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Annual and spatial variability of the beginning of growing season in Europe in relation to air temperature changes

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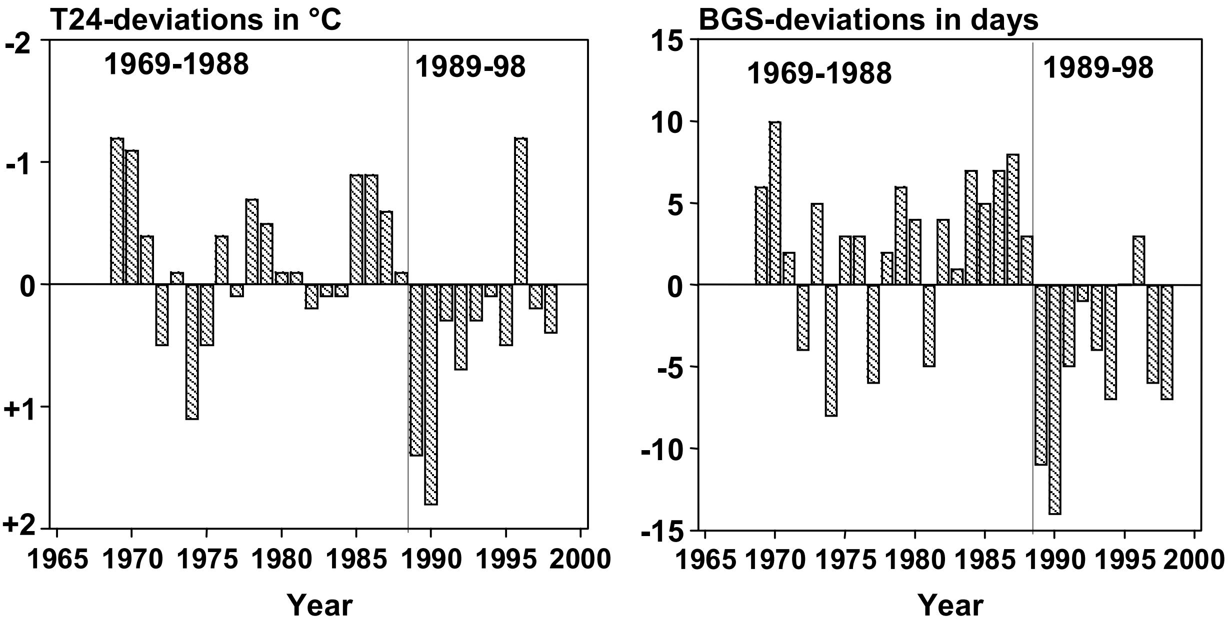

Fig.: Deviations of the mean air temperature from February and April (T24) and of the average beginning of growing season (BGS) in Europe, 1969-1998

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Annual and spatial variability of the beginning of growing season in Europe in relation to air temperature changes

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Abstract

To investigate the annual and spatial variability in the beginning of growing season across Europe, phenological data of the International Phenological Gardens for the period 1969-1998 were used. The beginning of growing season was defined as an average leaf unfolding index of four tree species (*Betula pubescens, Prunus avium, Sorbus aucuparia and Ribes alpinum*).

The study shows significant changes in the mean air temperatures from February to April and in the average beginning of growing season in Europe since 1989. In the last decade the mean temperature in early spring increased by 0.8 °C. As a result the average beginning of growing season advanced by 8 days. Between 1989 and 1998 eight out of ten years tend towards an earlier onset of spring. The absolutely earliest date was observed in 1990.

The relationships between air temperature and the beginning of growing season across Europe were investigated by canonical correlation analysis (CCA). The spatial variability of both fields can be described by three pairs of CCA-pattern. The first pattern, which explains most of the variance, shows a uniform structure with above resp. below normal temperatures in whole Europe and consequently an advanced resp. delayed beginning of growing season. The next two patterns show regional differences in the anomaly fields. Whereas the second CCA-pattern has a meridional structure, the third pattern shows a zonal distribution. In all cases the anomalies of the regional air temperature and of the beginning of growing season correspond very well. The correlation coefficients between the anomaly fields range between 0.90 and 0.66. For all patterns appropriate examples in the observed data were found.

***Key words**: Phenology · Growing season · Climate change · Air temperature· CCA*

Introduction

The annual timing of spring events (budding, leafing, flowering) is mainly driven by temperatures after the dormancy is released. In many studies a good correlation between spring phases and air temperature was found (Fitter et al. 1995, Walkovszky 1998, Wielgolaski 1999, Sparks et al. 2000). Therefore phenological observations are one of the most sensitive data for climate impact studies on vegetation in mid-latitudes.

On of the most striking events in spring is the first appearance of foliage, generally called the “green wave”. This conspicuous event is well visible in satellite images like the Normalized Difference Vegetation Index (NDVI) and can be used to calibrate remotely sensed data (Schwartz 1999, Schwartz and Reed 1999, Chen et al. 2000). In the last years more and more papers report on changes in the timing of phenological events (Braslavská and Kamenský 1999, Beaubien and Freeland 2000, Menzel 2000).

For Europe a correlation coefficient between the mean air temperature from February to April and the average beginning of growing season of -0.83 was found, an increase of the mean annual air temperature in early spring (February to April) of 1 °C corresponds to an advanced leafing by approx. 7 days (Chmielewski and Rötzer 2000).

The aim of this study was to investigate the annual and spatial variability in the beginning of growing season between 1969 and 1998.

Materials and methods

Phenological data

The International Phenological Gardens (IPGs) are a special phenological network in Europe which was founded by F. Schnelle and E. Volkert in 1957 (Chmielewski 1996). At present the network is coordinated by the Humboldt-University Berlin, Institute of Crop Sciences (www.agrar.hu-berlin.de/pflanzenbau/agrarmet/ipg.html).

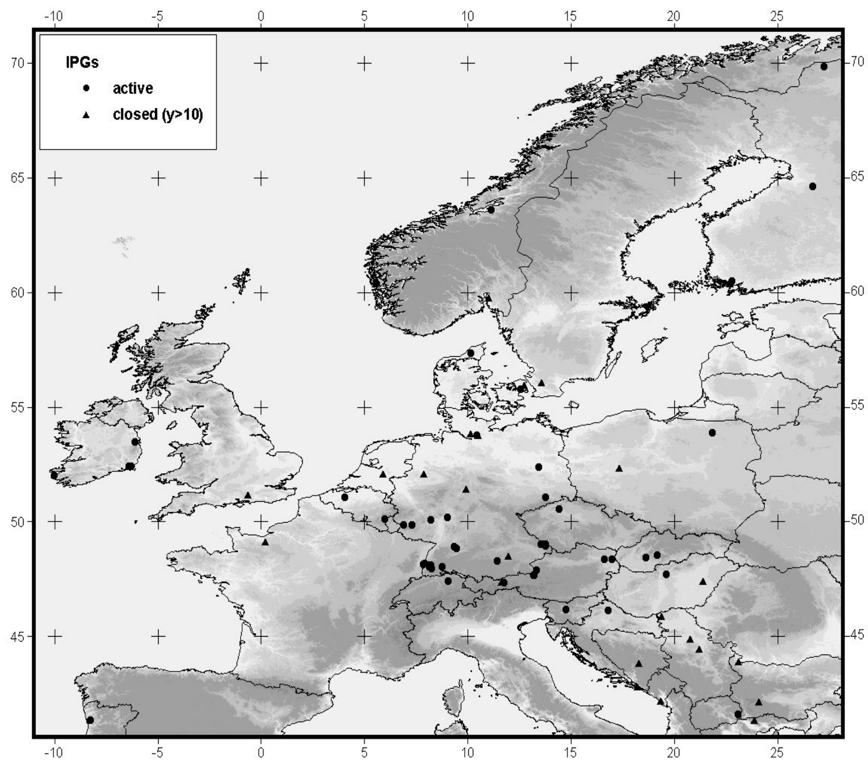

Fig. 1: Locations of the International Phenological Gardens (IPG) in Europe. Active and already closed stations with observations for more than 10 years are shown.

The idea of this network is to obtain comparable phenological data across Europe (among others beginning of leaf unfolding, flowering, autumn colouring, leaf fall) from plants which are not influenced by different genetic conditions. For this reason vegetative propagated species of trees and shrubs were planted at different sites in

Europe. In 1959 the first IPG started its phenological observations. Today about 50 IPGs across Europe record phenological data from 23 plant species (Fig. 1).

The network covers a large area in Europe from 69 °N to 42 °N and from 10 °W to 27 °E. For this study the 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. This index was calculated for each IPG over the period 1969-1998. In this paper the annual deviations from the long-term average were exclusively used. They were interpolated using a geographical information system to study the spatial structure of the beginning of growing season across Europe. Because of the very low density of IPGs in SW-Europe (France, Spain, Portugal) this area should be interpreted cautious.

Climatic data

In order to investigate the annual variability of the beginning of growing season in relation to air temperature, gridded surface temperatures (NCEP/NCAR reanalysis data, Kalnay et al. 1996) for the period 1969-1998 were used. The horizontal resolution of the NCEP data is about 210 km. The data cover a region extending from 70°N to 40°N and from 10°W to 25°E. So climatic as well as phenological data have nearly the same geographical dimensions.

Method

The canonical correlation analysis (CCA) can be used to investigate the relationships between two multidimensional data-sets. The statistical procedure was proposed by Hotelling (1936). In this study the method was used to study the relationships between the anomaly-fields of air temperature and the beginning of growing season across Europe. The method is well described in Manly (1986) as well as for climate research aspects in v. Stroch and Navarra (1995).

Results

Annual variability of the beginning of growing season

On the long-term average (1969-1998) the beginning of growing season in Europe starts on 23 April. Mainly, since 1989 very early dates prevail (Fig. 2). Between 1989 and 1998 eight out of ten years tend towards an earlier onset of spring. The earliest date was observed in 1990 (09 April). Because of the long and strong winter in 1995/96, the beginning of growing season in 1996 was relatively late. Mainly in SE-Europe the leaf unfolding started up to a half month later in this year (for example at the IPG in Skopje/Macedonia). The latest date of the period 1969-1998 was registered for 1970 (03 May).

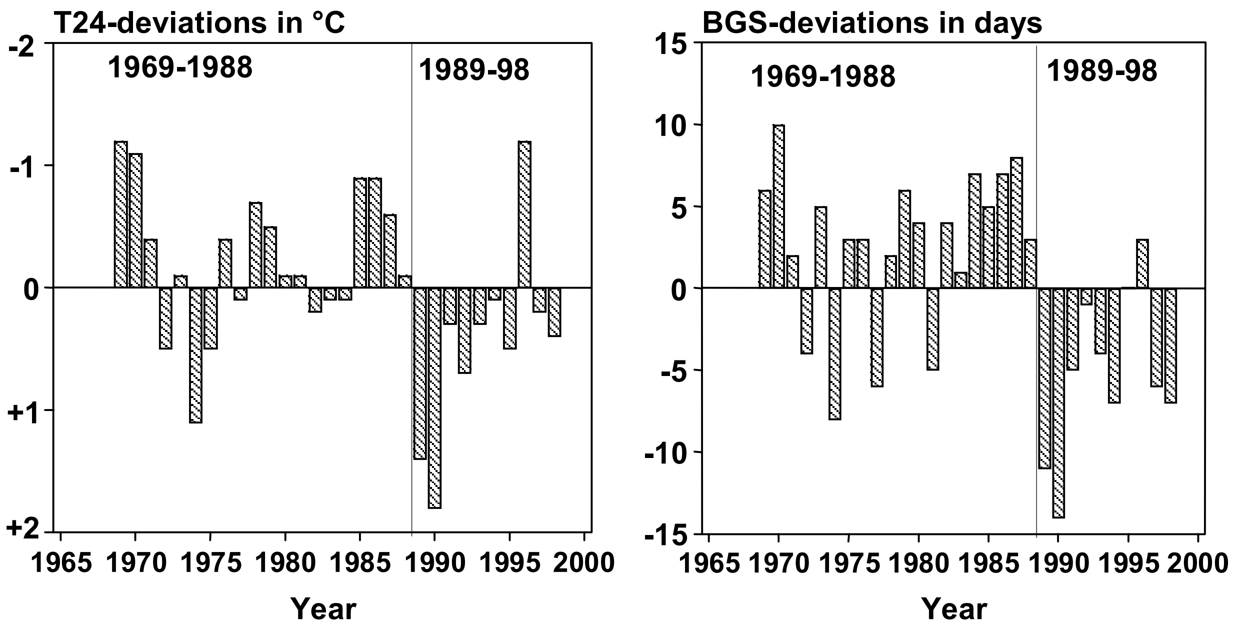

Fig. 2: Deviations of the mean air temperature from February and April and of the average beginning of growing season (BGS) in Europe, 1969-1998

The distinct changes in the average beginning of growing season in Europe since 1989 correspond well with changes in the mean air temperature from February to April. Between 1969-1988 and 1989-1998 the mean spring temperature in Europe (T24) increased by 0.8°C, the average beginning of growing season advanced by 8 days (Tab. 1). The differences between the means both for air temperature and beginning of growing season was significant with $p<0.05$.

Tab. 1: Mean air temperature from February to April (T24) and average beginning of growing season (BGS) in Europe for different periods

Period	T24 in °C	s in °C	BGS in Julian days	s in days
1969-1988	5.1[a]	0.59	116[c]	4.41
1989-1998	5.9[b]	0.78	108[d]	5.30
t-statistic	a/b: sign. difference, $p < 0.05$		c/d: sign. difference, $p < 0.05$	

Spatial variability of the beginning of growing season

The beginning of growing season shows a distinct spatial variability. Usually, the green wave across Europe moves annually with 44 km/d from south to north, with 200 km/d from west to east and with 32m/d with increasing altitude (Rötzer and Chmielewski 2000). In single years the spatial distribution of this wave vary to a great extent.

Fig. 3 shows the anomaly patterns of the beginning of growing season from 1969-1998. Red colours indicate an advanced, blue colours a delayed beginning of leafing related to the long-term means. Very impressive are the changes since 1989. Since this year red colours clearly prevail.

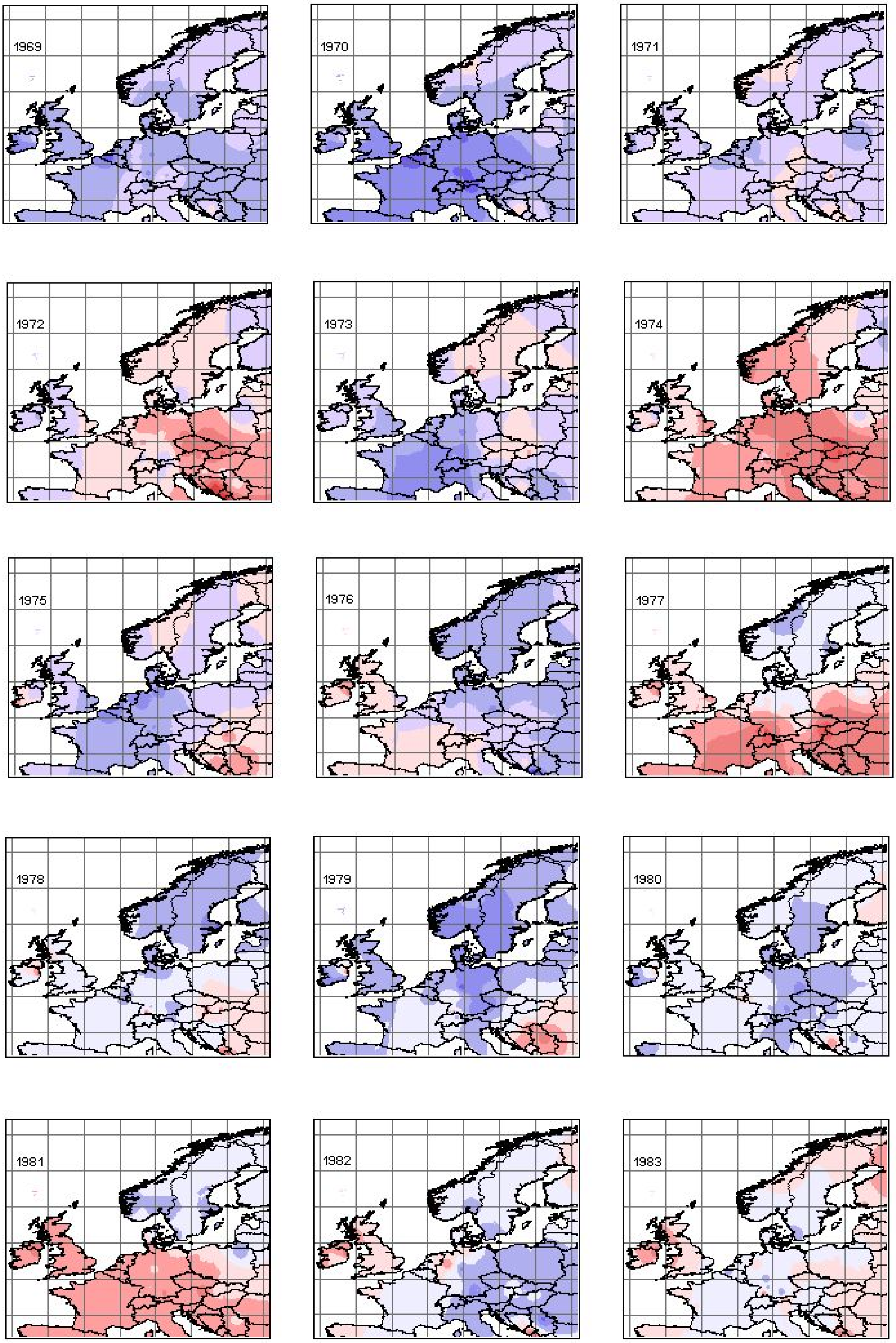

Fig. 3a: Regional deviations in the beginning of growing season from the long-term average 1969-1998, years 1969-83, (blue colours indicate a delayed, red colours an advanced BGS (7 classes: 0-5, 5-10, 10-15, 15-20, 20-25, >30 days, from light-blue or light-red to dark-blue or dark-red).

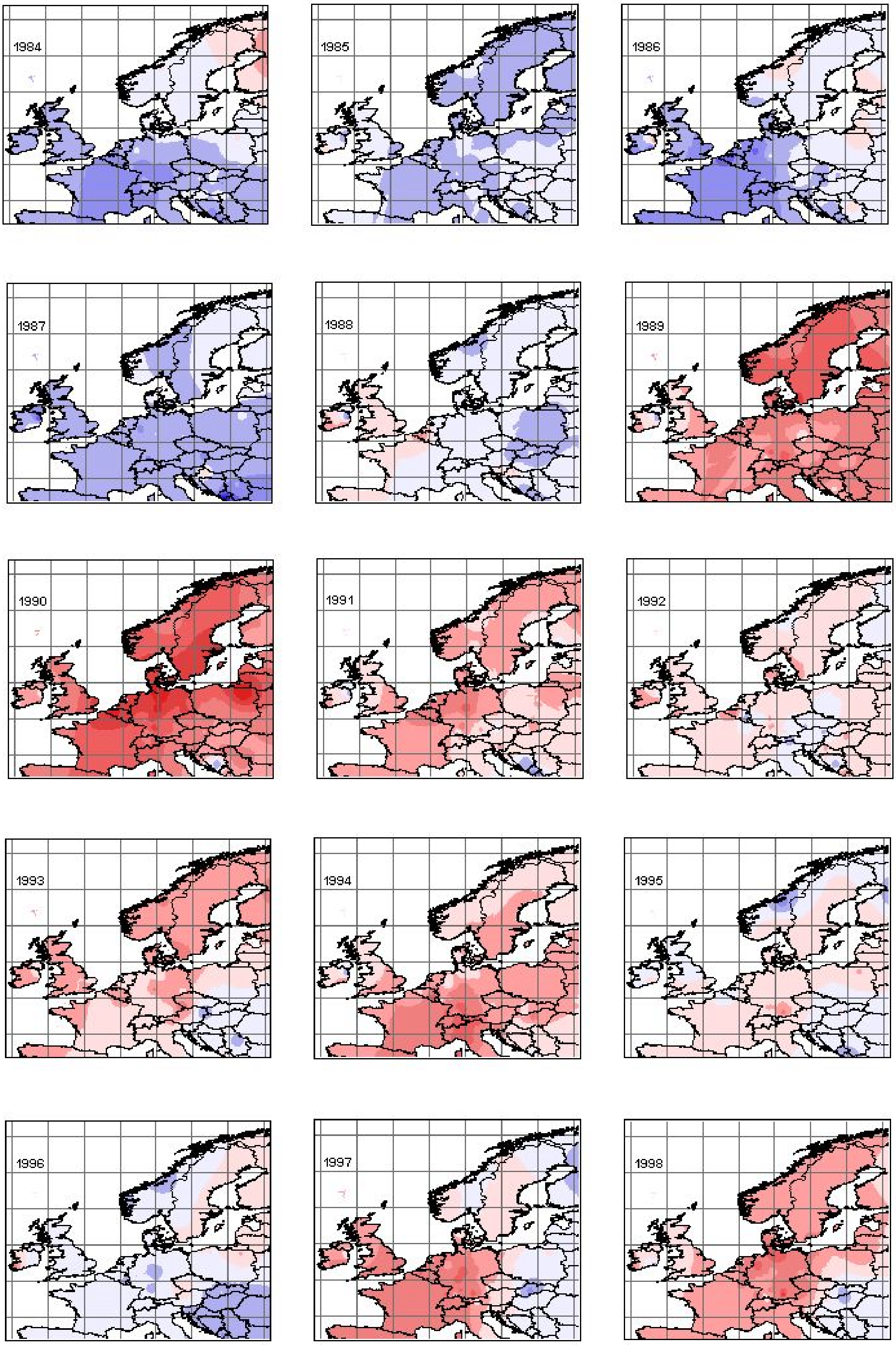

Fig. 3b: Regional deviations in the beginning of growing season from the long-term average 1969-1998, years 1984-98, (blue colours indicate a delayed, red colours an advanced BGS (7 classes: 0-5, 5-10, 10-15, 15-20, 20-25, >30 days, from light-blue or light-red to dark-blue or dark-red).

In order to investigate the different annual patterns of the beginning of growing season across Europe a canonical correlation analysis (CCA) between the annual pattern of mean air temperature from February to April T24 (340 grid points) and the beginning of growing season (52 IPG stations) was done. Before calculating the CCA the two anomaly fields of T24 and BGS were approximated by the leading three empirical orthogonal functions (EOF, v. Storch and Navarra 1995, Maak and v. Storch 1997). The EOF-patterns explain 83 % of the air temperature variability and 72 % of the variance of the beginning of growing season in the period 1969-1998.

The first pair of CCA-pattern (correlation coefficient: r=0.90) shows a relatively homogeneous structure in air temperature and phenology (Fig. 4). Uniform temperature anomalies over the entire area are associated with an early leafing at all IPGs. A mean temperature anomaly for Europe of ±0.6°C is related to an advanced or delayed beginning of growing season of 6 days on average. The strongest anomalies were found in Central Europe. Here positive anomalies of 1.2 - 1.4 °C in air temperature led to an advanced beginning of growing season by 6 - 10 days. In cold years the pattern would be reverse, so that leaf unfolding starts very late in all regions. This CCA-pattern explains 43 % of the variance in the beginning of growing season.

Good examples for the first canonical pair are the years 1970 and 1990 (Fig. 3). In 1970 the beginning of growing season in Europe was on average 10 days delayed. The latest dates were observed in central and northern Europe, ranging between +10 and +20 days. The reverse case was observed in 1990, with the earliest date of leaf unfolding between 1969 and 1998. In this year growing season started earlier with 14 days on average in whole Europe. Anomalies of the beginning of growing season in Central Europe with up to -27 days can be assigned to temperature anomalies from February to April with up to + 4.5 °C.

The second pair of CCA-pattern (r=0.76) shows a meridional structure with warm conditions in West- and cold temperatures in East-Europe. According to this temperature pattern the beginning of growing season is premature in the western part (on average -2 days) and late in the eastern part (+2 days) of Europe, so that in whole Europe the vegetation developed normal. This pattern explains 14 % of the variance in phenology.

This meridional structure is well discernible in the years 1976 and 1997 (Fig. 3). In 1976 the timing of leaf unfolding in the northern and eastern parts of Europe was relatively late. In Scandinavia delays between 5 and 8 day were observed. Also in Germany the beginning of growing season was on average one week later. Only in SW-Germany earlier dates of -2 days were observed. The strongest delay by 24 days was recorded at the IPG in Bar/Montenegro. Earlier dates than normal were observed in W- and SW-Europe.

While in 1976 striking delays can be found in East- and North-Europe, in 1997 an early beginning of growing season was predominant in W-Europe. In this year beginning of growing season had advanced up to -20 days in the western parts of Europe. The eastern parts of Europe mostly showed delays between 1 and 5 days. Only the IPGs in the Slovak Republic observed delays in leafing of more than 10 days.

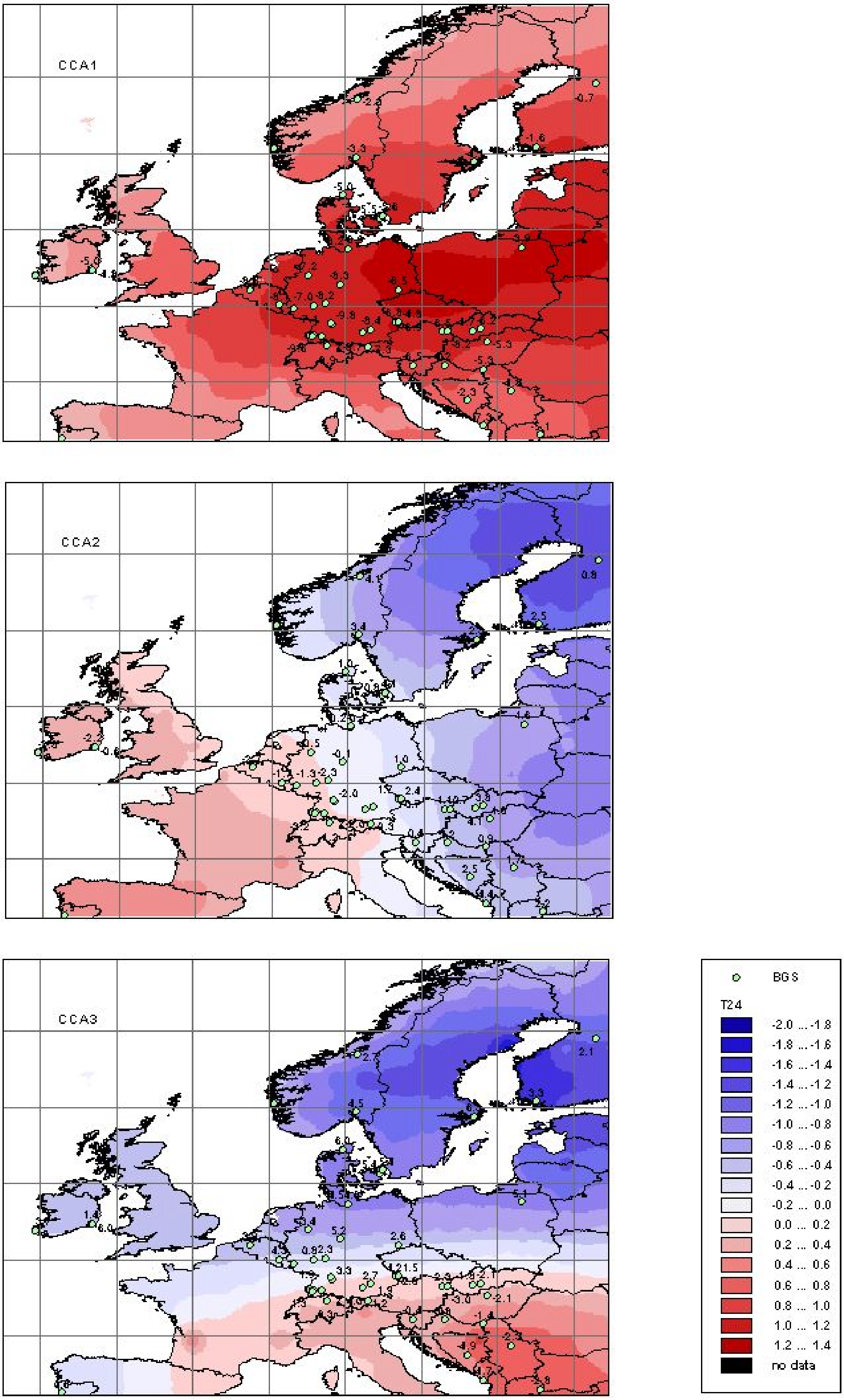

Fig. 4: Canonical correlation patterns (CCA1-CCA3) of mean monthly air temperature from February to April (T24) and the beginning of growing season (BGS) in Europe, 1969-1998. T24-anomalies are given in °C (positive anomalies are red, negative anomalies blue), BGS-anomalies in days, correlation coefficients (r) between the pattern: r(CCA1)=0.90, r(CCA2)=0.76, r(CCA3)=0.66

The third pair of CCA-pattern was correlated with r=0.66 and explains 16 % of variance. It showed a zonal structure with positive temperature anomalies in the south - mainly south-east Europe - and negative anomalies in the north - mainly in Scandinavia. The beginning of growing season is delayed by about 3 to 4 days in the northern latitudes and advanced up to 5 days in the south-eastern regions.

Good examples for this pattern were the years 1977 and 1981 (Fig. 3). In both years the beginning of growing season in Scandinavia was slightly delayed whereas in Central and South-Europe early dates prevail at all IPGs. In 1977 strong deviations from the long-term average were observed, the beginning of growing season advanced up to -26 days in SW-Germany and Switzerland and up to -22 days in SE-Europe.

According to the regional anomalies in the beginning of growing season the individual years can be classified as follows (Tab. 2).

Tab. 2: Classification of individual years to the canonical patterns (CCA1...CCA3), BGS: beginning of growing season in Europe

Classification	**Subgroups**	**Years**	**Av. anomaly of BGS for Europe**, in days
normal years		1992, 1983, 1995, 1971	-2, 0, 0, +2
CCA1 pattern	early years	1990, 1989, 1974, 1994, 1991	-15, -11, -8, -7, -5
	late years	1970, 1987, 1984, 1986, 1969, 1985, 1980, 1996	+10, +8, +7, +7, +6, +5, +4, +3
CCA2 pattern	meridional differences	1997, 1976, 1975, 1988	-6, +3, +3, +2
CCA3 pattern	zonal differences	1977, 1981	-6, -5
	only SE-Europe early	1978, 1979	+2, +4,
	only SE-Europe late	1998, 1993	- 7, - 4
undefined years		1972, 1973, 1982	-4, +5, +4

Summary and discussion

The increase in mean air temperature from February to April of 0.8 °C in the last decade led to an earlier beginning of the growing season in Europe by 8 days. This corresponds well with the findings of Walkovszky (1998), who found changes in the flowering dates of the locust tree (*Robinia pseudoacacia* L.) in Hungary and related it to the changes in the mean air temperature (period: 15 March to 15 May). Between the periods 1983-1994 and 1851-1931 he found a increase in mean air temperature of 0.7 - 1.0°C, which was in accordance with a shift in the flowering dates of -5 to -10 days.

In our study primarily the rapid change of the mean air temperature since 1989 and thus the shift in the average beginning of growing season in Europe was examined. The changes in air temperature correspond well with changes in the circulation over Europe: Between 1989 and 1998 ten out of eleven years showed positive phases of the average NAO-index from February to April (Chmielewski and Rötzer 2000). Positive phases of NAO in winter and early spring are generally associated with above normal temperatures in Europe, mainly in the central and northern parts of the continent. The changes found in air temperature are in accordance with the analysed trends by Schönwiese and Rapp (1997) and Rapp (2000).

The annual spatial variability in the beginning of growing season was investigated using the canonical correlation analysis. Similar to the results of Maak and v. Storch (1997) the CCA reveals a strong relationship between large-scale air temperature from February to April and the beginning of growing season in the International Phenological Gardens across Europe.

As a result of uniform temperature anomalies in Europe in more than 40 % of the years the beginning of growing season was either advanced or delayed in whole Europe (CCA1). The two other canonical patterns represent unbalanced years, with an early beginning of growing season in West-Europe and a late beginning in the eastern part (CCA2) or with earlier dates in South-Europe (particularly in south-east) and later dates in the North-Europe (CCA3). The reverse case is always possible. Together these patterns explain another 30 % of variance.

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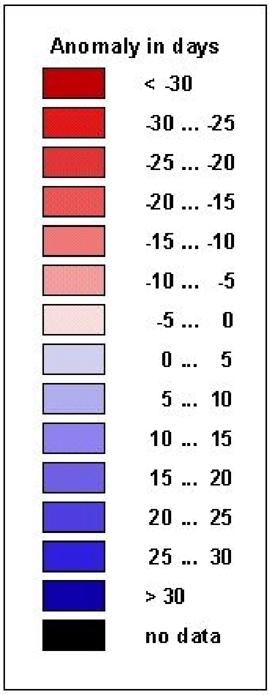
Fig. 3: Legend



Anomaly in days
< -30
-30 ... -25
-25 ... -20
-20 ... -15
-15 ... -10
-10 ... -5
-5 ... 0
0 ... 5
5 ... 10
10 ... 15
15 ... 20
20 ... 25
25 ... 30
> 30
no data

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