15.1 CLIMATE VARIABILITY AND TRENDS IN PLANT PHENOLOGY IN EUROPE AND IN GERMANY

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1. INTRODUCTION

Worldwide, a lot of recent phenological studies report on earlier spring events in the latest decade (Beaubien & Freeland, 2000; Menzel, 2000; Sparks et al., 2000; Chmielewski & Rötzer, 2001). The aim of this study was to show, what are the reasons for the observed and discussed changes in the timing of phenological events. The results indicate that the observed phenological trends in Europe and in Germany correspond well with recent climate changes.

2. DATA

2.1 *Phenological Data*

For the European scale phenological observations of the International Phenological Gardens (IPG) across Europe were used. In this study leafing dates of four species (*Betula pubescens*, *Prunus avium*, *Sorbus aucuparia* and *Ribes alpinum*) were combined in an annual leaf unfolding index to define the beginning of growing season in Europe (B). For the end of the growing season (E) the average timing of leaf fall of *Betula pubescens*, *Prunus avium*, *Salix smithiana* and *Ribes alpinum* was used. The difference between the end and the beginning of the growing season was defined as the length of growing season (L).

For Germany phenological observations of fruit trees from the German Weather Service in the period 1961-2000 were analysed.

2.2 *Meteorological Data*

In order to investigate the trends in phenology in relation to climate changes, for the European area gridded near surface temperatures (NCEP/NCAR reanalysis data, Kalnay et al., 1996) and the North Atlantic Oscillation Index (NAO: Hurrel, 1995) for the period 1969-1998 were used. For Germany the temperature data from the World Weather Records (WWR) between 1961-2000 were related to the phenological observations.

3. RESULTS

3.1 *Trends in the Growing Season Length in Europe*

The length of growing season is an important measure in forestry, agriculture and horticulture. On average the beginning of growing season in Europe starts on 23 April (Rötzer & Chmielewski, 2001). In the last 30 years, the beginning of growing season in Europe has advanced altogether by 8 days (Tab. 1). This corresponds to a significant trend of -2.7 days per decade ($p<0.05$). Mainly, since the end of the 1980s, early dates prevail. Between 1989 and 1998 eight out of ten years had an advanced onset of spring. Compared to B, the end of growing season shows smaller annual variations. The trend to a later end of about +1 day per decade is therefore relatively small. Mainly influenced by the beginning of growing season, the length of growing season had advanced for the period 1969-1998 by altogether 11 days, corresponding to a significant trend of +3.5 days per decade ($p<0.01$).

Tab. 1 Statistical parameters for the av. beginning (B), end (E) and length (L) of growing season in Europe, 1969-1998, (x: mean, s: standard deviation), trend significant with ***$p<0.01$, **$p<0.05$, *$p<0.1$

	x	s	Min.	Max.	Trend (days/10a)
B	23.04.	5.8	09.04.	03.05.	- 2.7**
E	28.10.	2.4	22.10.	01.11.	+ 0.9*
L	188	5.5	178	200	+ 3.5***

3.2 *Trends in Blossom of Fruit Trees in Germany*

As the natural vegetation in Europe, the flowering dates of fruit trees in Germany show also strong negative trends. For cherry trees as well as for apple trees the average date of blossom has advanced by 8 days in the last 40 years (Tab. 2). As discussed before the changes since the end of the 1980s were also very striking here (see Fig. 3).

Tab. 2 Statistical parameters for the av. blossom of fruit trees in Germany (cherry: B_C, apple B_A), 1961-2000, (x: mean, s: standard deviation), trend significant with **$p<0.05$

	x	s	Min.	Max.	Trend (days/10a)
B_C	27.04.	7.5	09.04.	11.05.	- 2.0**
B_A	05.05.	7.4	18.04.	19.05.	- 2.2**

3.3 *Relations to Air Temperature Changes*

In mid-latitudes, the annual timing of phenological events is to a great extent a temperature response.

Since the end of the 1980s abrupt changes in air temperature were observed in Europe (Chmielewski & Rötzer, 2002) and also in Germany (Fig. 1). Compared with the long-term average most of the last years since 1988 were to warm. These observed changes in air temperature correspond well to changes in the circulation pattern over Europe. The increased frequency of positive phases in the North Atlantic Oscillation (NAO) index since 1989 led to milder temperatures mainly in

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winter and in the early spring, because of the prevailing westerly winds in these seasons.

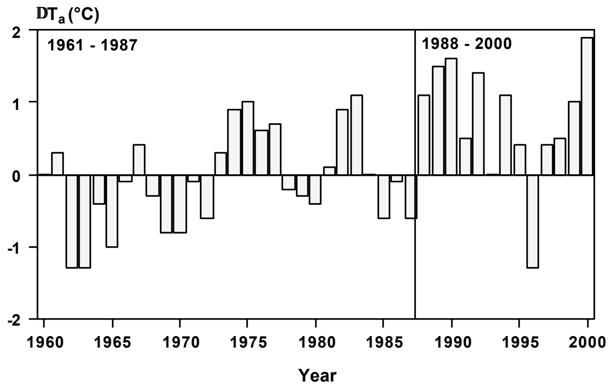

Fig. 1 Anomalies in the annual mean air temperature (ΔT_a) in Germany, 1961-2000 to the reference period 1961-1990.

For this reason, the average temperature between February and April changed distinctly, which is decisive for the plant development in spring.

This led to clear shifts in the timing of live cycle events such as phenological phases. As a result the growing season in Europe has extended and many of phenological spring events have advanced.

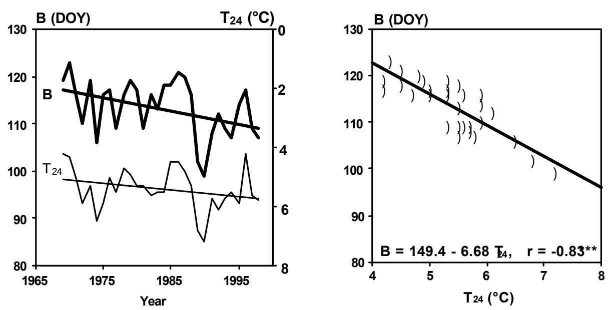

Fig. 2 Trends in av. air temperature from February to April (T_{24}) and in the av. beginning of growing season (B) in Europe, 1969–1998 (left). Correlation between T_{24} and B (right), DOY: day of the year.

The relationship between the average temperature from February to April (T_{24}) and the beginning of growing season in Europe is strong (r=-0.83, p<0.01). The extreme years in phenology (late: 1970; early: 1989, 1990) correspond well with the deviations in air temperature (Fig. 2). Both time-series show a significant trend. According to the regression equation, a warming in Europe between February and April of 1 °C leads to an advanced beginning of growing season by 6.7 days.

Also individual phenological events as the blossom of fruit trees in Germany (apple, cherry, etc.) were effected by the higher temperatures in the end of winter and in the early spring (Fig. 3). The calculations showed (regression between T_{24} and B_C or B_A) that an increase of average air temperature between February and April by 1 degree Celsius leads to an advanced blossom of trees (cherry, apple) in Germany by 5 days. This can cause a higher risk of spring frost damages in the future.

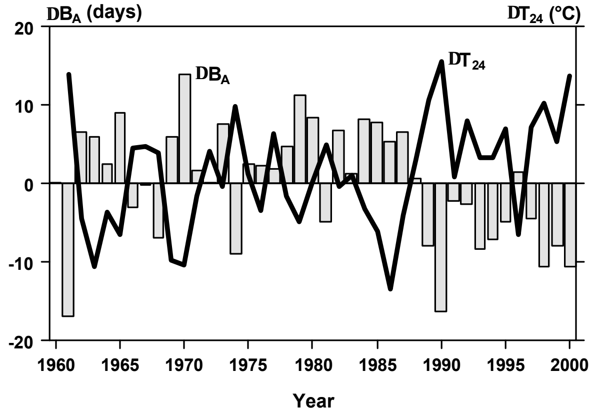

Fig. 3 Anomalies in the av. beginning of apple tree blossom (ΔB_A) and in the av. air temperature between February and April (ΔT_{24}) in Germany, (r=-0.85, p<0.01).

4. CONCLUSIONS

The investigations showed that for the most phenological spring events in Europe such as the beginning of leaf unfolding and the beginning of flowering the average, air temperature from February to April is a good climatic indicator. Higher temperatures in this time always led to an advanced leafing or flowering of trees. Therefore, the recent temperature changes are well reflected in the development of vegetation. Thus, phenological observations are a good indicator to evaluate possible impacts of climate changes on biosphere.

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