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An overview of the phenological observation network and the phenological database of Germany's national meteorological service (Deutscher Wetterdienst)

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Abstract. First phenological observations have been performed in Germany already in the 18th century. The onset dates of characteristic phases of plant development (phenological phases) are observed and recorded. Today, Germany's national meteorological service (Deutscher Wetterdienst, DWD) maintains a dense phenological observation network and a database with phenological observations. The data are used in many applications, esp. for advisory activities to agriculture or pollen dispersion information.

1 Introduction and history of phenological observations of plants in Germany

Phenology is the study of periodically recurring patterns of growth and development of plants and animal behaviour during the year (Lieth, 1974). These are closely related to weather and their long-term trends are therefore important indicators of the impact of climate change on the biosphere (Menzel, 2002; Settele et al., 2014). Phenological data are therefore a valuable source of information for agricultural advisory activities as well as for climate research (Richardson et al., 2013). Systematic collection of phenological data started in several European countries in the 18th century (see all contributions to Nekovář et al., 2008): in the UK Robert Marsham started to recorded 27 "indications of spring" in 1736. These included first flowering, first leafing and migrant bird records. Successive generations of the family continued with these recordings until 1958 (Sparks and Carey, 1995; Sparks and Collinson, 2008). In the middle of the 18th century the Swedish naturalist Carl von Linné initiated the first known phenological network with 18 stations in Sweden (Dahl and Langvall, 2008). The Economic Society of Bern founded the first phenological network of Switzerland in 1759 (Defila, 2008). About 30 years later the Societas Meteorologica Palatina carried out systematic phenological observations at several sites in Europe, with focus on Germany, between 1781 and 1792 (e.g. Ephemerides Societatis Meteorologicae Palatinae. observationes anni 1782; Wege, 2002). The first modern phenological network in the Austro-Hungarian Monarchy which included also parts of today's Czech Republic, Slovakia, Romania and Croatia was established by Carl Fritsch in the first half of the 19th century. Furthermore he developed und published several guidelines for phenological observations (Reiss, 1959; Koch et al., 2008).

In Germany the real breakthrough in phenology was achieved in 1882, when university professor Hermann Hoffmann and his colleagues prepared and published guidelines for the observation of phenological phases. These guidelines provided the basis for standardized observations in Germany and beyond. It gave rise to a Europe-wide monitoring network, as well as a number of regional networks in Germany.

The first long-term nationwide phenological observation network in Germany was set up by the Biological Institute for Agriculture and Forestry of the Reich in 1922. The network was run by this institute until 1936, when it was taken over by the Meteorological Service of the Reich and further developed by Fritz Schnelle (Schnelle, 1955).

Today, the phenological observation network is operated by Germany's national meteorological service (Deutscher Wetterdienst, DWD). An overview on the current status in European countries can be found in Nekovář et al. (2008).

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Table 1. Plants and their phenological phases in the current observation programme of Deutscher Wetterdienst. Abbreviations are explained in Table 2. German names are provided for users accessing the data via DWD's website.

Latin	English	German	observed phases (abbreviation)
	wild growing plants, forest and ornamental woody plants		
Acer platanoides	norway maple	Spitz-Ahorn	B
Aesculus hippocastanum	horse chestnut	Rosskastanie	A, BO, B, F, BV, BF
Alnus glutinosa	european alder	Schwarz-Erle	B, BO
Alopecurus pratensis	meadow foxtail	Wiesen-Fuchsschwanz	B, AB
Anemone nemorosa	wood anemone	Busch-Windröschen	B
Artemisia vulgaris	mugwort	Beifuß	B
Betula pendula, B. Verucosa, B. alba	european white birch	Hänge-Birke	A, BO, B, BV, BF
Calluna vulgaris	heather	Heidekraut	B
Colchicum autumnale	autumn crocus	Herbstzeitlose	B
Cornus mas	cornelian cherry	Kornelkirsche	B, F
Corylus avellana	hazel	Hasel	B
Crataegus laevigata, C. oxyacantha	hawthorn	Zweigriffeliger Weißdorn	B, F
Dactylis glomerata	orchad grass	Wiesen-Knäuelgras	AB
Fagus sylvatica	european beech	Rotbuche	BO, BV, BF
Forsythia suspensa	forsythia	Forsythie	B
Fraxinus excelsior	ash	Esche	B, BO
Galanthus nivalis	snowdrop	Schneeglöckchen	B
Larix decidua, L. europaea	european larch	Europäische Lärche	BO, BV, BF
Picea abies, P. excelsa	norway spruce	Fichte	M
Pinus sylvestris	scots pine	Kiefer	M, B
Prunus spinosa	blackthorne	Schlehe	B
Quercus robur, Q. penduncula ta	pedunculate oak	Stiel-Eiche	BO, F, BV, BF
Robinia pseudoacacia	black locust	Robinie	B
Rosa canina	dog rose	Hunds-Rose	B, F
Salix caprea	goat willow	Sal-Weide	B
Sambucus nigra	black elder	Schwarzer Holunder	B, F
Sorbus aucuparia	rowan	Eberesche	A, BO, B, F, BF
Syringa vulgaris	lilac	Flieder	B
Taraxacum officinale, T. vulgare	dandelion	Löwenzahn	B
Tilia platyphyllos, T. grandifolia	large leaved lime	Sommer-Linde	B
Tussilago farfara	coltsfoot	Huflattich	B
	agricultural plants		
Avena sativa	summer oats	Sommerhafer	BST, AU, SCH, AE, MR, GR, E
Beta vulgaris	sugarbeet or mangold	Zucker- oder Futterrübe	BST, AU, BG, E
Brassica napus, var.napus	winter rape	Winterraps	SCH, KNO, B, VR, E, BST, AU, RO
Hordeum vulgare	summer barley	Sommergerste	BST, AU, SCH, AE, GR, E
Hordeum vulgare	winter barley	Wintergerste	SCH, AE, GR, E, BST, AU
Secale cereale	winter rye	Winterroggen	SCH, AE, B, AB, GR, E, BST, AU
Triticum aestivum	winter wheat	Winterweizen	SCH, AE, MR, GR, E, BST, AU
Zea mays	corn	Mais	FAO, BST, AU, SCH, AE, B, MR, TR, GR, E
–	permanent grassland	Dauergrünland	ERG, E
	fruit and vine		
Malus domestica	apple	Apfel	SKZ, A, B, AB, EB, F, BF
Prunus avium	cherry	Süßkirsche	SKZ, B, AB, EB, F, BV
Prunus cerasus	sour cherry	Sauerkirsche	SKZ, B, AB, EB, F
Pyrus communis	pear	Birne	SKZ, B, AB, EB, F
Ribes rubrum, R.sylvestre	redcurrant	Rote Johannisbeere	SKZ, B, F
Ribes uva-crispa, Ribes grossularia	gooseberry	Stachelbeere	SKZ, A, BO, B, F
Vitis vinifera	vine	Wein	SKZ, BL, A, BO, B, AB, EB, F, L, BV, BF

2 The current status of the German phenological observation network

Currently, about 1200 observers contribute to this network, the large majority of them on a voluntary basis. At approx. 60 sites the observations are performed by weather observers of DWD. Approx. 160 phenological phases of wild plants, agricultural crops, fruit trees and bushes, and grape vines are observed and archived in the phenological database of DWD. Tables 1 and 2 show the list of currently observed phases.

Two types of reporting strategies are applied: "Yearly reporters" transmit their data once a year in a report sheet and approx. 400 observers submit their reports by phone to the next weather station immediately after occurrence of the phenological phase.

The observation programme of the yearly reporters contains widely distributed wild plants, forest trees and ornamental shrubs, the most important agricultural crops, as well as frequently grown fruit plants and grape vines. The phenomena to be observed expand over the whole vegetation period, e.g. unfolding of leaves, flowering or leaf fall. These phases are clearly visible events in the development cycle of the plants and represent a change in their physiological condition.

The main purpose of the immediate reporting network is to provide up-to-date information on the current stage of plant development. This is especially important for advice to farmers and pollen information services. The network is still sufficiently dense for these tasks, but measures are taken to avoid further degradation, e.g. advertising efforts in cooperation with other government agencies.

A detailed instruction manual serves as a plant identification book for the plants contained in the observation programme (Deutscher Wetterdienst, 1991). It contains a picture of the habit of each plant and a precise photographic presentation of each phenological phase.

Typically, the observer defines the size of the observation area himself. An area with a radius of 1.5 to 2 km is typically sufficient and the maximum distance to the origin should not exceed 5 km. The altitude of the sites of the plants should not differ by more than ±50 m from the base altitude. The area should preferably be open and plain, i.e. valleys, etc. should be avoided. Observations should be performed two to three times a week (Deutscher Wetterdienst, 1991).

3 The phenological database and quality control

The phenological reports have been archived since 1951. They are a component of the national climate database of DWD.

Until 1991, observations in Western and Eastern Germany have been carried out according to programmes that agreed in large parts. But in East Germany not all phases were integrated into the archives. However, activities have been started to also include these data, too. After the German reunification, a new observation programme with detailed observation instructions was defined in 1992 and has been used since then.

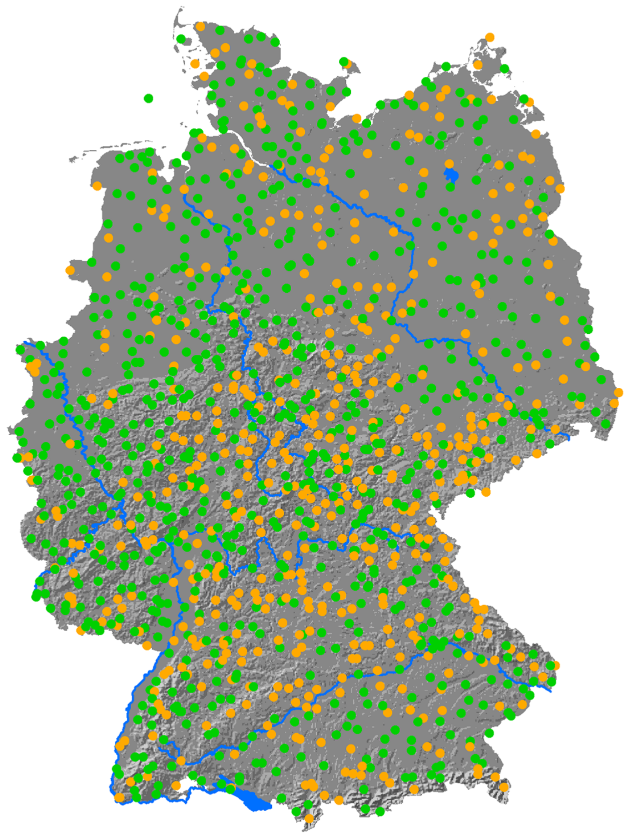

Figure 1. Locations of phenological observation sites and length of their time series. Green: at least 1 year of observations. Orange: 50 or more years of observations.

474 of the stations in the database cover a period of 50 years (or more; see Figs. 1 and 2), 164 stations cover a period of 60 years (within the period 1951–2010). However, not all phases have been observed over that period. Based on historical documents the database was expanded to the time before 1951. For the location Geisenheim these observations are available back to 1896 (Fig. 3).

An automatic quality control procedure is applied to the data (Zimmermann and Polte-Rudolf, 2013). In the first step, a test with predefined thresholds is applied, the temporal order of the phases is checked and it is tested if the temporal differences between subsequent phases are in a plausible range. In the next step, a spatial test is applied. Within a specific spatial range, the observed date of the phase at an individual site is compared with a statistically derived value for that area. The final result of the tests is provided as a quality indicator (e.g. "rejected" or "wrong") together with the data. But even if a value is flagged as "rejected", it might still be correct and useable. Frequently errors have causes that can

Table 2. Observed phases and their abbreviations.

Code	Name of the phase (English)	Name of the phase (German)
A	sprouting of leaves	Beginn des Austriebs
AE	panide emergence	Beginn des Ährenschiebens
	beginning of ear	Beginn des Rispenschiebens
AB	full blossom; general blossom	Vollblüte
AU	beginning of emergence	Beginn des Auflaufens
B	beginning of flowering; beginning of blossom	Beginn der Blüte
BB	beginning of formation of leaves	Beginn der Blattbildung
BF	leaf fall	Blattfall
	needle fall	Nadelfall
BG	closed stand	Bestand geschlossen
BL	first bleeding of the vines	Erstes Bluten
BO	unfolding of leaves	Beginn der Blattentfaltung
		Beginn der Nadelentfaltung
BST	tilling, sowing, drilling	Beginn der Bestellung
BV	colouring of leaves	Blattverfärbung
	colouing of needles	Nadelverfärbung
E	harvest	Ernte
	crop	Schnitt
EB	end of flowering	Ende der Blüte
ERG	beginning of turning green	Beginn des Ergrünens
F	first ripe fruits (forest and ornamental woody plants)	erste reife Früchte
F	fruit ripe for picking (fruit)	Beginn der Pflückreife
F	beginning of ripening (grape vines)	Beginn der Reife
GR	beginning of yellow ripeness	Beginn der Gelbreife
KNO	beginning of bud formation	Beginn der Knospenbildung
L	grape harvest	Lese
M	beginning of may sprouting	Maitrieb
MR	beginning of milk ripeness	Beginn der Milchreife
RO	beginning of rosette formation	Beginn des Rosettenbildung
SCH	beginning of growth in height	Beginn des Längenwachstums
	beginning of shooting	Beginn des Schossens
TR	beginning of wax-ripe stage	Beginn der Teigreife
VR	beginning of full ripeness	Beginn der Vollreife
SKZ	index-number of variety	Sortenkennziffer

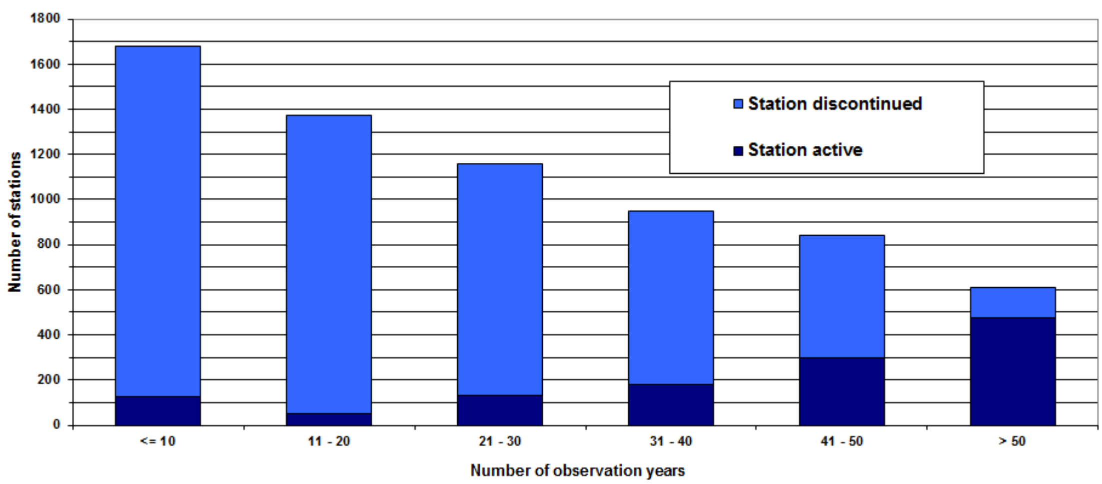

Figure 2. Number of stations in the database and length of their time series (within the period 1951 to 2010).

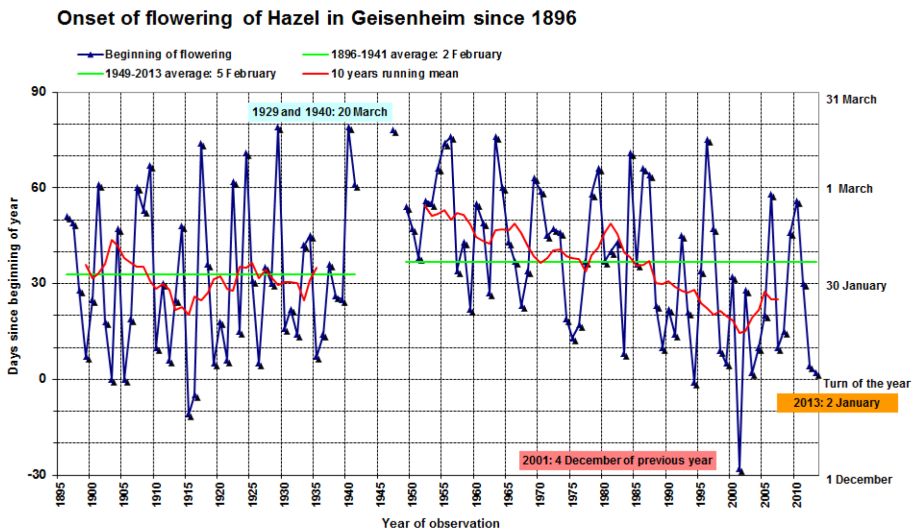

Figure 3. Some phenological records held by the research station at Geisenheim go back to 1896. These show a marked shift towards earlier flowering times over the past 60 years.

be corrected afterwards (e.g. caused during technical conversion).

Starting backwards from 2012, also the data of previous years are controlled. For 2012, 1.8 % of the data have been flagged as "wrong". For some stations, the error rate is significantly above the average rate. These cases are carefully analysed and where appropriate discussed with the observers.

4 Applications, phenological seasons and "clocks"

The data of the intermediate observers are used by DWD for pollen information service and agrometorological advice. In combination with the weather forecasts they provide a basis for pest management and field irrigation as well as for a decision on favourable harvest dates or to allow the estimation of pollen dispersion. The data are also provided to universities, research institutes, public authorities, the media and many other customers.

The data are also used by DWD to create different types of charts that provide easy to understand visualisations of the temporal course of vegetation development. Such diagrams can be used to illustrate the year-to-year development but also long term shifts.

One simple example is the definition of a phenological "growing season". The preferred choice for this purpose are wild growing plants that occur in all regions of Germany. DWD defines the growing season as the period between beginning of flowering of Forsythia and leaf fall of penduncuculate oak. Figure 4 shows an example.

A visualization with more detailed information are the "phenological clocks" that are based on the definition of the "seasons" of a "phenological year". For that purpose ten different "phenological seasons" are defined based on specific

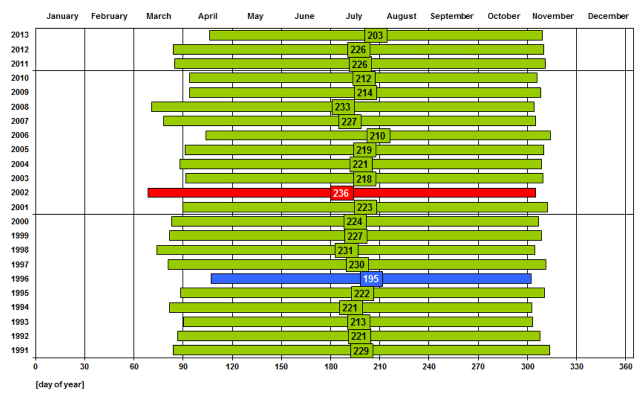

Figure 4. Growing seasons in Germany since 1991: mean beginning, duration (days) and ending defined by the period between "Forsythia (Forsythia suspensa) – beginning of flowering" and "Pedunculate Oak (Quercus robur) leaf fall".

growth stages of selected plants that are used as "indicator phases" (Table 3). This is typically done for a wider region but can also be done for individual sites. Each season begins with an indicator phase and ends with the beginning of the next season. When visualized as "double clocks" (concentric; see Fig. 5 for an example), these diagrams allow to easily compare a single year with the long-term mean or two climatological reference periods.

Table 3. Indicator phases used to define the phenological seasons. Each season begins with an indicator phase and ends with the beginning of the next season. The alternative phase can be used if the indicator phase is not available.

phenological seasons	indicator plants/phases	alternative plants/phases
prespring	hazel (flowering)	snowdrop (flowering)
first spring	forsythia (flowering)	gooseberry (leaf unfolding)
full spring	apple, mainly early ripeness (flowering)	pedunculate oak (leaf unfolding)
early summer	black elder (flowering)	black locust (flowering)
midsummer	large leaved lime (flowering)	red currant (fruit)
late summer	apple, early ripeness (fruit)	rowan (fruit)
early autumn	black elder (fruit)	cornelian cherry (fruit)
full autumn	pedunculate oak (fruit)	horse chestnut (fruit)
late autumn	pedunculate oak (leaf colouring)	rowan (leaf fall)
winter	pedunculate oak (leaf fall)	1. apple, late ripeness (leaf fall) 2. european larch (needle fall)

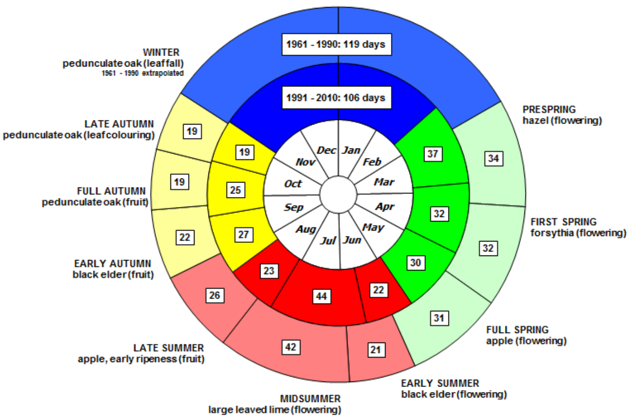

Figure 5. Phenological clock for Germany: indicator phases, mean beginning and duration of the phenological seasons. In this clock, the periods 1961–1990 and 1991–2010 are compared.

5 Data access and co-operation in Europe

The phenological data are freely available via the website of DWD; e.g.

– ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/phenology/ or

– http://www.dwd.de/phaenologie.

DWD contributes to the Pan European Phenology database (PEP725; successor of COST-725 "Establishing a European Phenological Data Platform for Climatological Applications", see Sparks et al., 2009), which was set up by the Austrian Central Institute for Meteorology and Geodynamics (ZAMG), the Austrian Federal Ministry of Science and Research and the Economic Interest Grouping of European National Meteorological Services (EUMETNET). The main aim of PEP725 is to promote and support phenological research by making available an annually updated pan-European database, providing open access to phenological data for science, research and training (www.pep725.eu).

Together with additional data sources, the phenological observations of DWD are integrated into the Plant-Phenological Online Database PPODB (http://www.ppodb.de/). The merged database comprises plant-phenological observations collected in Central Europe between 1880 and 2009 with an emphasis on Germany (Dierenbach et al., 2013).

6 Conclusions

Germany's national meteorological service maintains a dense phenological observation network. Observations are currently performed at about 1200 locations, mainly by voluntary observers. Approx. 400 observers submit their reports immediately after occurrence of the phenological phase. The information is used for several tasks of DWD, e.g. advice to farmers and pollen information services. The data are quality-controlled and stored in a database. The database contains times series covering several decades and is therefore a valuable source for research activities. The data are publicly available via the Climate Data Center of DWD and also integrated into international collections.

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