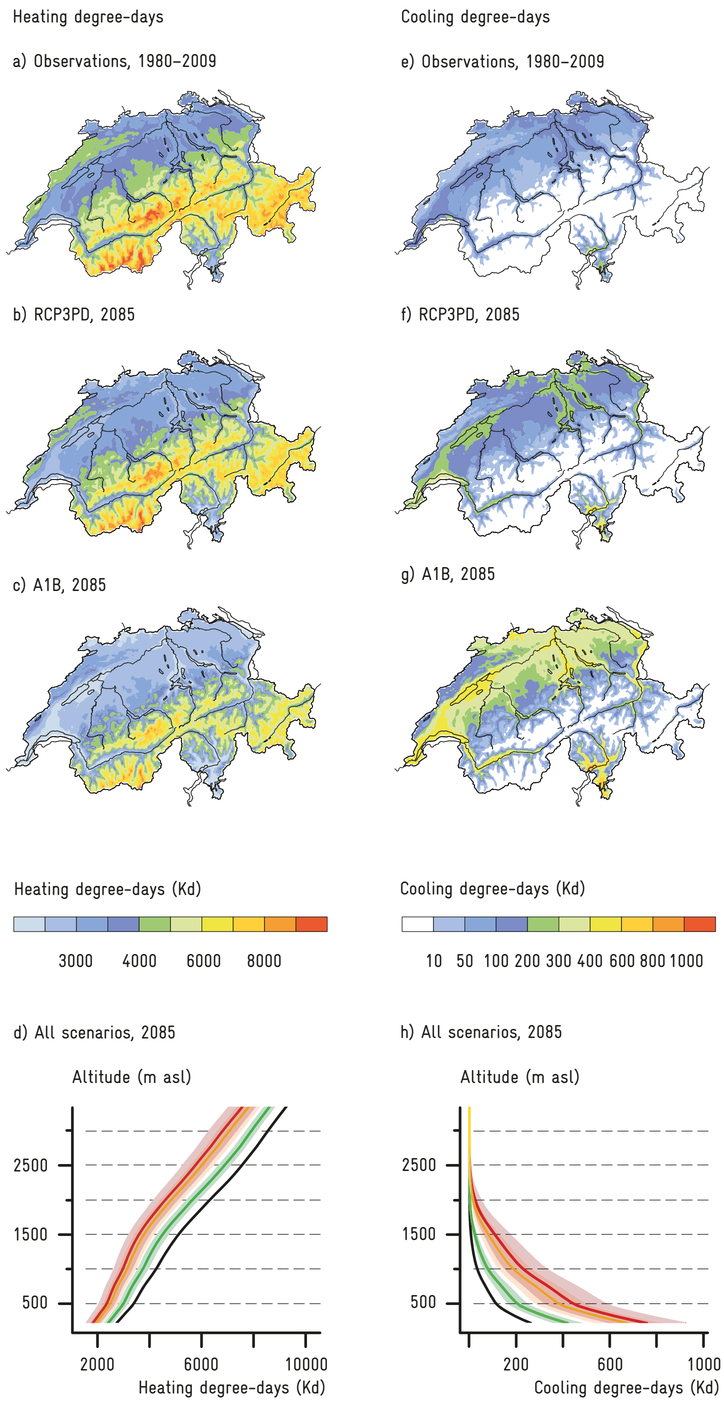

Figure 4.3: Heating degree-days (left) and cooling degree-days (right) in units of Kelvin-days (Kd): (a, e) 30-year mean over observations in the reference period 1980–2009, medium estimates of (b, f) the RCP3PD scenario (2085), and (c, g) the A1B scenario (2085). A2 is similar to A1B and is not shown as a map. (d, h) Vertical structure for all scenarios: In (d, h) the black line indicates the observations. The scenarios are displayed as follows: RCP3PD (green), A1B (yellow), and A2 (red). The lines in (d, h) correspond to mediums of height bins of 100 m over all grid points within Switzerland. Shading indicates the range from the lower and the upper estimate of each greenhouse gas scenario, respectively. Spatial variability is not displayed in the bottom panels.

4.4. IMPLICATIONS

The projected future changes in climate indices show a robust picture of more tropical nights and summer days, increasing cooling demand but reduced heating degree days, longer growing season, and fewer frost and ice days in a future climate. The changes in the investigated indices are highly sensitive to the greenhouse gas scenario considered and much larger for the two non-intervention scenarios than for the mitigation scenario. Although the evaluated indices are based on moderate temperature thresholds that are not related to highly damaging extreme events, a change in their value may still have substantial implications for related socio-economic sectors. They are relevant for the impacts discussed in the following chapters, e.g., for agriculture, biodiversity, permafrost and glacier melt, heating/cooling energy demand, health and human comfort indices, etc. Many of the changes that are highlighted by these indices reflect the Alpine topography, affecting high elevations more in some cases, and the densely populated Swiss Plateau in others.